1 Partial Discharge Characterization based on Leakage Current Pulses Waveform for Contaminated Glass Insulator String

N. A. Othman*, M. A. M. Piah and Z. Adzis.

Institute of High Voltage & High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia

* corresponding author: nazlin7@live.utm.com

Abstract

Partial discharge (PD) is an electrical discharge event that does not completely bridges the electrodes in the insulation systems under applied field. Although PD does not cause immediate breakdown of the insulation, it may affect the insulation performance in the long term due to repetition of PD events. The occurrence of PD causes leakage current (LC) to flow, thus an attempt to characterize PD based on LC pulses waveform is presented in this paper. Results show that PD can be characterized (according to their occurrence with respect to the AC supply) as follows: corona discharge occurring in lightly contaminated insulators, surface discharge occurring in medium contaminated insulators and finally internal discharge occurring in heavily contaminated insulators. The ability to distinguish the type of PDs from the LC waveform could be used to monitor and predict the condition of the insulator. The outcome can be incorporated in a conditioning monitoring system.

Keywords. Partial discharge; Leakage current; Glass insulator string;

— Introduction

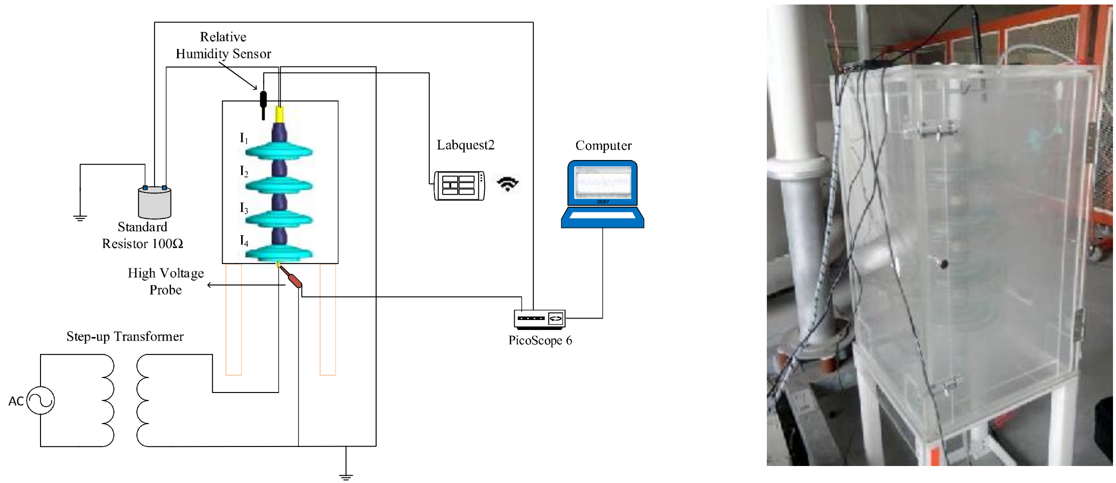
As quoted from IEC 60270 standard, partial discharge (PD) is defined as localized electrical discharges that only partially bridges the insulation between conductors which can or cannot occur adjacent to a conductor [1]. In accordance with the standard, PD pulse is current or voltage pulse that results from PD occurring within the object under test. Therefore, the leakage current (LC) pulses can be potentially used to indicate the occurrence of PD, referring to the concept applied in PD measurement itself.

Insulator strings that are widely used for overhead transmission line has beset crucial problems when dealing with contamination [2]. The voltage distribution of dry and contaminated insulators has uniform resistivity in the absence of water; but in wet condition, dry band forms due to LC flow. This is due to the unstable deposition of contamination source causing heat dissipation to occur rapidly in the presence of water. The non-uniformity nature of contamination layer could lead to more dry bands. The formation of dry band distorts the electric field within the band under influence of any moisture and leads to occurrence of PD.

Although PD does not cause immediate breakdown of the insulation, the appearance of PD indicates the presence of default which cause energy dissipation and further leads to insulation degradation. It is therefore, important to diagnose the existence of PD activities so that early prevention action can be taken into consideration. Therefore, an attempt to characterize the type of PD based on LC pulses waveform is presented in this paper. A string of four glass insulators (without grading ring) used as main sample was contaminated with different levels of contamination. The flow of LC is measured by using a shunt resistor of 100 Ω at the grounded end of the string insulators and analyzed by compilation of 10 cycle current pulse events.

— Methods

Ammonium chloride (salt) with the weight of 10 g, 50 g, and 100 g is dissolved in 1 liter of distilled water to form different salt solutions and subsequently tested for contamination level using Equivalent Salt Deposit Density (ESDD) method. Four units of high voltage (HV) glass insulators were pre-contaminated with those different salt solutions and were completely dried for 24 hours before entering the test chamber for voltage injection. Full measurement setup which is similar to [3] is illustrated in Figure 1 (a) with the insulators suspended vertically and wetted by clean steam fog as depicted in Figure 1 (b). The laboratory experiment for artificial pollution tests was conducted based on IEC 60507 [4]. The operating voltage of 33 kV AC was applied when the contamination layer is completely wetted and the relative humidity was in the range of 80 % to 100 %. The flow of LC was measured by a 100 Ω standard resistor at the grounded end of the string insulators without any electrical contact with the HV supply. The measured LC is then continuously captured by a PicoScope and subsequently recorded by a computer.



(a) (b)

Figure 1. (a) Full measurement setup and (b) Insulators wetted by clean steam fog

— Results and Discussion

Table 6 presents the contamination level of the tested salt solution according to an application guide for contaminated insulators proposed by CIGRE [5]. Based on this result, different level of contamination is obtained and the insulator was subsequently contaminated with this ammonium chloride.

Table 6 Contamination level according to salt solution

Salt weight (g)	ESDD (mg/cm^2)	Contamination level [5]
0	0.00	Clean
10	0.05	Light
50	0.07	Medium
100	0.13	Heavy

Clean String Insulator

Figure 2 shows the LC waveform for clean insulator string. As can be seen from the figure, there is a small pulse on the negative cycle of applied voltage. Small pulse of LC which is less than 1 mA can be considered as field noise [6]. This finding suggests that in clean and dry conditions, no LC flow along the insulator surface.

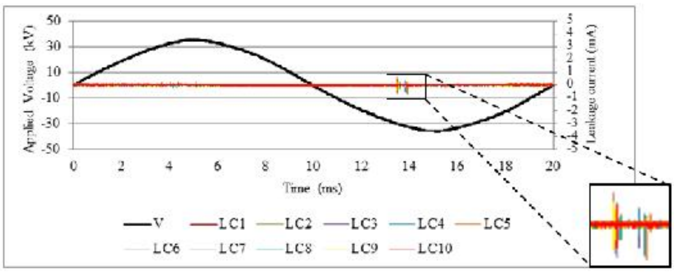


Figure 2. LC pulses waveform for clean insulator string

3.2 Lightly Contaminated String Insulator

Figure 3 presents the LC pulses waveform for lightly contaminated insulator string. It is apparent that the LC pulses occur at the phase angle of 90° in both cycle of applied voltage. The presented result can be characterized as corona discharge as the distribution of LC pulses occurs in the range of 80° to 100° phase of applied voltage [7]. The appearance of higher LC pulses in negative cycle of applied voltage is due to the formation of negative corona discharge and supported by [8]. This situation is due to the mobility of free electron is much faster than ion under the influence of applied voltage. Less LC activities occurred at positive cycle can be explained by considering that the inception voltage for positive corona is higher compared to negative corona [9]. It can thus be suggested that both corona discharge (negative and positive) occurs when the string insulators were lightly contaminated and agreed by [10]. It is also noticed from the presented result that LC pulses appear around the applied voltage spike with the range of amplitude between 0.02 A to 0.05 A.

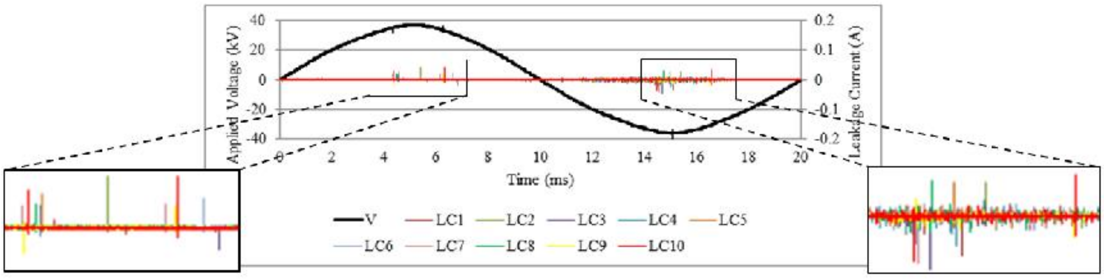


Figure 3. LC pulses waveform for lightly contaminated insulator string

3.3 Medium Contaminated String Insulator

Figure 4 illustrates the LC pulses waveform for medium contaminated insulator string. It is clear that the LC pulses are obtained at the location between 0° and 90° phase for positive cycle while 180° to 270° phase for negative cycle. The presented result corroborates the findings of researcher [11, 12] who classify discharge pattern distributed within the first and third phase quadrant of applied voltage as surface discharge. Surface discharge may occur due to the presence of high tangential field. The non-uniform contamination layer along the surface of glass insulator applied during the experiment could lead to the formation of this tangential field and enable the occurrence of surface discharge. It is worth to mention that the LC appears around the applied voltage spike with the range of amplitude is between 0.06A to 0.12 A.

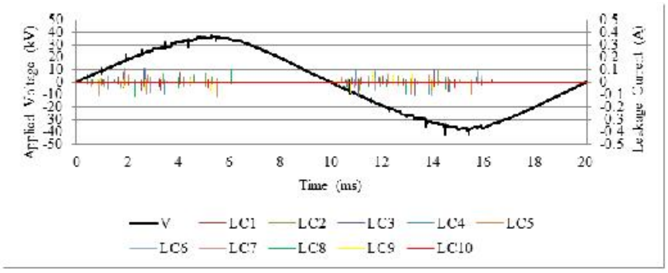


Figure 4. LC pulses waveform for medium contaminated insulator string

3.4 Heavily Contaminated String Insulator

Figure 5 depicts the LC pulses waveform for heavily contaminated insulator string. As revealed by the figure, again, the LC pulses appear at the location of applied voltage spike with the range of amplitude is between 0.16 A to 0.19 A. Interestingly, the LC pulse occurs at the phase of 0° to 90° and 135° to 180° for positive cycle while 180° to 270° and 315° to 360° for negative cycle. Referring to Figure 5, the distribution of LC pulses can be characterized as internal discharge as it has similar distribution of PD charge magnitude [8]. The result also appears to be consistent with the simulation study conducted by [13] in the void modeling using Monte-Carlo simulation. Their finding shows that the charge is distributed on the insulation surface initially, and then followed by a uniform distribution in the void and finally internal discharge occurs.

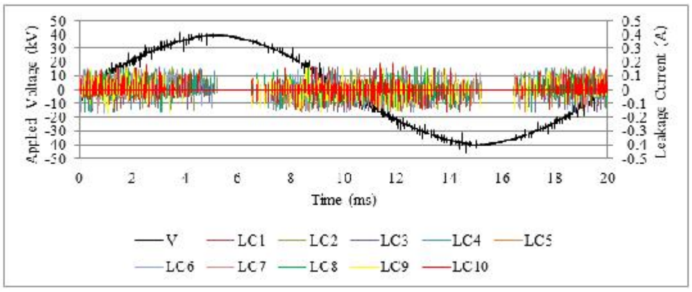


Figure 5. LC pulses waveform for heavily contaminated insulator string

– Conclusion

The present article provides the characterization of PD based on LC pulses waveform. Based on the presented results, PD can be characterized as follow: corona discharge occurs in lightly contaminated insulators, surface discharge occurs in medium contaminated insulators and finally internal discharge occurs in heavily contaminated insulators. The ability to distinguish the type of discharge from the LC waveform could be used to monitor and predict the condition of the insulator while energized and in service, so an immediate action can be taken thus increasing the reliability of the power system network. It is expected that when the LC pulses distributed at phase of 0° to 360° (all four quadrant), it can be used as a pre-warning of an impending breakdown.

ACKNOWLEDGMENT

The authors would like to thank Universiti Teknologi Malaysia (UTM) by awarding a research grants under vote 01H69, 03H86 and 4L133 from the Research Management Centre and Malaysia Ministry of Education (MOE).

References

1. B. S. Institution, "High-voltage test techniques. Partial discharge measurements," in *BS EN 60270*, ed. London, 2001.
2. R. Wilkins, "Flashover Voltage of High-Voltage Insulators with Uniform Surface-Pollution Films," *Proceedings of the Institution of Electrical Engineers, ,* vol. 116, pp. 457-465, 1969.
3. N. A. Othman, M. A. M. Piah, Z. Adzis, H. Ahmad, N. A. Ahmad, H. Kamarden, *et al.*, "Characterization of charge distribution on the high voltage glass insulator string," *Journal of Electrostatics,* vol. 72, pp. 315-321, 2014.
4. B. S. Institution, "Artificial pollution tests on high voltage insulators to be used on AC systems," ed. London, 1993.
5. "A Critical Comparison Of Artificial Pollution Test Methods For HV Insulators," *CIGRE Taskforce 33-04,* vol. Electra No 64, pp. 117-136, 1979.
6. D. Pylarinos, K. Siderakis, E. Pyrgioti, E. Thalassinakis, and I. Vitellas, "Investigation of Leakage Current Waveforms Recorded in a Coastal High Voltage Substation," *Engineering, Technology & Applied Science Research (ETASR),* vol. 1, pp. 63-69, 2011.
7. D. A. Nattrass, "Partial discharge measurement and interpretation," *IEEE Electrical Insulation Magazine, ,* vol. 4, pp. 10-23, 1988.
8. H. Illias, Y. Teo Soon, A. H. A. Bakar, H. Mokhlis, G. Chen, and P. L. Lewin, "Partial discharge patterns in high voltage insulation," in *2012 IEEE International Conference on Power and Energy (PECon),* , 2012, pp. 750-755.
9. F. H. Kreuger, *Industrial High DC Voltage*: Delft University Press, 1995.
10. F. F. Bologna, J. P. Reynders, and A. C. Britten, "Corona discharge activity on a string of glass cap-and-pin insulators under conditions of light wetting, light non-uniform contamination," in *2003 IEEE Bologna Power Tech Conference Proceedings*, 2003, p. 8 pp. Vol.3.
11. F. H. Kreuger, E. Gulski, and A. Krivda, "Classification of partial discharges," *IEEE Transactions on Electrical Insulation,* vol. 28, pp. 917-931, 1993.
12. D. Wanting, Z. Zhong, R. Ling, S. Yu, X. Qijia, and W. Hui, "Power apparatus insulation diagnosis through partial discharge in a smarter grid," in *Conference Record of the 2010 IEEE International Symposium on Electrical Insulation (ISEI)*, 2010, pp. 1-4.
13. K. Wu, Y. Suzuoki, and L. A. Dissado, "Improved simulation model for PD pattern in voids considering effects of discharge area," in *Annual Report. Conference on Electrical Insulation and Dielectric Phenomena, 2003.* , 2003, pp. 32-35.