Ultraviolet Pulse Measurements Associated with Leakage Current on the Surface of Contaminated Glass Insulators

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Abstract: This paper investigates the relationship between UV pulse emissions and leakage current (LC) on contaminated glass insulators under varying contamination levels, surface condition and discharge intensities. Experiments conducted under dry and wet conditions involved applying four applied voltage (7, 11, 15 and 22 kV) and varying contamination levels quantified using the Estimated Salt Deposit Density (ESDD) method. UV pulses were detected using a UV sensor together with the LC waveforms. The results revealed that number of UV pulses detected during surface discharges increased as the discharge intensities increased due to increase in contamination severity and electrical stress. Under dry conditions, UV pulses were found negligible. However, under wet conditions, it became prominent, particularly at higher voltages and contamination levels. The study reveals a direct relationship between the presence of the 3rd harmonic component in the distorted LC waveform caused by dry band arcing on the glass insulator's wet surface under medium to heavy contamination and the emitted UV radiation. The relationship of leakage current waveform containing surface discharges and UV radiation highlights the potential of utilizing UV pulse detection for monitoring insulator surface discharges for assessing insulator condition, predicting flashover, and evaluating contamination severity.

Keywords: Contamination, Leakage Current, UV pulse, surface Discharges, Flashover

1. Introduction

The environment is a primary factor contributing to insulator flashover and breakdown in power systems. Aerosols and pollutants that accumulate onto glass insulator surfaces lower their surface resistance thus facilitating the flow of leakage current (LC). This, can cause dry band arcing and surface discharges on the surfaces of the insulators [1], [2].

As the environmental condition that affects the insulators' performances during operation cannot be controlled, power utilities have to be periodically maintaining the glass insulator surface condition to prevent or minimize the risk of surface discharges could evolve to flashovers. Ineffective maintenance of insulators could result power system failure causing damage and will require high recovery cost. Recently, researchers have introduced a monitoring technique to forecast the condition of the insulators during operation and to prevent the flashover occurrence. The technique involves monitoring the surface discharges occurring on the insulators that could trigger a potential flashover.

So far, various detection methods have been employed, including infrared, ultrasonic, acoustic, leakage current, and ultraviolet (UV) methods[3]–[6]. Each method has its advantages and limitations [7]–[9]. Early detection of surface discharges will be helpful in predicting the flashovers and reduce power system failures.

UV radiation originate from several sources, including sunlight, electrical discharges, and special light sources such as mercury-vapor lamps. Studies have found that surface discharges on insulators emit UV radiation [6], [10], [11]. Electrical discharges such as corona produce UV radiation with wavelengths ranging from 280 nm to 400 nm, while some fall between 160 nm

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and 180 nm, known as the solar blind region [12], [13]. Many researchers have explored UV radiation from electrical discharges using the UV imaging method which is reliable for detecting and locating discharges but can be costly in field applications. Recently, a less costly proposed alternative is the UV pulse method which detects and measures UV pulses emitted by surfaces discharges on insulators. This method has shown a promising result. However, this method required a comprehensive study to guarantee its reliability and accuracy in detections, resolve potential constraints, improve adaptability to diverse environmental circumstances and enhance overall performance and efficiency in actual applications.

Meanwhile, LC flow on the surface of the glass insulators is known to be one of the many ways to predict the condition of the insulators. The glass insulator surface contaminates with extreme contamination and with the presence of moisture may results to elevate LC. Depending on the level of contamination, this elevated LC causes dry bands to form due to ohmic heating. The system voltage then concentrates in these dry bands, creating high electrical stress. This stress initiates dry-band arcing that can lead to breakdown. High electrical stresses typically occur at the narrow parts of the insulators, such as the shanks near the high voltage electrode, and other areas with lower resistance due to moisture or contamination. Over time, sustained arcing or discharges can lead to flashovers as these discharges combine and bridge the high voltage and ground electrodes [14]–[16]. The sustained discharge activities on the surface of insulators can damage their mechanical or electrical properties, leading to insulator aging and surface degradation [17]–[21]. Additionally, these discharges can interfere with high-frequency communications and radio systems used by utilities for communication between their transmission stations [22].

Research on detection of electrical discharges using UV pulse have been conducted in the past, however most of these studies have been limited to detection of the discharges generated on different electrode configurations, plane-rod, needle-plane etc; other studies were carried out on detection of arcs in switchgears and on transmission line insulators in-situ [13], [23]–[26].

In light of the foregoing, this paper presents the experimental work on the UV measurement associated with the LC on the surface of the glass insulator and the analyses as well as characterisation of UV pulses under different contamination levels and electrical stresses. The results from the UV pulse studies were further correlated with insulator LC under these conditions.

2. Methodology

Figure 1 shows the experimental setup of the surface discharge measurement based on UV emission detection associated with the LC occurrence. A glass insulator was housed in an acrylic chamber with relative humidity maintained between 60 – 70 %. High voltage stress was applied to the insulator by a step-up transformer rated 0.24/100 kV, 5kVA. The applied voltages were varied at 7 kV, 11, kV, 15 kV and 22 kV. The insulator was exposed to the contamination ranging from zero contamination level to light, medium and heavy contamination levels. Each contamination level was determined and computed using the Estimate Salt Deposit Density (ESDD). The ESDD was computed using the IEC60060. These contamination levels were chosen for this experiment to provide a variety of surface conductivities which will generate varying degrees of discharge intensities on the insulator surface when subjected to varying electrical stresses. Furthermore, measurements were conducted under two contamination conditions viz. dry and wet. Under dry contamination, the insulator is contaminated with the saltwater and then dried under the sun. Measurements then carried out after the contaminated insulator surface has dried. While under wet condition, the insulator is contaminated with the saltwater and while the surface is wet, tests are carried out. The IEC60507 was used to categorise the contamination levels based on the computed ESDD.

Table 1 shows the contamination level used in this work along with the salt concentration and conductivity of each level. The LC flowing on the surface of the insulator and the UV radiated from the surface discharge were measured simultaneously with a 330-Ω shunt resistor and UV sensor (UVTRON-R2868), respectively. The UV sensor, positioned 1 m from the discharge source, has a sensitivity of 5000 cpm under UV of 200 nm wavelength and 10 pW/cm^2 radiation degree. The LC and UV waveforms were measured and recorded by a PicoScope (a PC oscilloscope). The waveform was captured within 100 cycles of applied voltage for each frame. The data collected was analysed in MATLAB. The Fast Fourier Transform (FFT) of the LC to analyse its harmonic component was also determined using MATLAB. The LC harmonic component was also analysed to identify its relationship with the UV pulse detected.

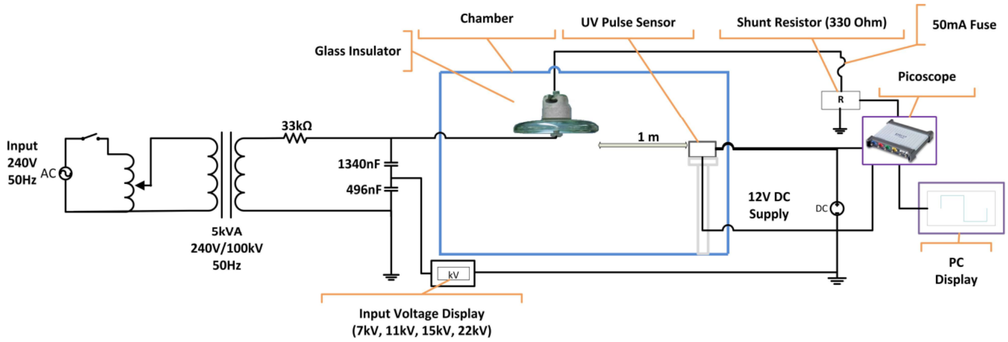


Figure 1. Experimental Setup

Table 1. Contamination level for each conductivity level

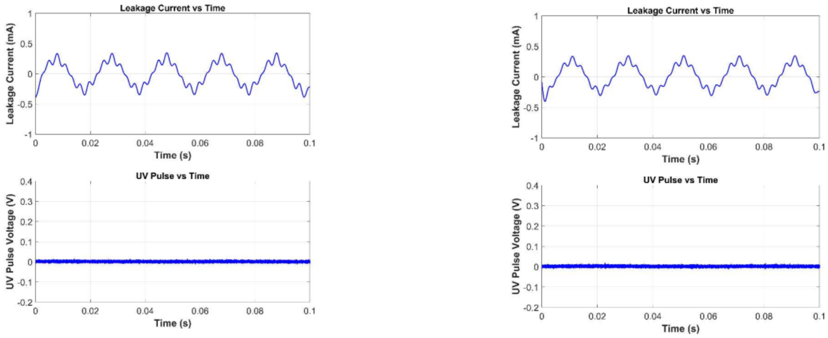
Salt (g/L)	Conductivity (µS/m)	ESDD (ms/cm^2)	Contamination Level
0	4.6	N/A	Zero
5	105	0.06	Light
30	240	0.21	Medium
120	344.6	0.47	Heavy

3. Result and Discussion

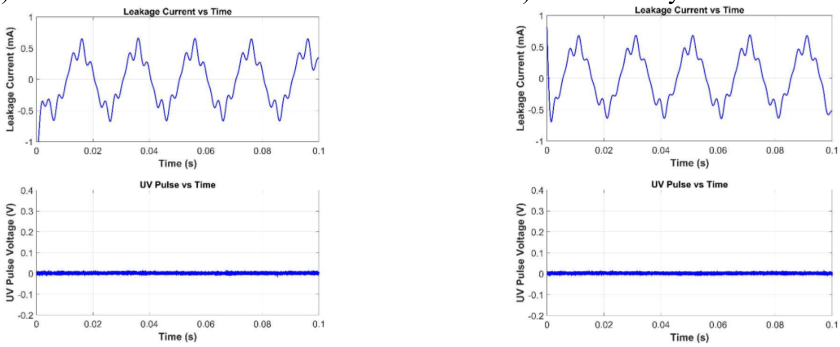
In this section, the experimental results are presented, analysed and discussed.

A. UV pulse measurement in relationship with LC under dry contamination conditions

Figure 2 presents the UV pulse measurement and the corresponding LC waveform under medium and heavy contaminations for voltage levels of 11 kV and 22 kV. Figure 3 shows the harmonic component of the LC waveform under the same condition. From Figure 2, it can be seen that the LC waveform is distorted. The non-uniform voltage distribution and high resistance dry bands on the surface of the insulator cause the insulator LC to behave non-linearly, leading to the distortion of the LC waveform. This distortion is seen in the presence of the 5^{th} and 7^{th} harmonics (see Figure 3). However, the 3^{rd} harmonic component of the LC is not detected due to the absence of arcing in the dry bands. UV pulses were also not detected due to the absence of dry band arching. The 3^{rd} harmonics is a strong indicator for the occurrence of dry band arching that may contribute to the UV emission [27]. This trend was similarly observed under the 7 kV and 15 kV voltage levels.

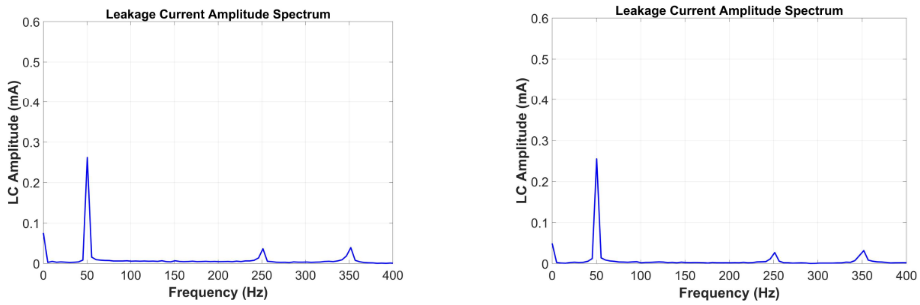


a) 11kV Medium Contamination b) 11kV Heavy Contamination

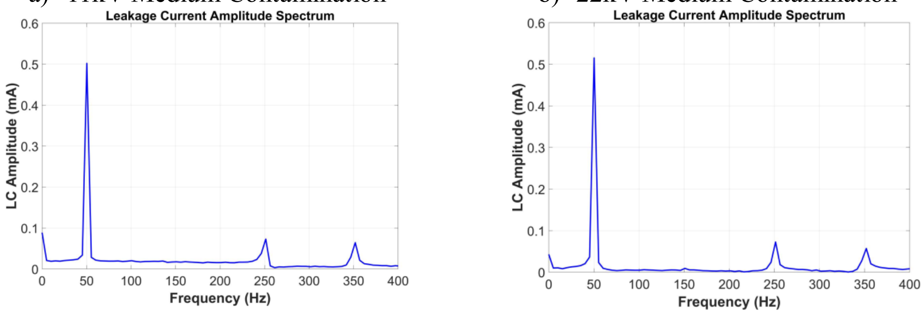


c) 22kV Medium Contamination d) 22kV Heavy Contamination

Figure 2. UV pulse and LC at 11 kV and 22 kV voltages for dry condition of medium and heavy contamination



a) 11kV Medium Contamination b) 22kV Medium Contamination



c) 11kV Heavy Contamination d) 22kV Heavy Contamination

Figure 3. LC Harmonic component amplitude for 11 kV and 22 kV voltages (medium and heavy contamination) under dry surface condition

B. UV pulse measurement in relationship with LC under wet contamination conditions

Figures 4 shows the UVP, and LC waveforms (time and frequency domains) for zero contamination level for all the 4 voltage levels used in this work. From the result it can be see that under zero contamination level, no UV pulses were detected by the UVP sensor except at 22 kV; implying the presence of dry band arcs at this voltage level. The discharges were not strong and thus not visible to the naked eyes. This trend was also observed under light contamination level. UV pulses were only detected for 22 kV as shown in the figure.

Figure 5 shows UVP, and LC waveforms (time and frequency domains) for all the 4 voltage levels under light contamination level. Similar to the zero contamination, discharges were only observed at 22kV voltage level. However, the discharge intensity is higher as the contamination level is light due to higher electrical stress and contamination; this is corroborated by the amplitude of the 3rd harmonic being higher than that under the zero contamination condition. The number of UVP pulses recorded were also higher indicating higher discharge intensity.

Figure 6 shows UVP, and LC waveforms (time and frequency domains) for all the 4 voltage levels under medium contamination level. The higher contamination level (medium) and wet surface resulted in dry band arcs at 7kV, 11kV and 15kV though relatively weak. The UV radiation was minimal thus less pulses detected by the UVP sensor. For voltage level of 22 kV, the dry band arcs were strong and visible, and the number of pulses detected by the UVP sensor increased. The LC waveforms were severely distorted due to the presence of arcs with the degree of distortion increasing with increasing electrical stress. The amplitude of the 3rd harmonic increased and became the dominant harmonic component.

Figure 7 shows UVP, and LC waveforms (time and frequency domains) for all the 4 voltage levels under heavy contamination level. The heavy contamination level and wet surface has drastically reduced the insulator's surface resistance thus leading to severe arcing activities on its surface with intensity increasing as the voltage stress increases. Discharges were visibly seen and recorded at all 4 voltage levels. Multiple UV pulses could be seen detected by the UVP sensor and the LC waveforms severely distorted due to the presence of the discharges. The 3rd harmonic component could be seen to be dominant in all 4 voltage levels.

Furthermore, the presence of discharges is corroborated by the presence of 3^{rd} harmonics in the LC frequency components (Figure 4d). The amplitude of the 3^{rd} harmonics was higher for the light contaminated glass insulator at the same voltage applied (Figure 5d). The number of UV pulses recorded are also higher in the light contaminated insulator compared to the uncontaminated insulator sample indicating more UV radiation was emitted from the arching. As the contamination level on the glass insulator increases to medium and heavy, the UV pulses were detected at all applied voltage levels (Figures 6 and 7); this corresponds to the dry band arching occurring at the medium and heavy contaminations level of glass insulator showing high frequency pulses occurs on LC waveforms. The magnitude of the 3^{rd} harmonics kept increasing as the voltage level increased from 7 kV to 22 kV. Likewise, the number of UV pulse significantly increased with the increasing applied voltage.

Table 2 summarizes the status of the UV pulses at various applied voltages for dry and wet contamination conditions. Figure 8 shows graph of number of UV pulses versus the applied voltage for the four contamination levels under wet condition over 100 cycles of the LC waveforms. For the zero and light contamination level, UV pulse detection started at 22 kV; implying the absence of dry band arching at 7 kV, 11 kV and 15 kV. In contrast, for medium contamination level, low number of UV pulses were detected from 7 kV up to 15 kV but rose sharply in number at 22 kV. The heavy contamination level exhibits the highest UV pulse counts across all voltages; the number of pulses increased exponentially from 7 kV all the way to the 22 kV. This trend suggests that contamination severity significantly impacted the development of dry band arching and consequently the UV pulse counts at higher electrical stress.

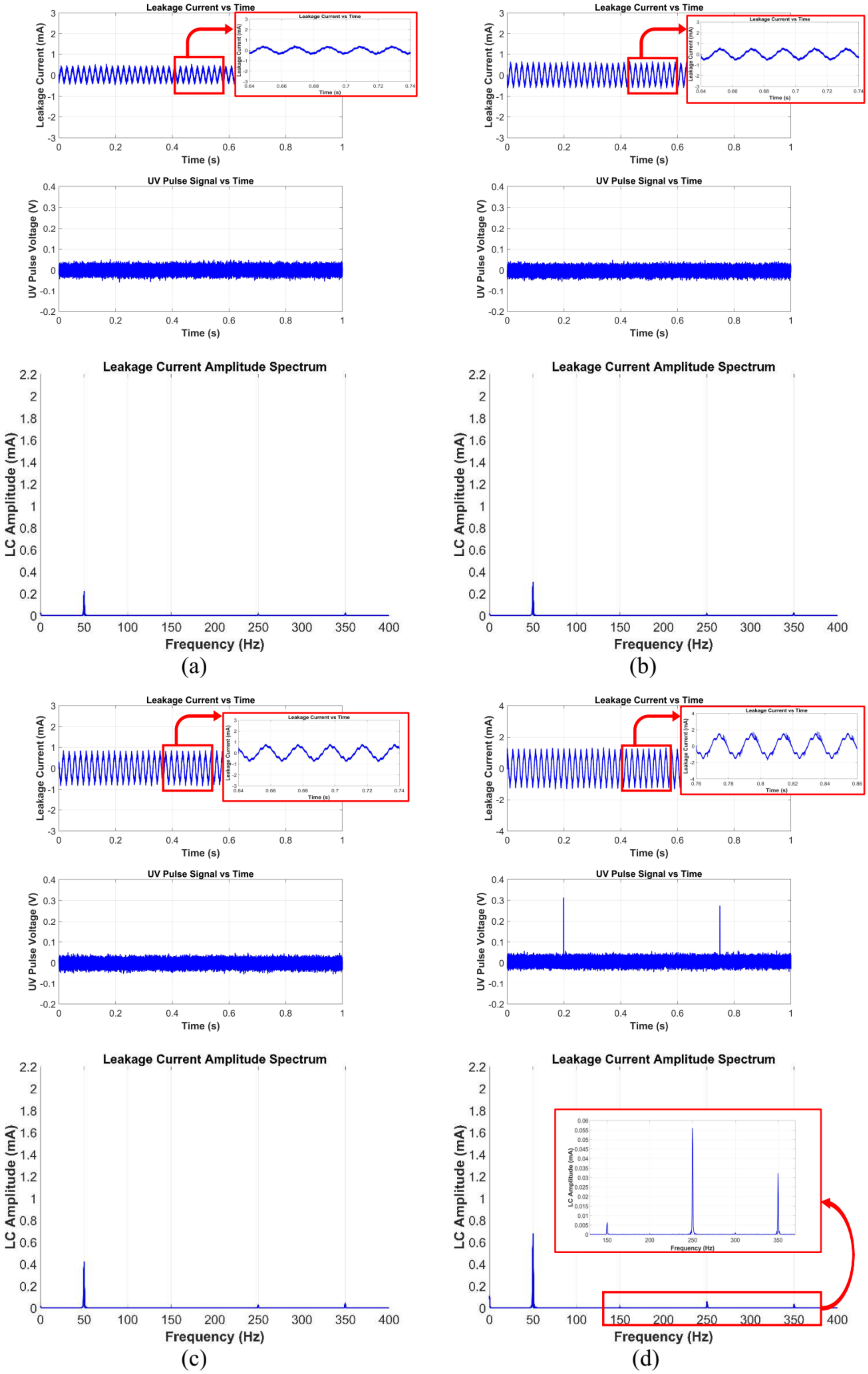


Figure 4. UV pulse and LC waveforms with its harmonic component for zero contamination level at different applied voltage (a) 7kV (b) 11kV (c) 15kV (d) 22kV

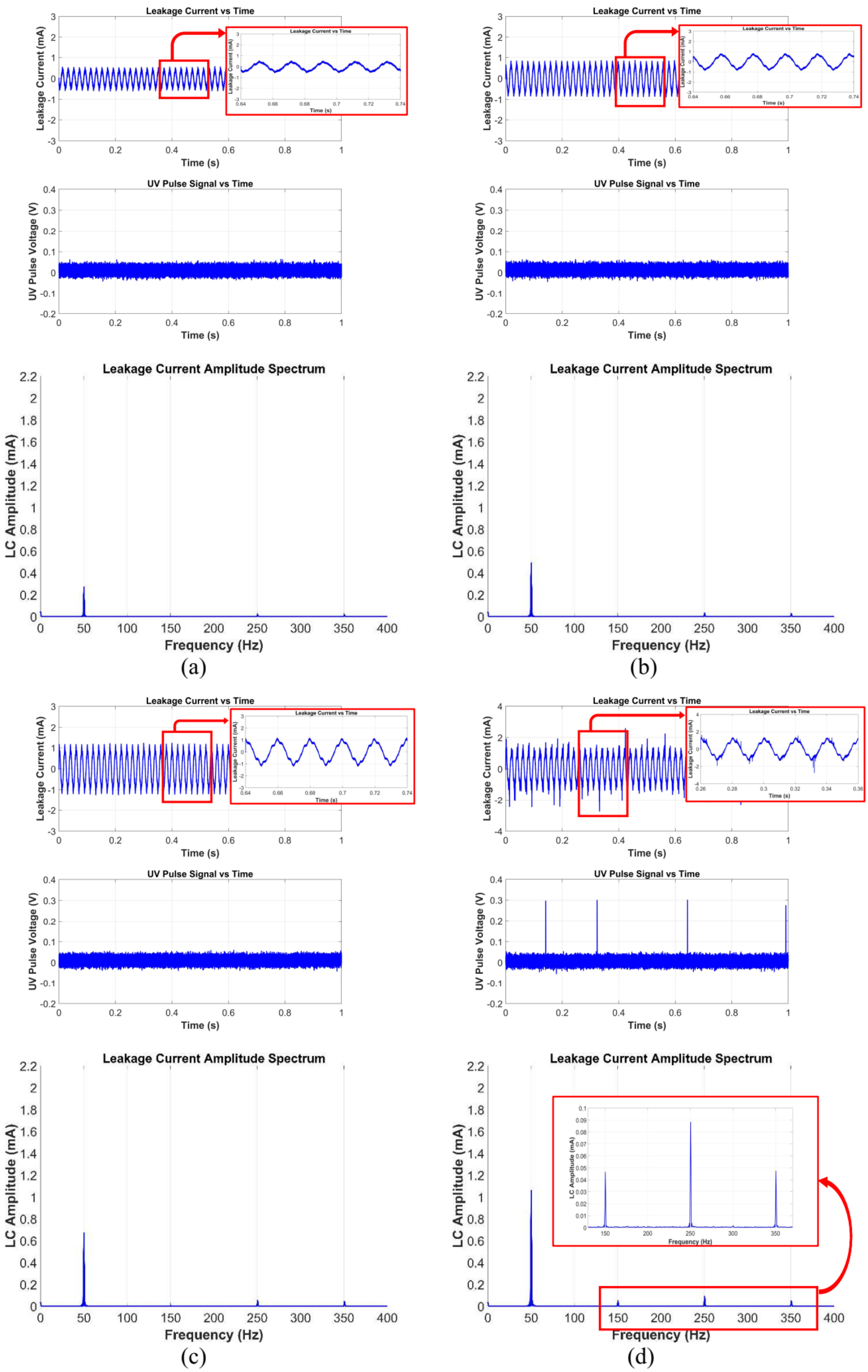


Figure 5. UV pulse and LC waveforms with its harmonic component for light contaminated glass insulator at different applied voltages (a) 7kV (b) 11kV (c) 15kV (d) 22kV

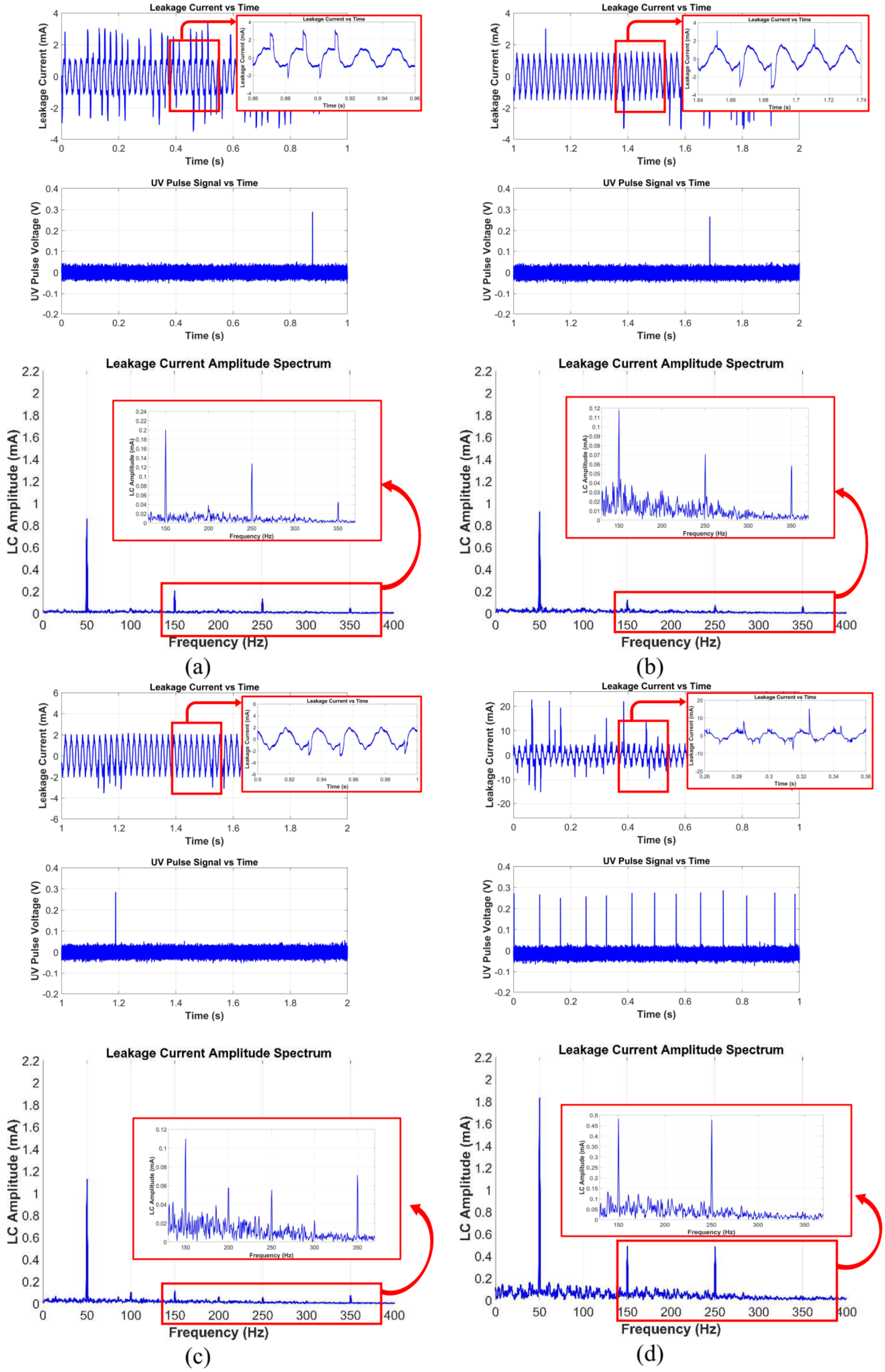


Figure 6. UV pulse and LC waveforms with its harmonic component amplitude for medium contamination level at different test voltage levels (a) 7kV (b) 11kV (c) 15kV (d) 22kV

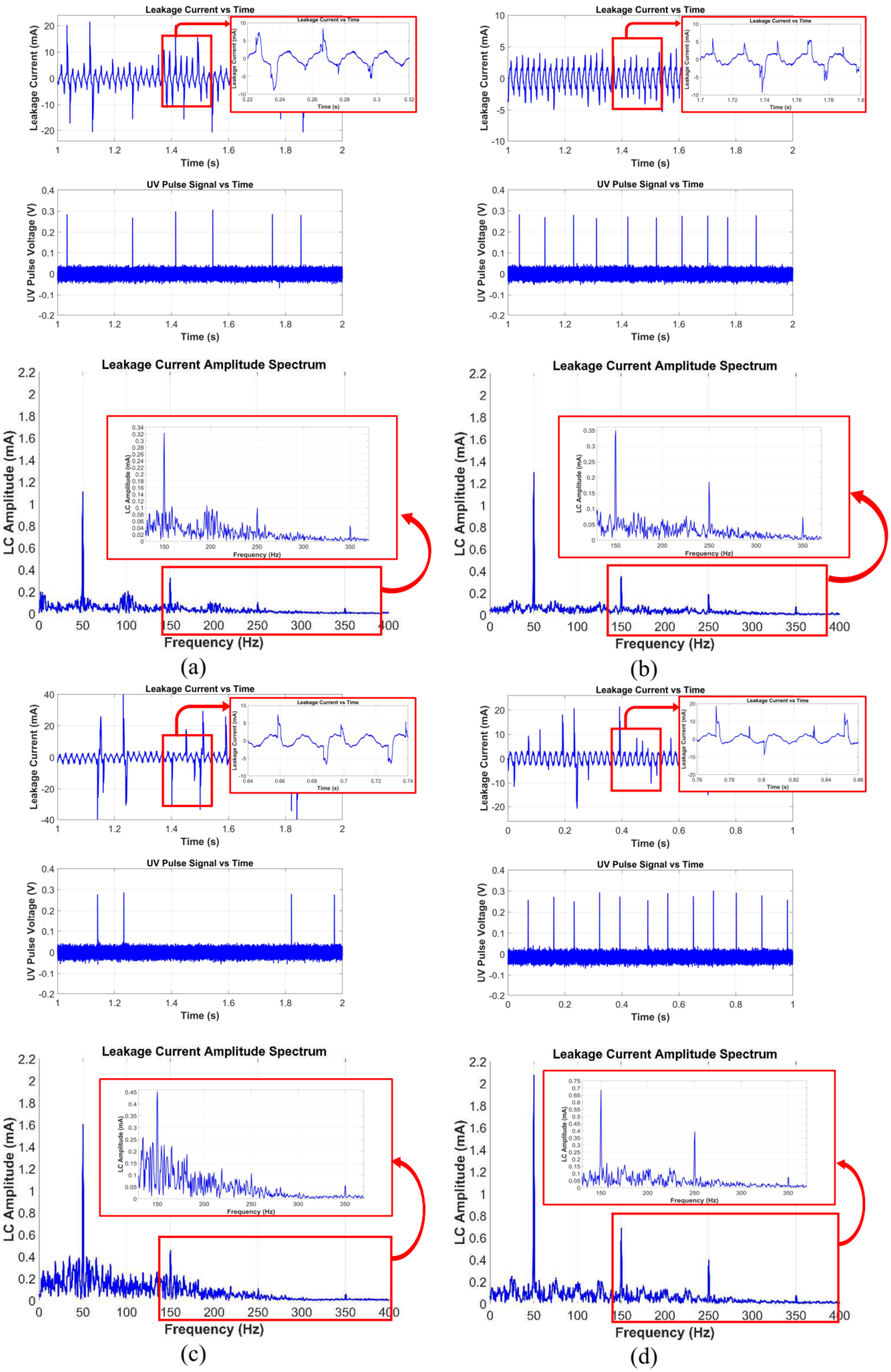


Figure 7. UV pulse and LC waveforms with its harmonic component amplitude for heavy contamination level at different test voltage levels (a) 7kV (b) 11kV (c) 15kV (d) 22kV

Table 2. Summary for UV pulse detection for all tested voltage and contamination level

Voltage Level	Contamination Level (Dry)				Contamination Level (Wet)			
	Zero	Light	Medium	Heavy	Zero	Light	Medium	Heavy
7kV	x	x	x	x	x	x	√	√
11kV	x	x	x	x	x	x	√	√
15kV	x	x	x	x	x	x	√	√
22kV	x	x	x	x	√	√	√	√

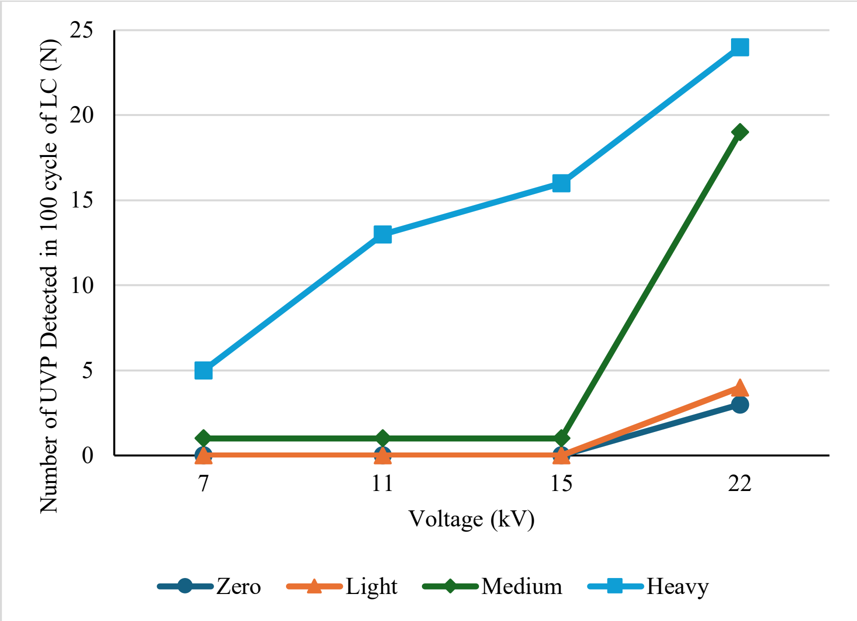


Figure 8. Number of UV pulse detected in 100 cycles of LC with respect to each voltage and contamination levels under wet conditions.

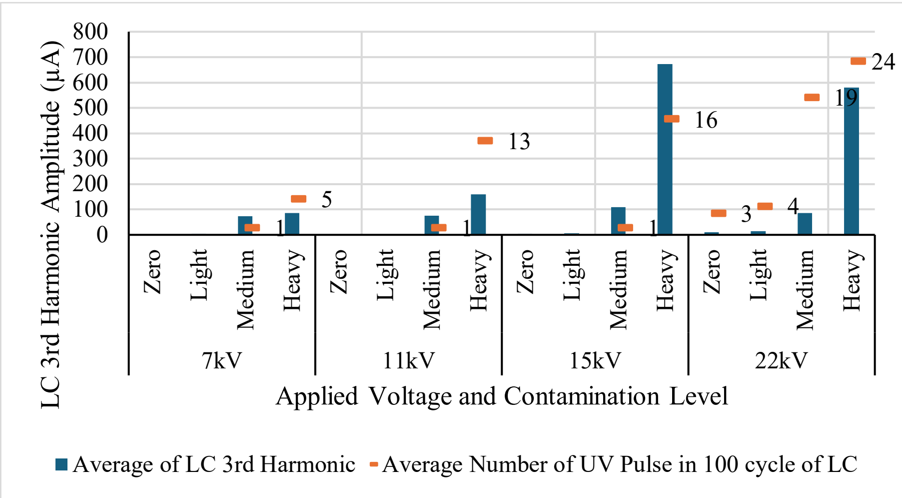


Figure 9. Average LC 3rd harmonic and the number of UV pulse in 100 cycles of LC

Figure 9 shows the relationship of the average LC 3rd harmonic and the number of UV pulse in 100 cycles of the LC. The 3rd harmonic component of the LC increased in amplitude as contamination severity and electrical stress increased. The 3rd harmonic amplitude increased as the severity of the dry band arching on the insulator became more intense resulting in the UV sensor detecting higher number of UV pulses. The figure illustrates that the number of UV pulses detected escalated in direct relation to the magnification of the 3rd harmonic component.

Figure 10 shows the average of LC Total Harmonic Distortion (THD) and number of UVP in 100 cycles of the LC. It can be seen that the UVP count under zero and light contamination was small but increased significantly under medium and heavy contamination. Both THD and the number of UVP increased significantly as the severity of the contamination increased. The increase in THD with increasing electrical stress (voltage level) and contamination suggests increase in the severity of the LC waveform distortion as a result of the presence of dry band arching.

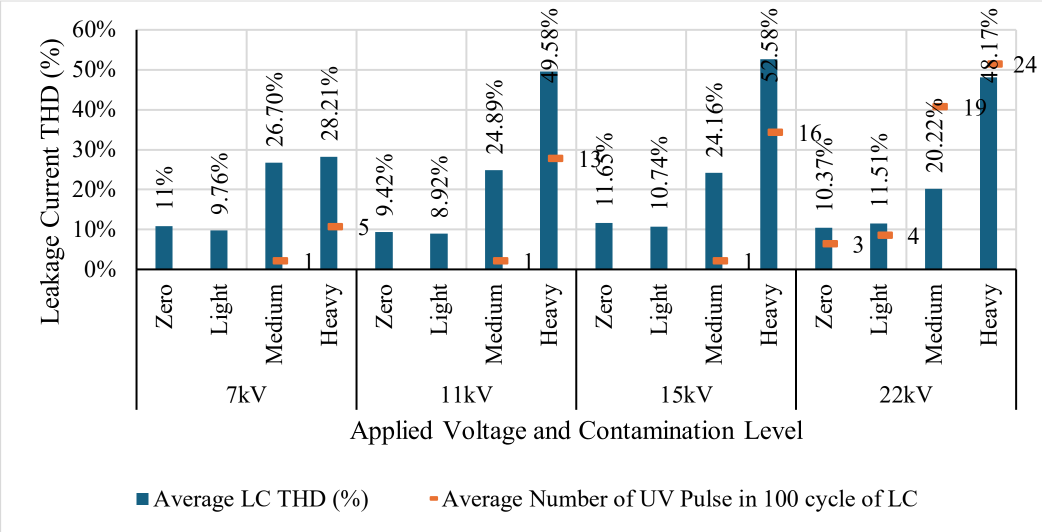


Figure 10. Average LC THD and the number of UVP in 100 cycles of LC

4. Conclusion

Studies on UV pulses associated with the LC under wet and dry contaminated glass insulator at four different applied voltage have been presented. The study can be concluded as follows:

i. The presence of 3rd harmonic component of the distorted LC waveform due to the presence of dry band arcing of the glass insulator wet surface condition under medium/heavy contamination indicates has a direct relationship with the emitted UV radiation from the arcing.

ii. The detected UV pulses increased with increasing electrical stress, contamination level and surface condition of the insulator indicating a relationship with the LC waveform distortions due to the presence of dry band arcing.

iii. UV pulse detected due to dry band arcing on the insulator surface can be a promising parameter for condition monitoring of insulator surface discharges which are precursors to flashover.

5. Acknowledgment

None

6. References

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