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Ultraviolet pulse pattern for different types of insulator material during surface discharge activities

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Abstract

In the past, there were several different types of discharge detection methods that have been employed for the detection and monitoring of surface discharge activities at transmission line insulators. However, the existing detection system does not work well when the discharge activity is weak and sensitive to surrounding temperature and environmental conditions. The recent development of surface discharge detection devices that have been employed currently are ultraviolet (UV) imaging and UV pulse devices but the former is known to be expensive. In this paper, a UV pulse sensor which is known as the R2868 UVTRON Flame Sensor has been employed to assess the effectiveness of the sensor for detecting the electrical discharge activity of the insulator surface. The samples used for the electrical discharge generation testing and measurement are the 11 kV glass and porcelain pin-type insulators. The tests have been conducted by exposing both the insulations to dry and wet conditions with each of them subjected to a variety of applied voltages across the samples. It was concluded that the experimental works had been successfully conducted and the sensor was sensitive and effective in detecting the electrical discharge activities on both two samples.

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Keywords: Surface discharge; Glass Insulator; Porcelain Insulator; UV flame sensor; Dry condition; Wet condition

1. Introduction

A reliable and uninterrupted operation in modern power system depends on reliable insulation [1–3]. Nowadays, maintenance and operation of power system are changing from time-based to condition-based monitoring, CBM [4].

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Online CBM is preferred by utility companies as this method can be done without interrupting the operation. Besides that, CBM determines what testing and maintenance procedures should be performed according to the equipment in the power system [5]. The common practice in most power utilities is to replace the insulator only after failure or to replace all the insulators regardless their condition once they reach a specific age [6]. Such maintenance strategies are no longer practicable instead CBM practices are becoming more relevant to distribution line insulators [6]. This work tries to use UV sensor in continuously detecting the electrical discharge activities in transmission. These discharge activities can give early indication on the insulators condition and can be used to predict the lifetime of the insulators.

Numerous studies by Suhaimi [7],Zang et al. [8,9],Rijun et al. [10],Suhaimi et al. [11],Duan et al. [12], Iezham Suhaimi et al. [13] have been carried out on UV imaging methods where UV images taken from the equipment are used to analyze the equipment's condition. It is a non-contact method that is easy to use by the utility company. The images obtained can provide information regarding the equipment's current condition but this method did not provide continuous information. This is because the image of the equipment is only captured at intervals times during scheduled monitoring activities.

Alternative to UV images, the UV pulse method was introduced by Suhaimi [7] This UV pulse method can be achieved in various ways such as by using a UV sensor, UV camera or even photomultiplier (PMT) for UV. Application of this method especially in the field is most welcome as it does not affect the ongoing operation of the system and the condition of the insulator can be monitored throughout time. Furthermore, with the development of the newest sensor especially for UV sensor, it is crucial to choose suitable sensor that can be used in UV pulse method during different environment conditions. The sensor also must be able to give authentic data that can be used for further analysis. In addition, both UV pulse method and UV imaging method can be applied together. Results from both methods can be crossed together to ensure the consistency of the data obtained.

With respect to the UV pulse method, most of the studies have been limited to the detection and measurement of the UV pulse signals of the insulator. Factors that influence the measurement such as weather; wet (rainy day condition) and dry (non-raining day condition), insulator material; porcelain and glass and sensor positions have never been studied before. Water has a great influence on the value of discharge level and intensity, because of that, it is important to investigate how the UV pulse measured is affected by the wet and dry condition. Because of these, this study was proposed to investigate the changes in the UV pulse signal at difference discharge intensity level when the insulator experiences different weather conditions and the sensor positioning is changed. The finding of this study will further support this method application onsite.

2. Experimental setup

The experimental setup to assess the sensitivity and effectiveness of the UVTRON R2868 Flame Sensor is depicted as shown in Fig. 1. The process flow of this work is shown in Fig. 2.

The setup consists of a variable transformer which can be varied from 0 to 60 kV, the RS2868 UVTRON Flame Sensor — a UV Pulse detection method, the C106807 UVTRON Driving Circuit, the PICOSCOPE 2200 A Series and the computer data acquisition system, the environmental chamber and two sets of samples with glass and porcelain pin-type insulators which are shown in Fig. 3. The UVP sensor was used to detect and measure the UV signals. The sensor was placed approximately 1 m away from the insulator sample under test. The samples were donated by Tenaga National Berhad (TNB), a Malaysian multinational electricity company. Each of the sample is rated at 11 kV, with a withstand voltage of up to 33 kV in accordance to the IEC Standard.

In the experiment, the generation of the electrical discharge activity from each of the samples, encapsulated in the chamber was recorded each time a varying voltage of up to 50 kV is applied. The discharge intensities that have been produced in the experiment were recorded as shown in Table 1.

During dry condition experiment, the laboratory temperature is set at 27 °C. The insulator surface discharge experiment is performed first at dry conditions. The voltage supply is increased until it reached the required discharge intensity level. The UV flame sensor was placed within the limit distances of the sensor specification. The output of the sensor is connected to PICOSCOPE and transferred to computer. The UV signal is recorded.

The same procedures for the wet conditions were repeated as same the dry conditions as explained above. The precipitation rate of rain was 0.4 mm/min. It is considered light rainfall. The rain remained applied throughout the application of high voltage which would last for around 18 min. The time interval between each voltage discharge intensity step is about two minutes.

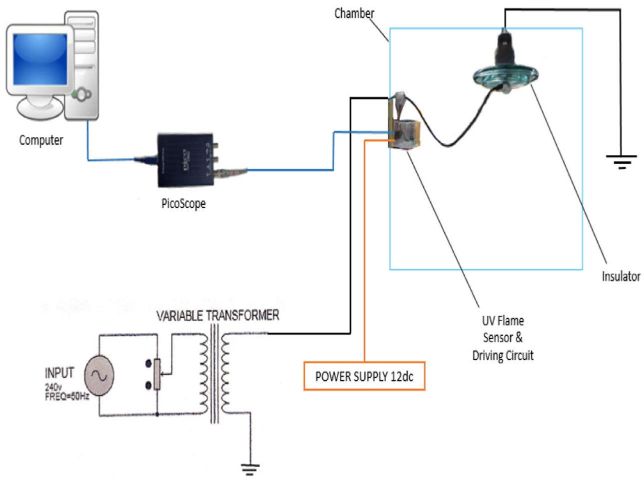


Fig. 1. Experimental Setup.

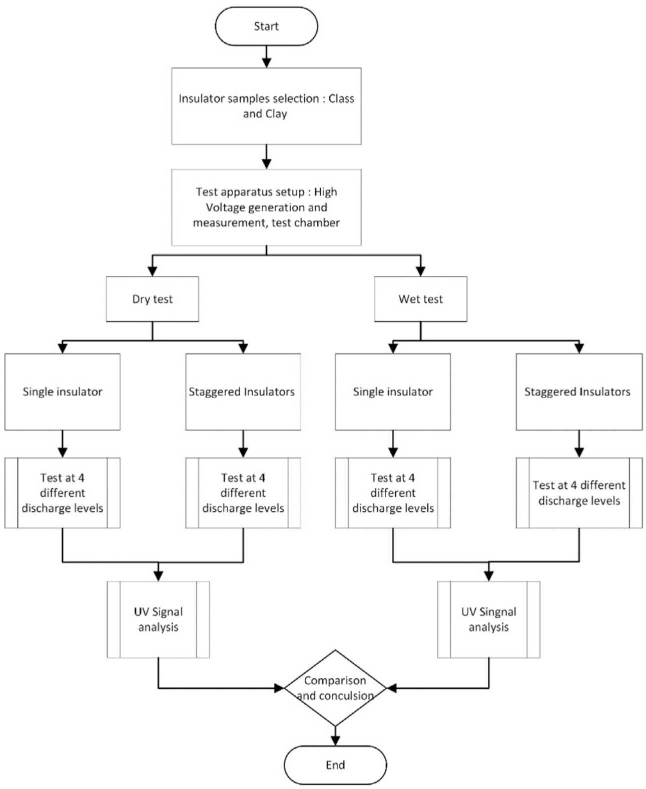


Fig. 2. Research flow.

3. Results

3.1. Flame sensor signal in the absence of surface discharge

UVTRON R2868 connected to the PICOSCOPE produces sinusoidal waveform output signal when there is the presence of any detected UV signal. Fig. 4 shows the sensor output in the absence of any detected UV signal.

(a) (b) (c) (d)

Fig. 3. Insulator sample (a) Glass A (b) Porcelain A (c) Glass B (d) Porcelain B.

Table 1. Classification of insulator surface discharge intensity levels.

Insulators condition	Discharge intensity level	Observation
Dry	Hissing	Hissing without any visible discharge
	Discharge at pin of the insulators	Hissing sound plus spot discharge at the pin of the insulators
	Discharge at cap of the insulators	Louder hissing noise, discharges at both 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)
Wet	Hissing	Hissing sound without discharge
	Spot discharge	Spot discharge appear on insulator surfaces
	Continuous discharge	Continuous discharge happens on insulator surfaces
	Severed discharge	Severed discharge happen on insulator surfaces

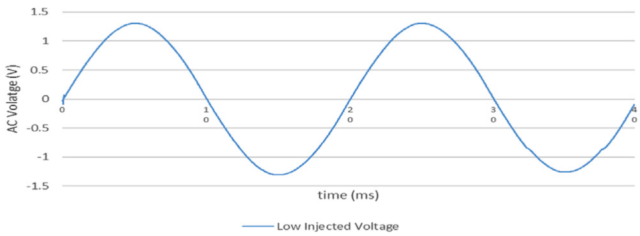


Fig. 4. Signal Detected at Low Injected Voltage of 5 kV at no UV signal was produced.

This signal was used as a reference signal in this work. When discharge is present at the insulator, this signal will experience distortion.

3.2. Flame sensor signal in the presence of surface discharge

3.2.1. Single insulator during dry condition

The results for dry glass and porcelain insulator conditions are shown in Fig. 5. From the figures above, the magnitude of the UV signal waveforms increases with increasing discharge intensities. Hissing condition had the lowest magnitude while severe discharge had the highest. There is only slight difference in magnitude between discharge at cap and at pin. Besides that, it could be seen that the distortion of waveform is throughout the cycle for all condition. Moreover, the disturbance getting severe as the discharge intensities increased. Tables 2 and 3 shows the injected voltage and average peak to peak voltage of UV signal waveforms for glass and porcelain insulator under dry condition.

There is a correlation between the UV signal peak-to-peak amplitude (detected by the UV sensor) and the discharge intensity levels. As the discharge intensity levels of the insulators increase, the UV signals detected due to the UV radiated from the discharges increase as well

Fig. 5. Ultraviolet Signal During Dry Test for (a) Glass Insulator (b) Porcelain Insulator.

Table 2. Injected voltage and average peak to peak voltage of the UV signals for glass insulator during dry condition.

	Range of injected voltage (kV)	Average peak to peak voltage
Hissing	15–23	18.65
Discharge at pin	26–33	25.18
Discharge at cap	35–40	34.18
Severe	44–57	36.68

Table 3. Injected voltage and average peak to peak voltage of the UV signals for porcelain insulator during dry condition.

	Range of injected voltage (kV)	Average peak to peak voltage (V)
Hissing	13–20	22.71
Discharge at pin	23–30	28.28
Discharge at cap	33–43	33.53
Severe	45–58	38.64

3.2.2. Staggered insulators during dry condition

For this section, the number of insulators is increased where the procedures were maintained the same in the previous section. The voltage injected to achieve the desired discharge intensity is also the same in accordance to respective condition. The results for dry glass and porcelain insulators conditions are shown in Fig. 6. The figures show that the magnitude of the UV signal waveforms also increases with increasing discharge intensities. Hissing condition still had the lowest magnitude while severe discharge had the highest. There is only slight difference in magnitude between discharge at cap and at pin. The UV signal disturbance getting severe as the discharge intensities increased. Tables 4 and 5 shows the injected voltage and average peak to peak voltage of UV signal waveforms for glass and porcelain insulator under dry condition.

The correlation between the UV signal peak-to-peak amplitude (detected by the UV sensor) and the discharge intensity levels exists as same as the dry condition for one-unit glass and porcelain type pin insulator previously. The UV signals detected due to the UV radiated from the discharges increase as the discharge intensity levels of the insulators increase. Due to the increase of units of insulator, the average peak-to-peak voltage for two-unit insulator decreased compared to one-unit insulator. It can be said that the electrical insulation of the insulators increased with the number of strings of insulator.

3.2.3. Single insulator during wet condition

Under the wet condition, rain condition was simulated inside the environmental chamber by using water spray. This is to see the effectiveness of the flame sensor in detecting the UV signal emitted if the surface of the insulators

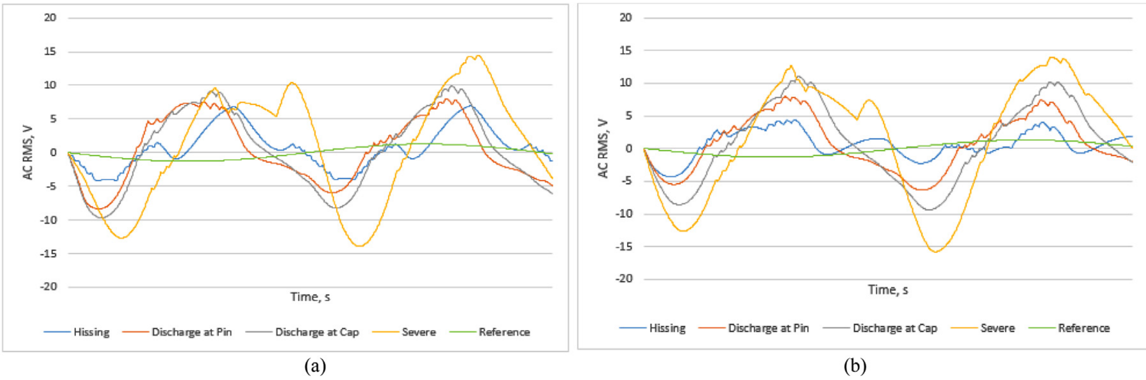


Fig. 6. Ultraviolet signal of two-unit insulators under dry condition for (a) Glass insulators (b) Porcelain insulators.

Table 4. Injected voltage and average peak to peak voltage of the UV signals for staggered glass insulator during dry condition.

	Range of injected voltage (kV)	Average peak to peak voltage (V)
Hissing	15–23	11.1
Discharge at pin	26–33	16.35
Discharge at cap	35–40	19.5
Severe	44–57	28.4

Table 5. Injected voltage and average peak to peak voltage of the UV Signals for staggered porcelain insulator during dry condition.

	Range of injected voltage (kV)	Average peak to peak voltage (V)
Hissing	13–20	8.75
Discharge at pin	23–30	14.29
Discharge at cap	33–43	20.45
Severe	45–58	29.8

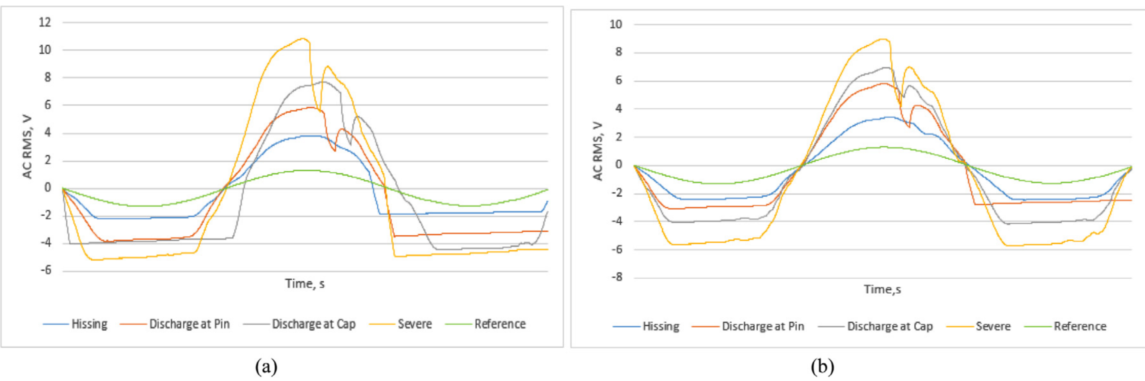


Fig. 7. Ultraviolet Signal for (a) Glass Insulator during Wet Test (b) Porcelain Insulator during Wet Test.

is wet during surface discharge activities. The intensity of the discharge during wet conditions is different from the dry condition. The results of detected UV signals for the wet condition are shown in Fig. 7.

Table 6. Injected voltage and average peak to peak voltage of the UV signals for glass insulator during wet condition.

	Range of injected voltage (kV)	Average peak to peak voltage (V)
Hissing	6–10	6.05
Spot discharge	12–15	9.70
Continuous discharge	18–23	12.18
Severe	25–30	16.00

Table 7. Injected voltage and average peak to peak voltage of the UV signals for glass insulator during wet condition.

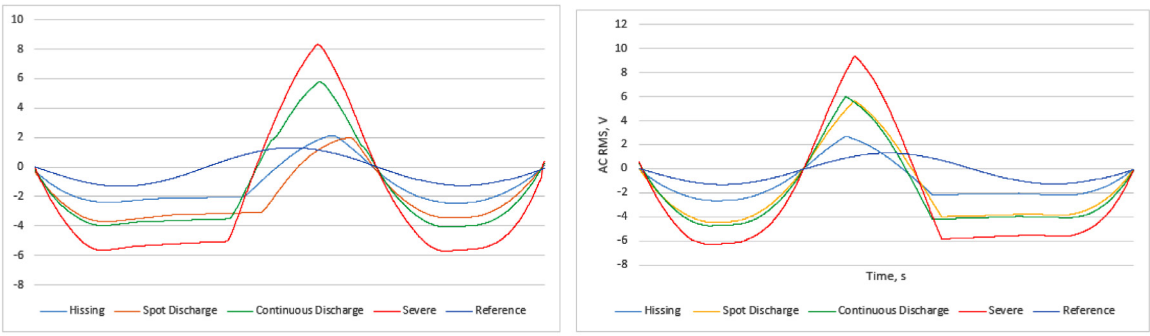
	Range of injected voltage (kV)	Average peak to peak voltage (V)
Hissing	6–10	6.05
Spot discharge	12–15	9.70
Continuous discharge	18–23	12.18
Severe	25–30	16.00

Based on the result obtained, it also can be seen that the magnitude of the UV signal waveform increased from hissing to severe conditions. The hissing condition had the lowest magnitude whereas the severe condition had the highest magnitude. This is because, when the surface of the insulator samples is wet, they will possess lower resistance compared to the dry surface insulators, thus higher magnitude LC will flow. The distortion of the UV signal waveform is also getting severe as the discharged intensities increase. The shape of the waveform between dry and wet conditions somehow are different this may be due to the ability of the flame sensor in detecting the UV signals during the wet condition. However, it is still able to show that there are surface discharge activities on the insulators as much as during dry conditions.

Tables 6 and 7 show the injected voltage and peak-to-peak value of the UV signals for glass and porcelain insulators. During the wet condition, less injected voltage is required for the hissing condition to start taking place compared to the dry condition. This is because of the lower resistance of the insulator sample because of the presence of moisture.

3.2.4. Staggered insulator during wet condition

Fig. 8 shows, the magnitude of the UV signal waveform for two units of glass and porcelain pin-type insulators increased from hissing to severe condition. The hissing condition had the lowest magnitude whereas the severe condition had the highest magnitude. Higher LC magnitude flow causes lower resistance compared to the dry



(a) (b)

Fig. 8. Ultraviolet signal of staggered insulators under wet condition for (a) Glass insulator (b) Porcelain insulator.

Table 8. Injected voltage and average peak to peak voltage of the UV signals for staggered glass insulator during wet condition.

	Range of injected voltage (kV)	Average peak to peak voltage (V)
Hissing	6–10	5.90
Spot discharge	12–15	9.50
Continuous discharge	18–23	11.86
Severe	25–30	16.14

Table 9. Injected voltage and average peak to peak voltage of the UV signals for staggered porcelain insulator during wet condition.

	Range of injected voltage (kV)	Average peak to peak voltage (V)
Hissing	5–11	6.45
Spot discharge	14–18	11.39
Continuous discharge	19–22	13.51
Severe	24–31	17.67

surface insulators since the surface of the insulator samples is wet. Besides that, electric field distribution along the leakage path of insulator surface might also be distorted because of the leakage current. The distortion of the UV signal waveform is also getting severe as the discharged intensities increase. However, the waveform distortion is not as severe as one unit of insulator. Although both possessed different shapes of the waveform distortion, the UV flame sensor was still able to detect the UV radiation emitted during discharge activities as much as during discharge activities at a one unit insulator.

Tables 8 and 9 show the injected voltage and peak-to-peak value of the UV signals for glass and porcelain insulators. The injected voltage is the same as for a one unit insulator during the wet condition to make it easier in making comparisons. The average peak-to-peak voltage for the two-unit insulator respectively is a little bit lower than the one-unit insulator. The electrical insulation is better since the electrical insulation of the insulator depends on the individual insulators. The greater the number of insulators used in a string, the better the electrical insulation.

Fig. 9 is the comparison of the average peak-to-peak voltage for single and stagged glass and porcelain insulator at dry and we condition. The figure shows that in wet conditions the average peak-to-peak voltage is lower compared to dry conditions. However, the average peak-to-peak voltage at different discharge intensities levels is almost the same without much difference in value between staggered with the single unit of the insulator in both conditions.

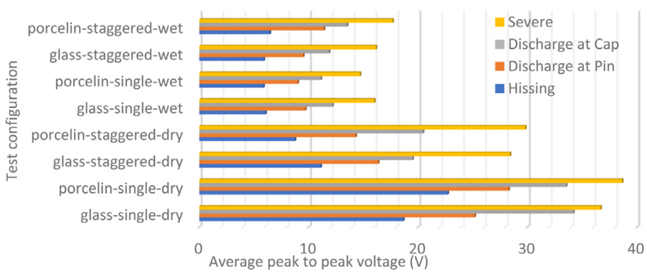


Fig. 9. Comparison for all test configurations for glass and porcelain insulator.

4. Conclusions

In this study, glass and porcelain type of pin insulators were used to verify the effectiveness of flame sensors in detecting ultraviolet pulses from different materials of insulators. Results on UV radiation emitted by varying discharge intensities during dry and wet conditions were presented. The main findings from this work are as follows:

(i) Insulator surface discharges for both glass and porcelain type of pin insulators were successfully detected by the UV pulse method using a UV flame sensor. (ii)This UV pulse method is able to detect insulator surfaces under varying discharge intensities levels during the dry and wet conditions for both material types of insulators. (iii) Under the dry condition, a strong correlation exists between the UV signals and discharge intensity level. The average peak-to-peak voltage of the UV signal gradually increased with increasing of discharge intensity level. (iv) There is also the distortion of waveform detected and the distortion gets severe as the discharge intensity level increases.

Based on the experimental result under wet conditions, similar correlations were also observed under dry conditions.

Declaration of competing interest

The authors declare no conflict of interest

Data availability

No data was used for the research described in the article.

Acknowledgments

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