



## Investigating Insulator UV Signal Frequency Components as Potential Tools for Condition Monitoring of Ceramic Insulators

Saiful Mohammad Iezham Suhaimi<sup>1</sup>, Nouruddeen Bashir<sup>1,3\*</sup>,  
Nor Asiah Muhamad<sup>1,2</sup> and Mohd Aizam Talib<sup>4</sup>

<sup>1</sup>*Institute of High Voltage & High Current, Faculty of Electrical Engineering,  
Universiti Teknologi Malaysia, 81310, UTM Johor Bahru, Malaysia*

<sup>2</sup>*School of Electrical & Electronic Engineering, Engineering Campus,  
Universiti Sains Malaysia, 14300 Nibong Tebal, Penang*

<sup>3</sup>*Power Equipment & Electrical Machinery Development Institute (PEEMADI),  
National Agency for Science and Engineering Infrastructure (NASENI),*

*PEEMADI Complex, KM 6, Okene-Auchi Expressway, P.M.B. 1029, Okene, Kogi State Nigeria*

<sup>4</sup>*No. 1, Kawasan Institusi Penyelidikan, Jalan Ayer Itam, 43000 Kajang, Selangor, Malaysia*

### ABSTRACT

Contaminated and ageing transmission line insulators often suffer from temporary or permanent loss of their insulating properties due to flashover resulting in power system failure. Surface discharges are precursors to flashover. To pre-empt any occurrence of flashovers, utility companies monitor the conditions of their insulators. There are numerous insulator surface monitoring techniques such as Leakage Current, Acoustics, and Infrared. However, these techniques may not be suitable for in-situ condition monitoring of the insulators as they are prone to noise, affected by environmental conditions or contact methods. Monitoring of the UV signals emitted by the surface discharges of these insulators has been reported to be a promising technique. However, comprehensive studies on this technique is lacking, especially on aged insulators. This paper investigated the UV signals of contaminated and aged insulators detected during surface discharge activities using UV pulse method. The time and frequency domain of the UV signals were analysed for a group of insulator samples having varying levels of contamination and phases of ageing. Results show that there is a strong correlation between the contamination level and ageing of the insulators with the amplitude and harmonic components of the UV signals. This correlation can be useful to monitor in-service insulator surface conditions.

*Keywords:* UV pulse method, UV pulse sensor, surface discharge, THD, discharge intensity

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#### *E-mail addresses:*

saifuliezham91@gmail.com (Saiful Mohammad Iezham Suhaimi),

nouruddeen@gmail.com (Nouruddeen Bashir),

norasiah@utm.my (Nor Asiah Muhamad),

mohdaizam@tnbr.com.my (Mohd Aizam Talib)

\*Corresponding Author

### INTRODUCTION

Transmission lines are one of the most important parts of a power system. This is due to the fact that they electrically insulate the

line from the towers (which are grounded) as well as mechanically support (hold) the lines. During service, these insulators experience operational hazards which affect their functionality. These hazards are mainly environmental in nature. Surface contamination due to pollution from various sources such as industrial and coastal as well as wetting of their surfaces reduce surface resistance of the insulators (Looms, 1988). This leads to discharges on the surface of the insulators which are precursors to flashover or surface degradation (ageing). It has been reported that 70% of line outages are as a result of insulator failures with the cause of such failures due to contamination flashover or ageing. Ironically, although these insulators account for a very small fraction of transmission line capital costs, almost half of the line maintenance costs are incurred by transmission line insulators (Gorur et al., 2005).

When insulators are contaminated or experience degradation, leakage current (LC) flows on the surface of the insulators. The presence of surface discharges distorts the LC waveform thereby leading to harmonics. The frequency components of LC waveforms have been reported to be a good indicator of insulator surface discharges and ageing (Du & Liu, 2008; El-Hag et al., 2003; Suda 1999; Bashir & Ahmad 2010).

Many types of surface discharge detection methods have been studied in the past to monitor corona discharges with new methods introduced from time to time. The most common methods that have been reported are LC method, infrared method, and acoustics method. These methods have their own advantages and drawbacks. Leakage current method, has ceased to be the preferred detection method for surface discharges due to its detection inaccuracy as it is prone to noise and electromagnetic interference, thus, affecting the reliability of leakage current data. In addition, the method involves direct contact measurement which is undesirable to utility companies. The Acoustics detection method is mostly used for partial discharge detection but is immune to electromagnetic interference (Markalous et al., 2008; Tsuji et al., 2005; Lundgaard, 1992). Ultrasonic detection method is sensitive to the background noise. Although it can easily locate discharges, it has poor sensitivity and sound attenuation. Infrared method is mostly related to temperature detection and most commonly used to detect the temperature of the corona discharge current. The reliability of infrared detection method is affected by weather especially during hot and sunny conditions. Additionally, as the temperature of the discharges is very small it makes the detection using the infrared method difficult, thus affecting detection accuracy (Kim & Shong 2011).

Studies have shown that electrical discharges on the surface of insulators emit UV radiation (Wang et al., 2014) which can be detected in many sources such as sunlight, electric discharge and special lights (mercury-vapor lamp, back light) (Zhao et al., 2003). These UV radiations have different wavelengths. The UV radiations from electrical discharges such as surface discharge are usually in the waveband of 240 nm to 280 nm (Lu et al., 2010) which is also known as the solar blind region. This means that in this wavelength, the UV radiations detected from the discharges are not affected by UV from sunlight. These ultraviolet signals have been shown to be a good method to detect corona discharge from insulator transmission line. Studies have shown that this method could locate the discharge area with relatively high accuracy. The method also has high sensitivity, thus, making the detection more accurate and reliable compared with the other methods mentioned earlier. In addition, it is a non-contact method. Ultraviolet pulse method and ultraviolet imaging method are two methods involved

in the detection of the ultraviolet signals emitted by the surface discharges. With regards to the UV pulse method, most of the studies have been limited to detection and measurement of the UV pulse signals of the insulator surface discharges. Studies on characterisation and pattern recognition of the UV pulse signal in relation to surface condition of the insulators are lacking.

The objective of this paper is to study the correlation between the time and frequency components of UV signals due to emitted UV radiations during surface discharge activities and the surface condition of commercial field-aged insulator samples.

## METHODOLOGY

### Insulator Samples and Artificial Contamination

In this study, insulator samples of varying degrees of ageing were used. The samples were full scale commercial ceramic glass insulators that were naturally aged while in service. The insulators were obtained from the 132 kV transmission lines of the Malaysian national power company, Tenaga Nasional Berhad (TNB); they have standard profile having leakage distance of 290 mm. Table 1 shows the description of the insulators.

Table 1  
*Insulator Samples*

| Insulators | Service History        | Number of samples | Ageing   |
|------------|------------------------|-------------------|--|
| A          | Less than 10 years     | 2                 | Good condition   |
| B          | Between 10 to 20 years | 2                 | Mild corrosion at cap  |
| C          | Greater than 20 years  | 2                 | Discoloration of glass dielectric, severely corroded cap and pin |

To investigate the relationship between the UV signals emitted during surface discharge activities and surface condition of the insulators, the insulator samples were artificially contaminated with salt as the contaminant according to IEC 60507 (IEC 1991). Three contamination levels were produced, and the ESDD level of each contamination level measured. Using the ESDD level, the contamination levels were classified using IEC 60815 (IEC 1986). Table 2 shows the contamination levels used in this study. During service, contaminated insulators could possess dry contamination or wet contamination depending on the environmental conditions. In this study, only the former was considered.

Table 2  
*Insulator samples' artificial contamination*

| Salt (g/L) | ESDD (mg/cm <sup>2</sup> ) | Contamination Level |
|------------|----------------------------|---------------------|
| 0          | N/A                        | N/A                 |
| 5          | 0.06                       | Light               |
| 30         | 0.21                       | Medium              |
| 120        | 0.47                       | High                |

### Experimental set-up and procedure

Figure 1 shows the experimental set-up of this study. A 100 kV step-up transformer was used to inject high voltage to the insulator. The high voltage supply from the transformer was controlled using a voltage regulator. The insulator sample was housed in a chamber made up of acrylic glass measuring 80 cm X 80 cm X 80 cm. The UV radiation emitted during discharge activities was detected using a UV pulse sensor which was placed outside the chamber. The UV sensor used in this study had a waveband between 185nm and 260nm (Zang et al., 2009), which defines the waveband of the UV signals produced on the surface discharge which can be detected by the sensor. The sensor was powered by a 12 V DC battery and was placed at a distance outside the chamber. The output of the sensor was connected to a computer via a PICO SCOPE for measurement and to record the UV pulse signals. The signal data were saved in PICO SCOPE files before being transferred into Excel and MATLAB for further analysis. MATLAB was used to remove the noise in the signals to make it easier for pattern identification, and also to find the harmonic distortion of the signals and the frequency component of the signals.

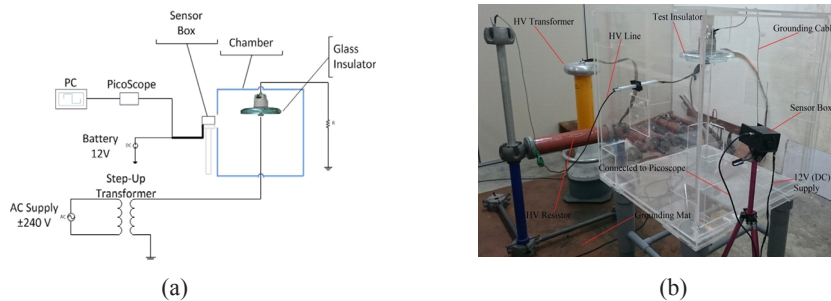


Figure 1. Experimental Setup (a) Schematic diagram (b) Pictorial view

### Insulator surface discharge level

In this study, to generate the discharges of various intensities on the surface of the insulator samples, different voltages were applied. Various discharge intensities were simulated to closely mimic service condition as well as processes that lead to flashover of insulator during service. Table 3 depicts the discharge intensities produced in this study due to varied applied voltages. Voltage was applied to the insulator and steadily increased. Once the required discharge intensity level was reached, the applied voltage, UV signal voltages and waveforms were recorded.

Table 3  
Classification of Insulator surface discharge intensity levels

| Electrical strength discharge level | Description   |
|-------------------------------------|---|
| Hissing                             | Hissing without any visible discharge   |
| Discharge at pin of the insulators  | Hissing sound plus spot discharges at the pin of the insulators   |
| Discharge at cap of the insulators  | Louder hissing noise, discharges at both the pin and cap of the insulator samples                                 |
| Severed discharge                   | Very loud hissing noise, intense sparking discharge on the pin and cap of the insulator (just prior to flashover) |

## RESULT AND DISCUSSION

### UV pulse signals

The UV signals emitted by the insulator samples during discharge activities were recorded and plotted. Figure 2 shows the UV signal waveform for Group A non-contaminated (0 g/l) insulator samples at various discharge intensity levels.

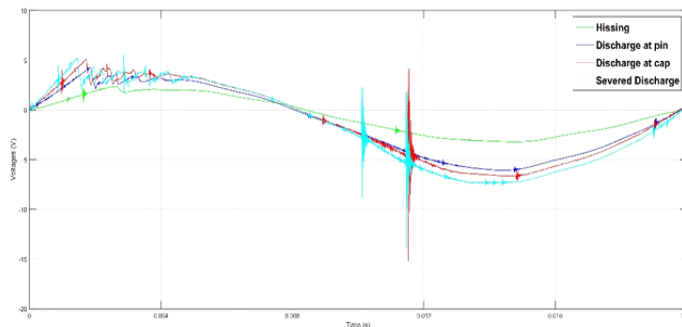


Figure 2. UV signal waveform of non-contaminated Group A insulator samples

The presence of electrical discharge distorts the waveforms thereby creating harmonics. There is a strong correlation between the discharge intensity and UV signal distortion. From Figure 2, it can be seen that the harmonic distortions at the first half cycle of the signals increased when discharge intensity is increased, from hissing to severe discharge. However, in the second half cycle of the waveform, there appears to be a marked difference between the harmonic distortions of the discharge intensities. The hissing and discharges at pin, which were discharges of lesser intensity appeared to have lesser distortions compared with discharges at cap and severe discharge. In addition to the relationship between the discharge intensity and wave distortion, there also appeared to be a relationship between discharge intensity and the amplitude of the sinusoidal waveform. As the surface discharges became increasingly intense, the amplitude of the waveform also increased. Table 4 shows the injected (applied) voltages and the average UV signal peak-to-peak voltages.

Table 4  
Voltage Amplitudes of UV signals for non-contaminated Group A insulator samples

| Voltages<br>Discharge<br>Intensity<br>levels | Non-Contamination                            |   | Light Contamination                         |   | Medium Contamination                        |   | Heavy Contamination                         |   |
|--|--|---|---|---|---|---|---|---|
|  | Range<br>Injected<br>Voltage, $V_i$<br>=(kV) | Average<br>Peak to<br>Peak<br>Voltage, $V_{p-p}$<br>(V) | Range<br>Injected<br>Voltage, $V_i$<br>(kV) | Average<br>Peak to<br>Peak<br>Voltage, $V_{p-p}$<br>(V) | Range<br>Injected<br>Voltage, $V_i$<br>(kV) | Average<br>Peak to<br>Peak<br>Voltage, $V_{p-p}$<br>(V) | Range<br>Injected<br>Voltage, $V_i$<br>(kV) | Average<br>Peak to<br>Peak<br>Voltage, $V_{p-p}$<br>(V) |
| Hissing                                      | 27 – 35                                      | 5.6   | 20 – 32                                     | 6.4   | 20 – 32                                     | 6.3   | 20 – 31                                     | 6.5   |
| Discharge at pin                             | 40 – 50                                      | 10.3  | 42 – 50                                     | 11.8  | 40 – 50                                     | 11.0  | 35 – 48                                     | 11.9  |
| Discharge at cap                             | 54 – 56                                      | 11.6  | 50 – 54                                     | 12.4  | 50 – 54                                     | 12.1  | 44 – 49                                     | 12.2  |
| Severe                                       | 60 – 63                                      | 12.5  | 60 – 63                                     | 12.6  | 60 – 63                                     | 12.5  | 56 – 59                                     | 12.2  |

The distortion and voltage amplitude pattern in Figure 2 and Table 4 were similarly also observed for all cases of the insulator samples investigated in this study.

### THD and Fundamental Frequency Component

The measured THD and fundamental frequency component of the UV signal harmonics are presented in Figures 3 and 4 respectively. The THD in this case is the percentages of the sinusoidal signals detected by the UV sensor being disturbed due to the detected UV signal produced by the surface discharges of the insulator samples. On the other hand, the fundamental frequency is the lowest frequency of signals being detected (Nam et al., 2002). From Figure 3, it can be seen that in almost all cases with respect to contamination level for all three insulator sample groups, the THD values increased as the surface discharge intensity increased. The THD values for hissing varied between 5% and 10% while for severe discharges their THD percentages were from 10% and 31%.

Similar patterns were also observed with the fundamental frequency component of the signals as shown in Figure 4. The fundamental frequency components increased as the discharge intensity increased. A large increase is observed in fundamental frequency components from hissing to appearance of a visible discharge at the pin. For transmission line insulators, visible discharges normally originate from the pin as that is the point with the highest electrical stress. However, as the strength of the discharge intensity progresses, the rate of increase in the fundamental frequency component of the UV signal reduces.

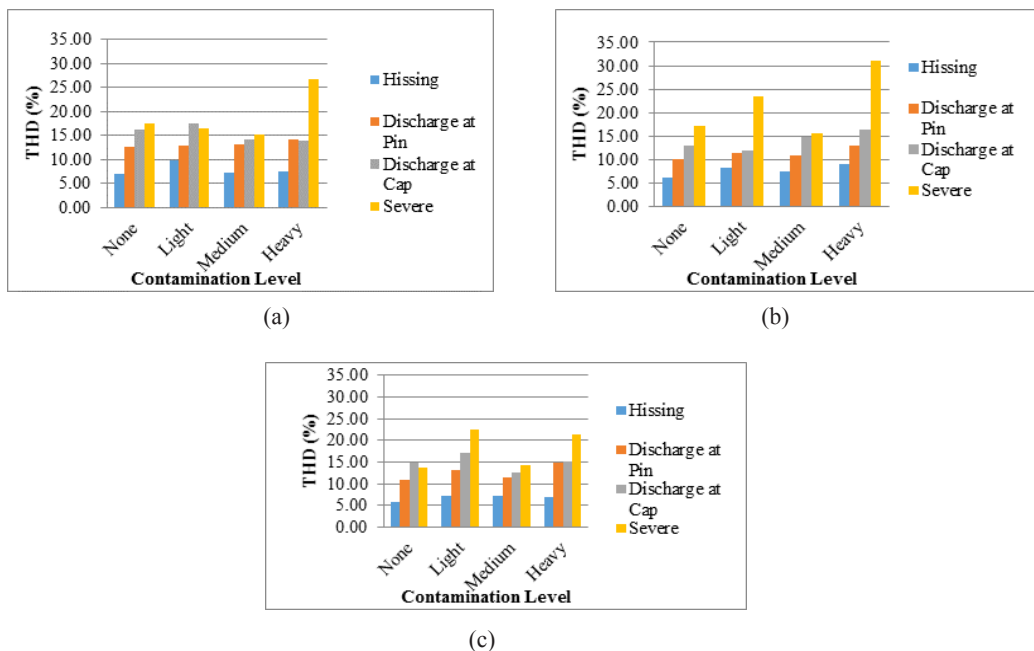


Figure 3. Insulator samples UV signals THD; (a) Group A; (b) Group B; (c) Group C

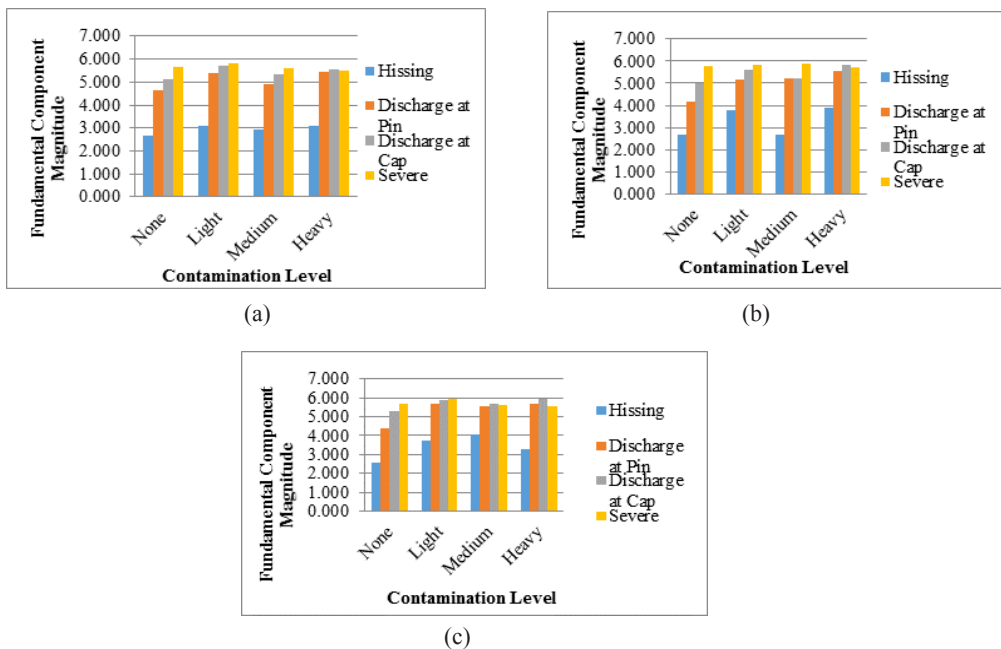


Figure 4. Insulator samples UV signals Fundamental frequency component; (a) Group A; (b) Group B; (c) Group C

## CONCLUSION

In this study, the time and frequency components of detected UV signals emitted by insulator surface discharges using UV pulse method has been presented. The signals were analysed under different surface contamination levels and varying degree of ageing. The UV pulse method was able to show a positive correlation between the UV signals' harmonic distortions levels and the surface condition of the insulators. This suggests that the UV pulse method can be a promising technique in monitoring transmission line insulators. Unlike previously used techniques, the UV detection method is non-contact and immune from noise, thus, making it a good tool for monitoring insulators.

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