Statistical Features Used for Recognition of Partial Discharge under AC-DC Combined Voltages

Tianyan Jiang[1], Jian Li[1], Stanislaw Grzybowski[2], Zhiman He[1], Ruijin Liao[1]
[1]State Key Laboratory of Power Equipment & System Security and New Technology
Department of High Voltage and Insulation Engineering
College of Electrical Engineering
Chongqing University
Chongqing, 400044, China

[2]High Voltage Laboratory
Department of Electrical and Computer Engineering
Mississippi State University
Mississippi State, MS 39762, USA

Abstract: Recognition of partial discharges (PDs) has great advantages in condition estimation of high voltage (HV) converter transformers. This paper presents an approach for recognition of PD under AC-DC combined voltages. Four artificial insulation defect models were designed to generate PD signals under the combined voltages. PD data were detected by a Rogowski coil sensor in experiments. A series of statistical PD histograms were established for features extraction. Furthermore, statistical features of PD distributions were computed for PD recognition. For verifying the validity of the statistic features, a support vector machine (SVM) was used for recognition of PDs generated from different artificial insulation defect models. The recognition results show that the SVM and the proposed features were qualified for PD pattern recognition under AC-DC combined voltages.

1. INTRODUCTION

Recognition of partial discharge (PD) sources has been considered as an effective method to assess the insulation status in high voltage (HV) power equipment [1]. High voltage direct current (HVDC) converter transformers play very important roles in HVDC transmission systems. Valve-side windings withstand complex stresses combined with AC, DC and pulse voltages. PD will be happened in weak oil-paper insulation of converter transformer with increase of the transmission voltage rating [2]. Therefore, identification of oil-paper insulation under combined voltages is very important to the normal operation of the converter transformer.

A variety of features had been used for recognition of PD under individual voltage of AC, DC, or pulse. Statistical features [3] and fractal parameters [4] extracted from PD statistical histograms consisted of count, magnitude and phase of PD pulses, were used for recognition of PD under AC voltage. Histograms based on alternate time Δt between two neighboring discharge impulse, and several other derivative histograms of PD under DC voltage were proposed in literature [5]. Statistic features extracted from these proposed histograms were used for recognition of PD under DC voltage. In addition, statistic parameters of PD were used for analysis of aging properties for insulation under pulse voltage [6]. However, there is little investigation of recognition for PD under combined voltages.

This paper presented statistic features for recognition of PD under AC-DC combined voltages. Four artificial insulation defect models were designed to generate PD signals under AC and DC combined voltages, which were detected by a Rogowski coil sensor in experiments. A series of histograms consisted of $H_{qn}(\varphi)$, $H_{qm}(\varphi)$, $H_n(\varphi)$ and $H_n(q)$ were established for features extraction. Statistic features combined with asymmetry, cross-correlation factor, skewness, kurtosis and numbers of peaks in PD distributions were computed for recognition of PDs. For verifying the validity of the statistic features, a support vector machine (SVM) was used for recognition of PDs generated from different artificial insulation defect models. The recognized correctness ratios showed that the SVM and the proposed features were qualified for PD pattern recognition under AC-DC combined voltages.

2. EXPERIMENTS

2.1. Insulation Defect Models and Experiment Setup

Four types of insulation defect models, as shown in Figure 3, were designed for experiments to generate PD UHF signals. Figure 3(a) shows a corona discharge model with a needle-to-plate electrode system, called as the defect model P1. Figure 3(b) shows a model to generate surface discharge in oil with a cylinder-to-board electrode used, which is called as the model P2. Figure 3(c) shows the model of air cavity discharge with three layers of oil-impregnated papers and a sphere-to-board electrode. The model is called as the model P3. Figure 3(d) is the model of floating discharge. A metal particle is fixed on the oil-impregnated paper and a cylinder-to-board electrode system is used. The insulation defect model is called as the model P4. The thickness of the oil-impregnated pressboards of every model is 0.5 mm.

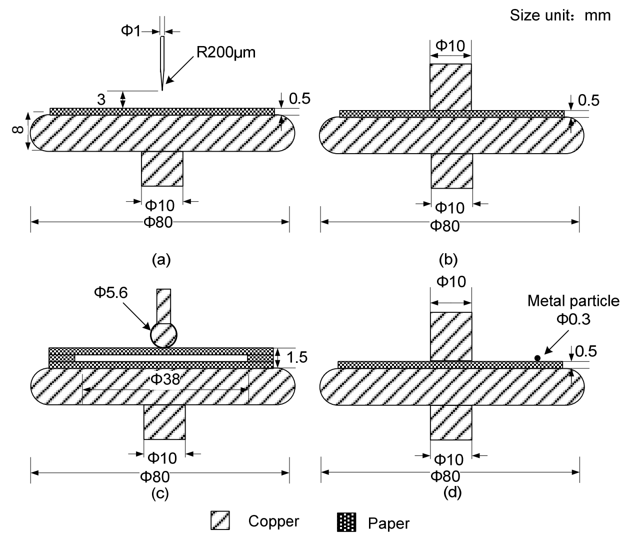

Figure 1: Four types of artificial defect models: (a) defect model P1; (b) defect model P2; (c) defect model P3; (d) defect model P4.

The experimental setup of PD detection under AC-DC voltage is shown in Figure 2. The polarity of applied voltage is positive and the ratio of DC to AC peak voltages of testing voltage equals to 1: 1. The artificial defect models were put into a synthetic glass box filled with transformer oil and the experiments were carried out in an electromagnetic shielded laboratory. A Rogowski coil sensor, S in Figure 2, was used for PD detection in the experiments. The sensor has good performance with a wide frequency pass-band between 50 kHz and 10 MHz. A high performance digital oscilloscope with a sampling frequency of 50 MS/s was used to observe and record PD signals obtained by the sensor. The calibrated coefficient of our experiment is about 6.098 pC/mV.

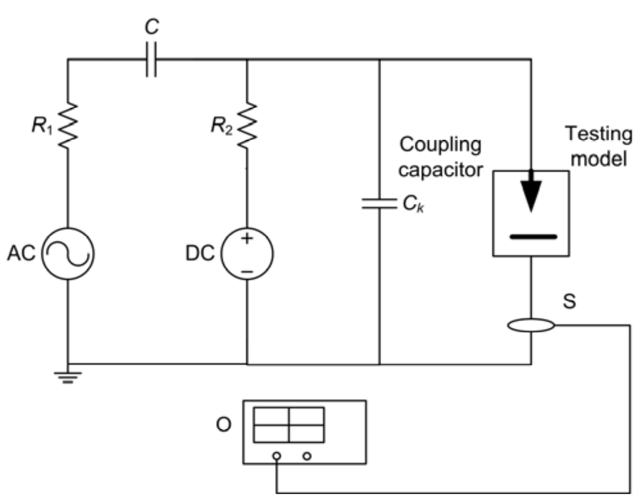

Figure 2: The setup of PD experiment in laboratory

Table 1 shows the inception voltages and test voltages of the four PD models in experiments. 3000 cycle numbers of PD signals generated from each defect model were detected for establishing statistic histograms when discharge sufficiently. 25 samples were obtained at each voltage for every PD model. The total number of sample data of PD signals was 200.

Table 1: PD Experiment Conditions

PD model	Inception voltage (kV)	Test voltage (kV)	Sample numbers	Cycle numbers
P1	14.4	17	25	3000
		21	25	3000
P2	12.8	14	25	3000
		15	25	3000
P3	3.8	7	25	3000
		10	25	3000
P4	10.8	11	25	3000
		12	25	3000

2.2. PD histograms

Phase-resolved PD histograms, with respect to discharge magnitude q, pulse number n, and phase angle φ, were obtained from the measured PD sample data. Four different types of histograms: $H_{qn}(\varphi)$, $H_{qm}(\varphi)$, $H_n(\varphi)$ and $H_n(q)$ of the four defect models are shown in Figures 3 to 6, which is mainly referred to publication [7]. Phase distributions of corona discharge focus on the phase ranges of 45° to 135° and 200° to 270°. And discharge number of the positive half cycle is larger than that of the negative half cycle. Figure 4 shows that phase distributions of positive and negative half cycles from surface discharge have certain similarities. And phase distributions focus on three phase ranges 0° to 120°, 210° to 270° and 300° to 360°. Figure 5 shows that the phase distributions of gas-cavity discharge are narrower than that of surface discharge. And the phase distributions of gas-cavity discharge are asymmetrical. In addition, phase distributions of floating discharge focus on the phase range of 0° to 150° and 300° to 360°. Experimental results show that statistic histograms generated from different artificial defect models are different from each others. And these are different from PD phase distributions under AC voltage.

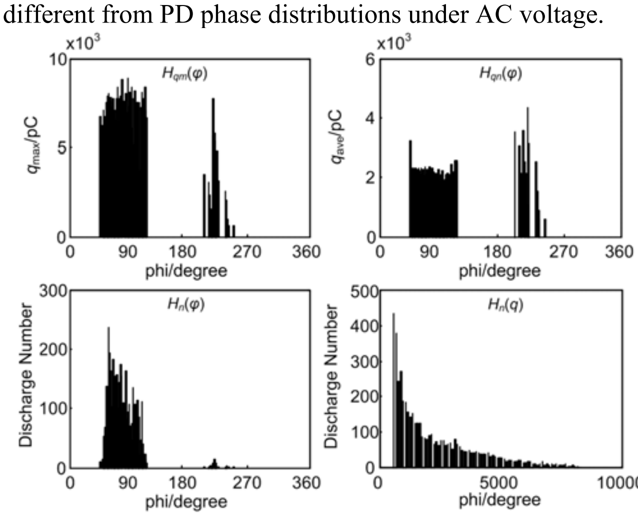

Figure 3: Statistic PD histograms of defect model P1 when discharge sufficiently

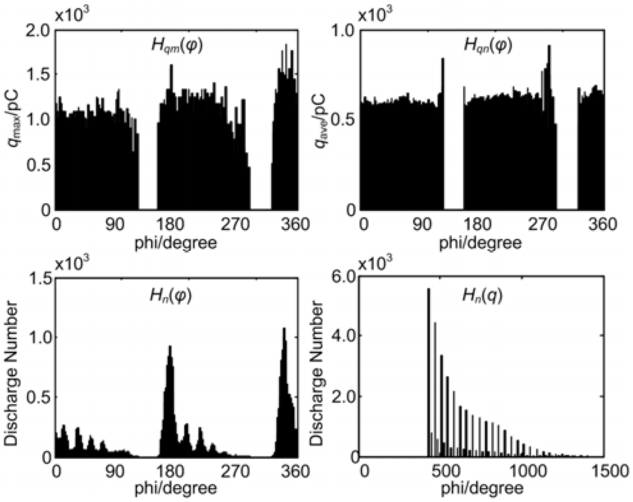

Figure 4: Statistic PD histograms of defect model P2 when discharge sufficiently

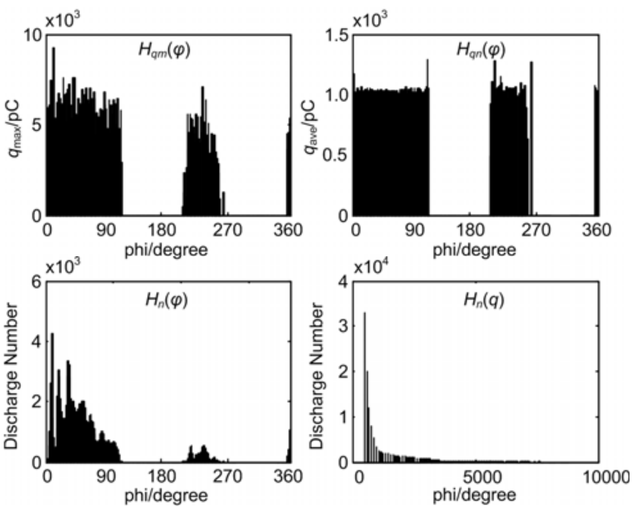

Figure 5: Statistic PD histograms of defect model P3 when discharge sufficiently

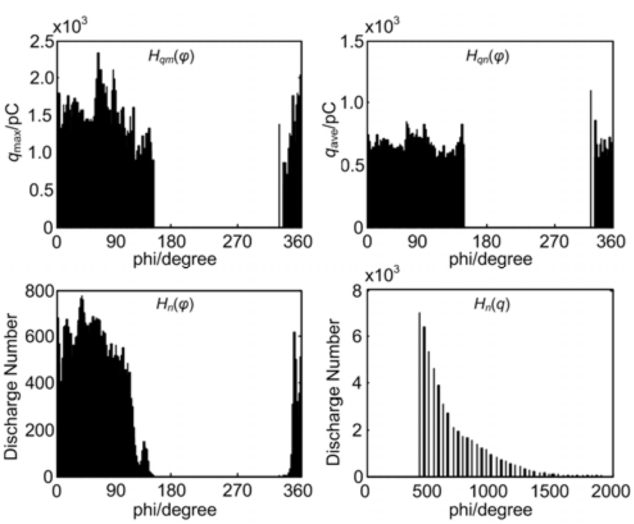

Figure 6: Statistic PD histograms of defect model P4 when discharge sufficiently

3. RECOGNITION RESULTS

3.1. Feature Extraction of PD UHF Signals

Statistical features were computed from the four types of histograms. For each half of the voltage cycle, the first three histograms were separated into two distributions: for the positive half voltage cycle $H^+_{qn}(\varphi)$, $H^+_{qm}(\varphi)$, and $H^+_n(\varphi)$, and for the negative half voltage cycle $H^-_{qn}(\varphi)$, $H^-_{qm}(\varphi)$, and $H^-_n(\varphi)$. Table 2 shows the 26 statistical operators selected as the statistical parameters for recognition. The description of these parameters is referred to publication [8]. Figures 7 to 10 show the 95% confidence interval [9] of statistical features. The calculated results show that statistical features of different defect models are different from each others, although 95% confidence intervals of several parameters are big. This is helpful for recognition by analysis to the statistic features of detected PD signals.

Table 2: Selected statistical operators of PD distributions

Distribution		$H_{qn}(\varphi)$		$H_{qm}(\varphi)$		$H_n(\varphi)$		$H_n(q)$
Parameter	*Asy*	Asy_1		Asy_2		Asy_3		
	Cc	Cc_1		Cc_2		Cc_3		
Half distribution		$H^+_{qn}(\varphi)$	$H^-_{qn}(\varphi)$	$H^+_{qm}(\varphi)$	$H^-_{qm}(\varphi)$	$H^+_n(\varphi)$	$H^-_n(\varphi)$	
Parameter	*Sk*	Sk_1	Sk_2	Sk_3	Sk_4	Sk_5	Sk_6	Sk_7
	Ku	Ku_1	Ku_2	Ku_3	Ku_4	Ku_5	Ku_6	Ku_7
	Pe	Pe_1	Pe_2	Pe_3	Pe_4	Pe_5	Pe_6	

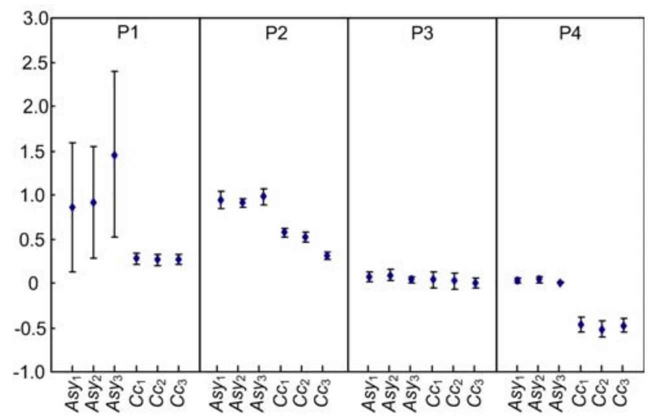

Figure 7: Plot of 95% confidence interval of *Asy* and *Cc* of different PD models

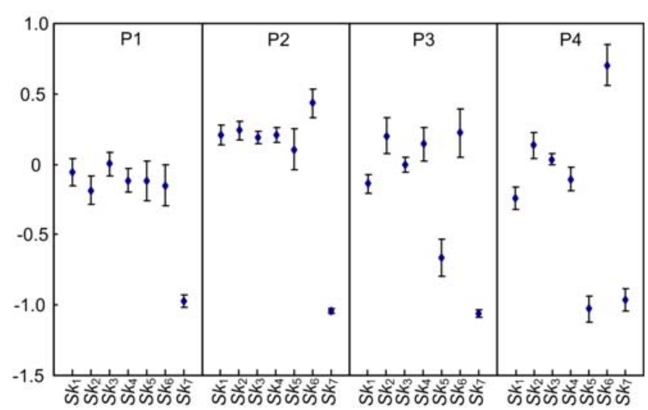

Figure 8: Plot of 95% confidence interval of *Sk* of different PD models

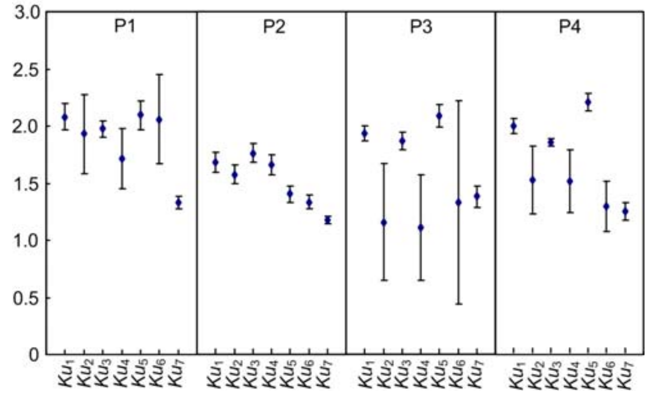

Figure 9: Plot of 95% confidence interval of *Ku* of different PD models

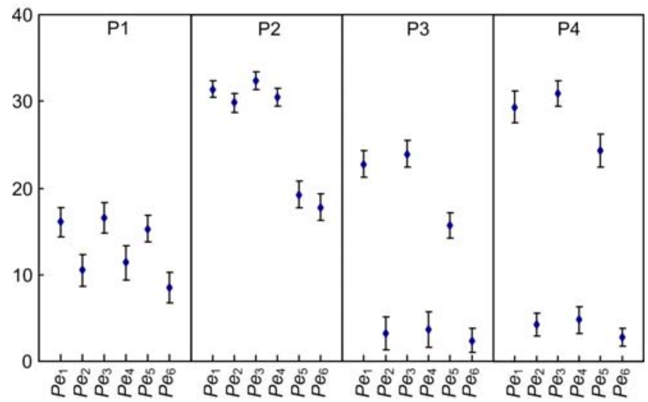

Figure 10: Plot of 95% confidence interval of *Pe* of different PD models

3.2. Recognition Results

For verifying the validity of the statistic features, a support vector machine (SVM) was used for recognition of PDs generated from different artificial insulation defect models. The design of SVM classifier is mainly referred to literature [10]. For each type of PD models, a total of 20 of randomly selected PD data of each model are used for training the SVM. The rest 120 PD data separated into testing data are recognized by the SVM. One hundred replications with different random splits are made and averaged. The averaged recognized results of the four different PDs were 90.33%, 97.44%, 85.17% and 97.33%, respectively. And the all recognition correctness ratio reached 93.21%. This indicates that the proposed approach is qualified to recognize PD signals generated by different sources under AC-DC combined voltages.

4. CONCLUSIONS

This paper presented a novel recognition approach for PD signals detected under AC-DC combined voltages. Four statistic histograms of detected PD signals were established. And 26 statistic parameters were input to a support vector machine (SVM) for PD signals recognition under AC-DC combined voltages. The results of the above work and analysis were concluded as follows:

(a) Statistic features computed from different types of histograms: $H_{qn}(\varphi)$, $H_{qm}(\varphi)$, $H_n(\varphi)$ and $H_n(q)$ of the four defect models are different from each others and suitable for recognition. And these are different from PD phase distributions under AC voltage.

(b) Statistic features were input into a support vector machine (SVM) for recognition of PDs generated from different artificial insulation defect models. The overall averaged recognition correctness ratio of one hundred calculations reached 93.21%. The SVM and the proposed parameters were qualified for PD pattern recognition under the AC-DC combined voltages.

5. ACKNOWLEDGMENT

The authors acknowledge the funding from the 863 Program (No. 2009AA04Z416). The Funds for Innovative Research Groups of China (51021005) and the Important Projects in the Scientific Innovation of Colleges and Universities (Project *v*-200704) are also appreciated for supporting this work.

6. REFERENCES

[1] L. Hao and P. L. Lewin, "Partial Discharge Source Discrimination using a Support Vector Machine", IEEE Transaction on Electrical Insulation, Vol. 17, pp.189-197, 2010.

[2] G. Bhuvaneswari, and B. C. Mahanta, "Analysis of Converter Transformer Failure in HVDC Systems and Possible Solutions", IEEE Transactions on Power Delivery, Vol. 24, pp.814-821, 2009.

[3] M.Cacciari, A.Contin, G.C.Montanari, "Use of a mixed-weibull distribution for the identification of PD phenomena", IEEE Transaction on Dielectrics and Electrical Insulation, Vol. 2, pp. 614-627, 1995.

[4] Jian Li, Qian Du, Caixin Sun, "An improved box-counting method for image fractal dimension estimation", Pattern Recognition, Vol. 42, 2009, pp. 2460-2469.

[5] Peter H.F. Morshuis and Johan J. Smit, "Partial discharges at DC voltage: their mechanism, detection and analysis", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 12, pp.328-340, 2005.

[6] Kai Zhou, Guangning Wu, Jiandong Wu, Jun Liu, Xi Liu, "Analysis of Aging Properties for Insulation Based on Statistical Parameters of Partial Discharge Under Pulse Voltage", Transactions of China Electrotechnical Society, Vol. 23, pp.6-12, 2008.

[7] Jian Li, Ruijin Liao, Grzybowski S., Lijun Yang, "Oil-paper aging evaluation by fuzzy clustering and factor analysis to statistical parameters of partial discharges", IEEE Transactions on Dielectrics and Electrical Insulation, Vol.17, pp.756-763, 2010.

[8] E. Gulski, F. H. Kreuger, "Computer-Aided Recognition of Discharge Sources", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 27, pp. 82-92, 1992.

[9] Hu Yang, qiongsun Liu, Bo Zhong, "Mathematical Statistics", High Education Press, 2004.

[10] Tianyan Jiang, Jian Li, Mingying Chen, Grzybowski, S., "Recognition on ultra-high-frequency signals of partial discharge by support vector machine", International Coference on High Voltage Engineering and Application (ICHVE), pp.634-637, 2010.