

# Impact of Pollution Location on Time and Frequency Characteristics of Leakage Current of Porcelain Insulator String under Different Humidity and Contamination Severity

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## ABSTRACT

One of the important factors influencing outdoor insulators performance is pollution phenomenon. The pollution, especially during humidity condition, reduces superficial resistance of insulator and lead to a flow of Leakage Currents (LC) on the insulator surface, which may result in total flashover. The LC characteristics are affected by parameters such as nature and severity of pollution. Location of pollution is another parameter that can be effective. This paper presents the analysis of LC waveforms of insulator strings under different pollution location and Equivalent Salt Deposit Density (ESDD). The tests was performed on the HV porcelain suspension insulator string in which three adjacent discs of insulator string were contaminated and location of them changes along the insulator string. Besides, the effect of humidity and operating voltage on LC waveforms were investigated. Experimental data were analyzed in both time and frequency domain. Obtained results indicate that there is strong correlation between the location of pollution and LC parameters such as peak value ( $I_h$ ), harmonic components and Total Harmonic Distortion (THD). Also, the ratio of fifth to third harmonic component ( $K_{5/3}$ ) is presented as an important index that has strong relationship to the pollution location.

**KEYWORDS:** Humidity, Insulator, Leakage current, Pollution.

## 1. INTRODUCTION

An overhead power line is a structure used in electric power transmission and distribution to transmit electrical energy along large distances. The electrical characteristics of a transmission line depend on the construction of line and their insulations. Insulators are the necessary part of the ingredients making up transmission and distribution systems. These insulators are exposed to environment pollution such as salt, chemicals, dust, sand, etc. Contamination layers are progressively deposited on the insulators surface and reduce the dielectric strength of insulators. This pollution coating does not have a detrimental effect when the insulator is dry.

When the pollution combined with fog or rain, it causes a formation of wet conducting films and Leakage Current (LC) flows on the insulator surface. Due to rise in atmospheric temperature, this film of water evaporates and dry band forms on the surface of insulator. When this dry band is formed, the current flow is interrupted and a voltage gradient appears across the dry band. This voltage gradient exerts electrostatic stress across the surface and causes further evaporation and an increase in the width of the dry band. This increase in width of the band causes a higher voltage gradient, which causes minor arcing. Such arcs may elongate until they bridge the electrodes and finally direct to total flashover. Therefore, the insulator pollution phenomenon is an important factor for insulation designing in insulator string of overhead transmission lines.

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LC monitoring provides the direct and accurate way of determining the behavior of the insulator during pollution [1-7]. It has been shown that the contamination severity and the relative humidity (RH) both can lead to the increase of the LC of the power line insulators [8-10]. The maximum value of the LC pulses, number of pulses and the highest peak currents are also employed as a useful index for pollution monitoring [11, 12]. Phase difference between the LC and the applied voltage ( $\theta$ ) is also explored as a characteristic phase parameter and it has been shown that the  $\theta$  decreases with the increase of RH [10, 13]. Correlation coefficient is another parameter used to analysis of the LC on polluted insulators [14].

Harmonic components of LC are used as diagnostic tools to study the insulator condition. In [15], the relation between ratio of fifth to third harmonic component of LC ( $K_{5/3}$ ) and the probability of flashover occurrence has been studied and shown that when this ratio less than 30%, the probability of flashover occurrence becomes more than 90%. In addition, there is a strong correlation between insulator degree of ageing and the insulator LC's third to fifth harmonic ratios [16]. It was concluded that in a post-pin ceramic insulator, the magnitude as well as the waveform and the Total Harmonic Distortion (THD) of LC were significantly correlated with the insulator surface conditions [17]. Using the online monitoring of LC and artificial neural network, flashover can be predicted [18, 19].

As mentioned in the above, the impact of some parameters such as nature, severity and uniformity or non-uniformity of pollution on LC characteristics has been studied in many previous researches. This paper presents a new approach to the insulators pollution studies and examines the influence of location of pollution. The main objective of present work is to investigate the effect of location of pollution on LC parameters and subsequently flashover process. For this purpose, experimental tests

were performed on the porcelain suspension insulator string in which three adjacent discs of insulator string were contaminated and location of them changes along the insulator string from HV side to grounded side. Besides, experiments were carried out under different RH and various applied voltage. Then, the results of experiments were analyzed in both time-domain and frequency-domain and the effect of pollution location on LC parameters has been examined. The results show that the LC parameters such as peak value of LC ( $I_h$ ), harmonic components and THD are affected by location of pollution.  $K_{5/3}$ , the fifth harmonic component to third ratio is also proposed as an important index and it has been shown that there are close relationship between it and the location of pollution.

## 2. EXPERIMENTAL TEST

### 2.1. Test setup and sample insulators

The experimental arrangements have been prepared according to IEC60507 as shown in Fig. 1. All experiments were carried out in a fog chamber in the high voltage laboratory of Babol University of Technology with a volume of 400 cm×400 cm×370 cm. The main power supply is a single phase, 220 V/100 kV, 5 kVA, 50 Hz transformer.



Fig. 1. Experimental setup: power supply, CVD and fog chamber.

AC voltage up to  $132 \text{ kV} \div \sqrt{3} = 76.2 \text{ kV}_{\text{rms}}$  was applied to the sample insulator string to simulate 132 kV overhead transmission lines. The power supply is connected to sample insulator string through a protective resistance

( $R_p$ ). In addition, the high-voltage terminal of power supply is connected to a Capacitor Voltage Divider (CVD) with the divider ratio of 500:1. The LC waveform is measured from voltage drop across a specific resistor  $R_1$  (470  $\Omega$ ). All of the waveforms and their Fast Fourier Transform (FFT) are recorded and stored by Digital Oscilloscope (DO). Figure 2 shows an example of LC, applied voltage and FFT waveforms recorded by D.O. A sample insulator string used for the experiments includes 9 porcelain suspension insulators. The unit profile and its parameters are shown in Fig. 3. The schematic of test circuit is indicated in Fig. 4.

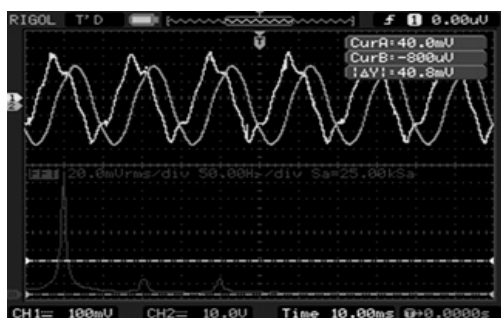


Fig. 2. LC, applied voltage and FFT waveforms recorded by oscilloscope.

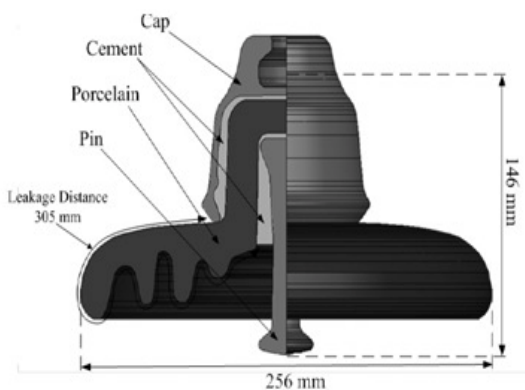


Fig. 3. Main dimensions, parameters and configuration of sample insulator.

### 2.2. Insulators contamination

The solid layer method was used to artificially produce uniform pollution layers on the surface of insulators according to IEC60507 standard. In order to prepare the contamination solution, 40 gr kaolin and salt were poured in one liter

distilled water and have sprayed on insulator surface. The amount of salt determines the electrical conductance of contamination slurry. Equivalent Salt Deposit Density (ESDD) was measured to determine the amount of insulators' surface pollution level according to IEC60507 standard after measuring LC.

The tests were carried out at two levels of ESDD to simulate two contamination states, namely, light and heavy. The amount of ESDD in light and heavy contamination level is equal to 0.26 and 0.358  $mg/cm^2$ , respectively. In the next stage, pre-contaminated insulators were suspended vertically to dry out naturally for 24 hours before entering the fog chamber.

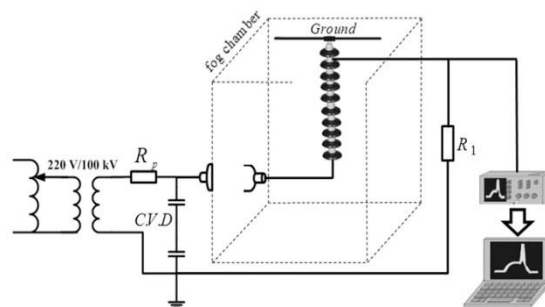


Fig.4. Schematic diagram of test setup.

### 2.3. Test procedure

The aim of the experimental tests is to assess the effect of location of pollution on LC waveforms. For this purpose, three adjacent discs of insulator string were contaminated and location of them has been changed along the insulator string. These three polluted discs were located in three different locations, namely near the high voltage side, middle the string and finally, near the grounded side. The placement of polluted discs in insulator string for three mentioned cases is shown in Fig. 5. The tests were carried out in three RH levels, namely 55% (ambient humidity), 75% and 95% and various applied voltage. In humid condition, clean fog produced by fog generator. As soon as the surface pollution layer was wetted for 15-20 min, the operating voltage was applied. In each of the cases, LC signals were recorded and

analyzed in both time-domain and frequency-domain.

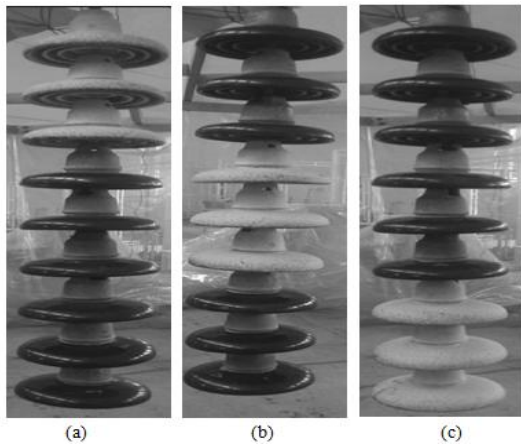


Fig. 5. Location of polluted discs: (a) near grounded side, (b) middle the string and (c) near H.V side.

### 3. EXPERIMENTAL RESULTS AND DATA ANALYSIS

#### 3.1. Peak value of LC

$I_h$ , the peak value of LC on surface of insulators has been employed as a one of the characteristic parameters of LC in time domain to investigate the impact of location of pollution on LC waveforms [8-10]. Based on experimental results, it was realized that  $I_h$  is also affected by the location of pollution. Figures 6 and 7 show the variation of  $I_h$  for several pollution locations under two contamination levels at different RH and applied voltage. In both contamination levels, it was observed that  $I_h$  increases when the pollution deposited closer to the grounded side. In low RH level, the variation of  $I_h$  in three cases is slight, but as the humidity increases, the one become noticeable.

According to Figs. 6 and 7, it can be seen that LC increases with the increase of the RH and contamination severity.

#### 3.2. Harmonic components of LC

Harmonic components of LC can be used as a tool for further evaluating the relationship between the LC waveforms and location of pollution.

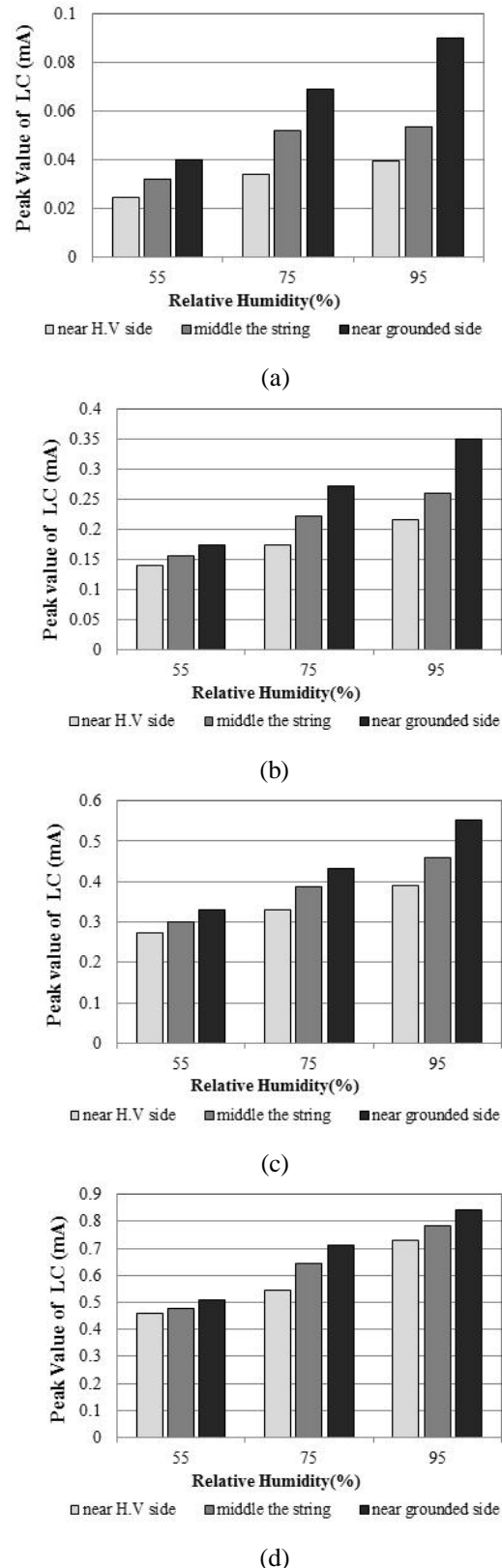
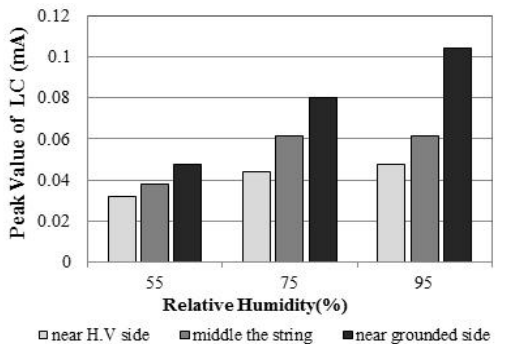
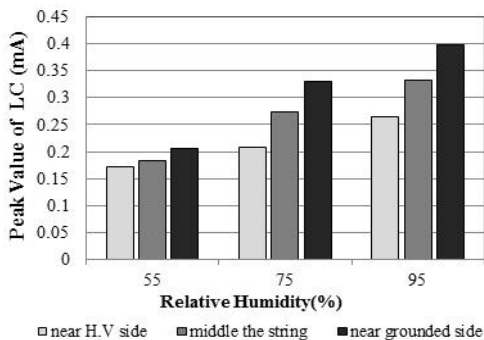


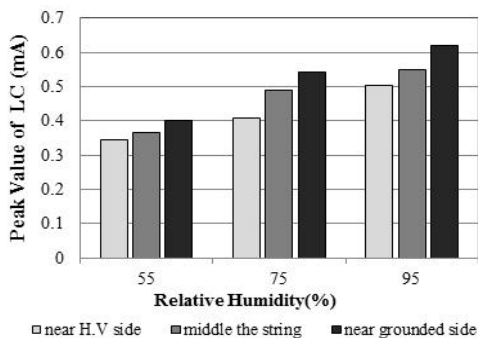
Fig. 6. The variation of  $I_h$  for several pollution locations under light contamination level at different RH and applied voltage: (a) 4.5 kV<sub>rms</sub>, (b) 27.4 kV<sub>rms</sub>, (c) 54.8 kV<sub>rms</sub> and (d) 76.2 kV<sub>rms</sub>.



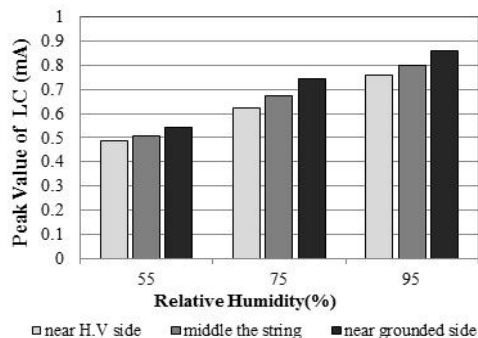
(a)



(b)



(c)

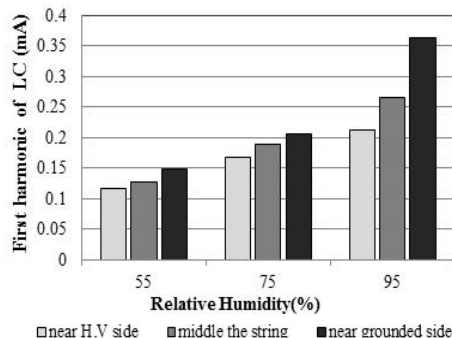


(d)

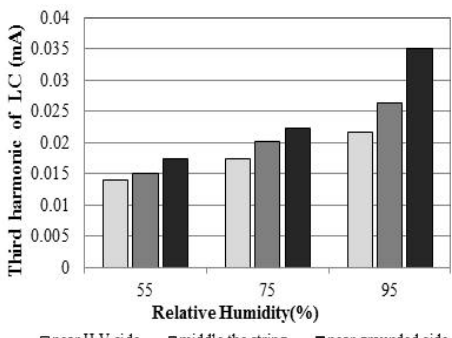
**Fig. 8.** The variation of  $I_h$  for several pollution locations under heavy contamination level at different RH and applied voltage: (a) 4.5 kV<sub>rms</sub>, (b) 27.4 kV<sub>rms</sub>, (c) 54.8 kV<sub>rms</sub> and (d) 76.2 kV<sub>rms</sub>.

Harmonic components show good correlation with the location of pollution as

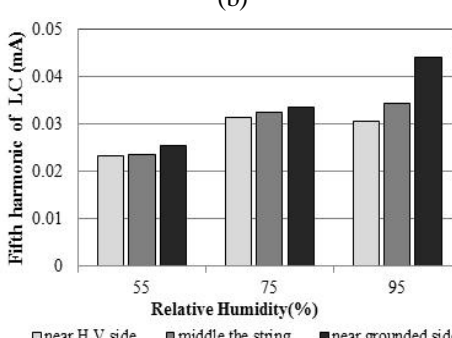
shown in Figs. 8 and 9. From these figures, it can be seen that first and third harmonic components of LC affected significantly by pollution location. In fact, the amplitude of first and third harmonic components increases significantly when the polluted discs approach to the grounded side. However, the fifth harmonic component shows slight variation with the changing of pollution location. For other applied voltage levels, this trend is similar to nominal voltage (76.2 kV<sub>rms</sub>).



(a)

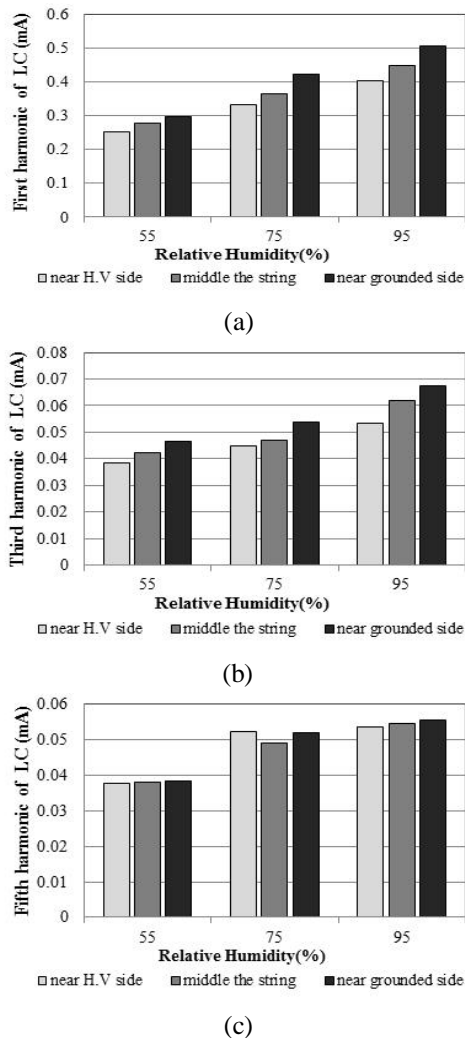


(b)



(c)

**Fig. 9.** The variation of harmonic components of LC for several pollution locations under light contamination level at 76.2 kV<sub>rms</sub> and different RH: (a) first harmonic component, (b) third harmonic component and (c) fifth harmonic component.



**Fig. 10.** The variation of harmonic components of LC for several pollution locations under heavy contamination level at 76.2 kV<sub>rms</sub> and different RH: (a) first harmonic component, (b) third harmonic component and (c) fifth harmonic component.

Surface discharges occurrence is the reason of third harmonic component increase. As mentioned in the above, when the pollution deposited closer to the grounded side, LC increases. Because of LC increment, dry regions form and then surface discharges occur on the surface of insulator, which distort the waveform of the LC. Eventually, LC waveform includes third harmonic content. The growth of surface discharges deforms the LC waveform more and causes the third harmonic component to be increased. As a result, when the discs locating near the grounded side are contaminated, the LC and number of surface discharges increases and flashover will occur in lower voltage level.

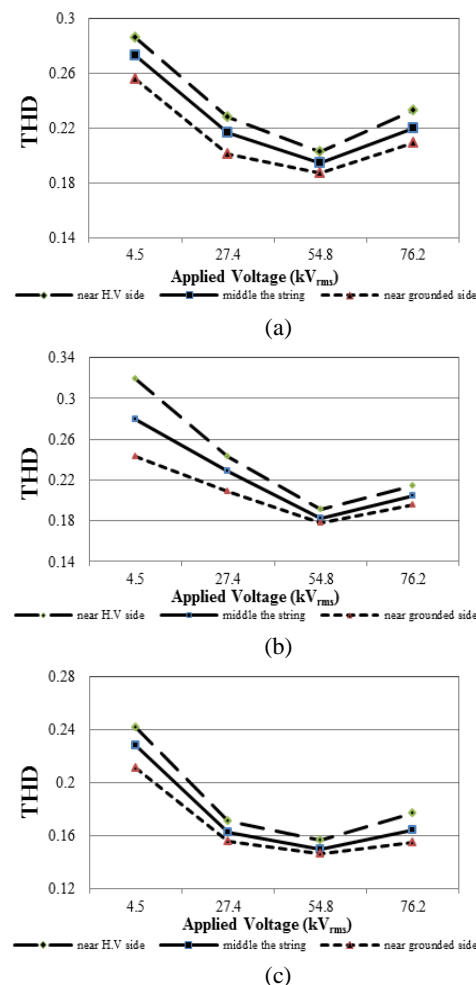
### 3.3. Total harmonic distortion of LC

THD, total harmonic distortion of LC is one of the important parameter defined to quantify the harmonic components of the LC [10, 17]. The THD of LC were significantly correlated with the insulator surface conditions and used as a tool for diagnosis of the insulator. The THD can be calculated using the (1):

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \quad (1)$$

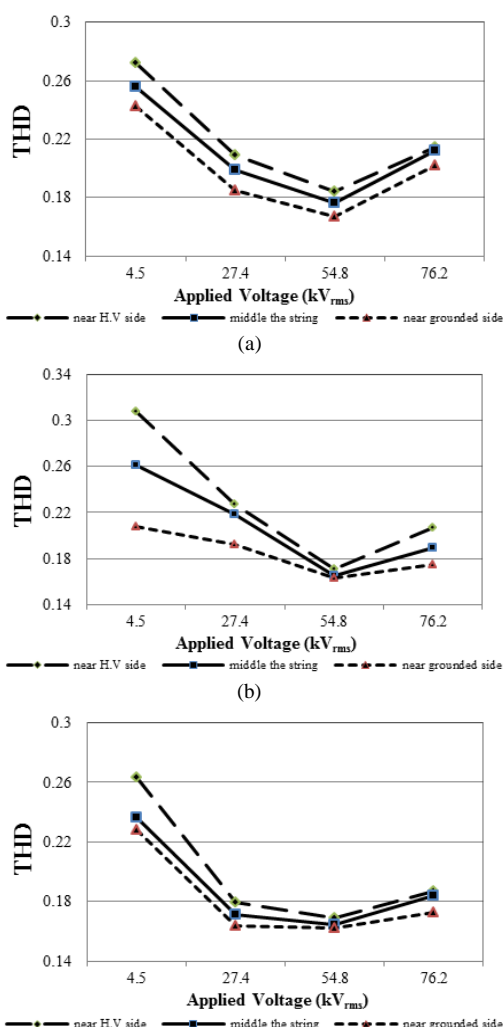
where  $I_n$  and  $I_1$  are nth order harmonic and first order harmonic of LC, respectively.

Figures 10 and 11 show the effect of pollution location on THD under different applied voltage.



**Fig. 11.** The variation of THD versus applied voltage for several pollution locations under light contamination level at different RH: (a) RH=55%, (b) RH=75% and (c) RH=95%.





**Fig. 12.** The variation of THD versus applied voltage for several pollution locations under heavy contamination level at different RH: (a) RH=55%, (b) RH=75% and (c) RH=95%.

It was observed that THD is affected by location of pollution. In both contamination levels, it can be seen that THD decreases as the pollution deposited closer to the grounded side. It can also be concluded from Figs. 10 and 11 that the THD has a nonlinear relationship with RH and ESDD. When the RH is low, THD decreases with the increase of ESDD. However, at high RH, the increment of ESDD will lead to the increase of THD.

**3.4. Fifth to third harmonic component ratio**

$K_{5/3}$ , the fifth to third harmonic ratio known as useful index to assess insulators condition in many LC studies [15, 16]. Thus, it has been focused on this ratio in this paper.

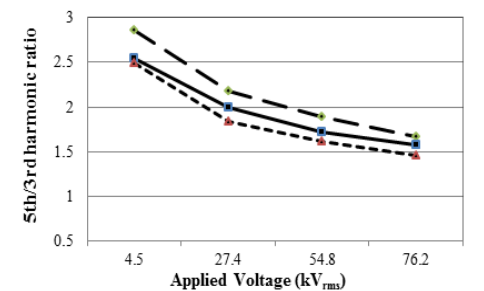
The existing research results show that the amplitude of third and fifth harmonic components and subsequently  $K_{5/3}$  will vary with the variation of contamination. In clean condition, the amount of fifth harmonic component is greater than the one of the third and thus  $K_{5/3}$  is greater than one. Due to surface discharge occurrence under contamination condition, the amplitude of third harmonic component increases significantly and will lead to  $K_{5/3}$  reduction. Test results in this paper were consistent with existing study results. In this work, it has been shown that  $K_{5/3}$  has a strong correlation with the location of pollution. The variation of  $K_{5/3}$  for two contamination levels is represented in Tables 1 and 2 when the location of pollution changes along the insulator string. In addition, Figures 12 and 13 show the relation between location of pollution and  $K_{5/3}$  under two contamination levels at different RH and applied voltage.

**Table 1.** The amount of fifth to third harmonic ratio for several pollution locations under light contamination level at various RH and applied voltage.

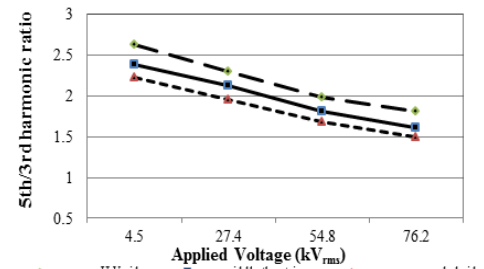
Applied voltage (kV <sub>rms</sub> )	RH (%)	Fifth to third harmonic component ratio		
		Near HV side	Middle the string	Near grounded side
4.5	55	2.85914	2.5463	2.49
	75	2.623	2.37316	2.521
	95	2.196	1.984	1.7
27.4	55	2.17891	1.99051	1.84168
	75	2.29458	2.12743	1.95
	95	1.94303	1.78235	1.4638
54.8	55	1.88274	1.71629	1.61
	75	1.9812	1.80815	1.6865
	95	1.4792	1.38712	1.3002
76.2	55	1.67	1.57213	1.46341
	75	1.80487	1.61385	1.5001
	95	1.41176	1.30714	1.2381

**Table 2.** The amount of fifth to third harmonic ratio for several pollution locations under heavy contamination level at various RH and applied voltage.

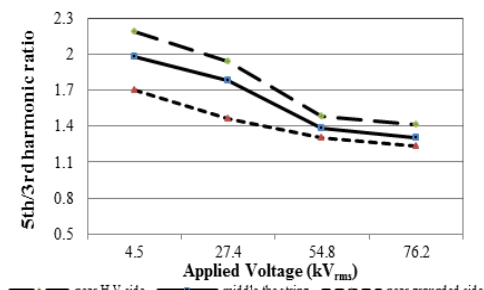
Applied voltage (kV <sub>rms</sub> )	RH (%)	Fifth to third harmonic component ratio		
		Near H.V side	Middle the string	Near grounded side
4.5	55	2.64705	2.5158	2.52174
	75	2.52174	2.33816	2.24615
	95	2.029	1.8238	1.7
27.4	55	1.98214	1.734	1.53571
	75	2.02702	1.82	1.7
	95	1.64705	1.5182	1.36283
54.8	55	1.2745	1.14724	1.04762
	75	1.45614	1.35461	1.21621
	95	1.30370	1.18417	1.136
76.2	55	0.99	0.9	0.82568
	75	1.17142	1.04276	0.93133
	95	1.001	0.88625	0.82201



(a)

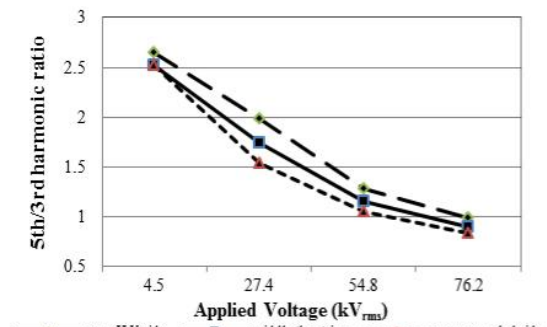


(b)

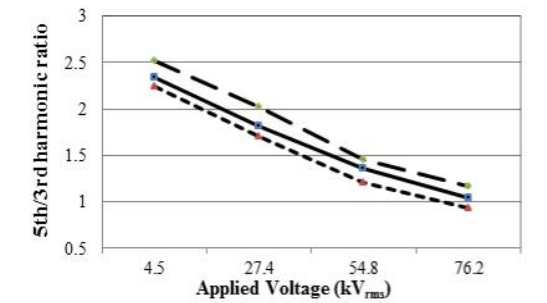


(c)

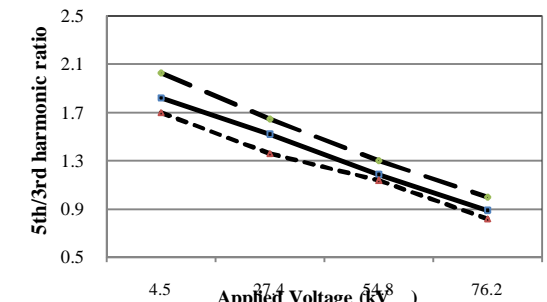
**Fig. 13.** The variation of fifth to third harmonic ratio versus applied voltage for several pollution locations under light contamination level at different RH: (a) RH=55%, (b) RH=75% and (c) RH=95%.



(a)



(b)



(c)

**Fig. 14.** The variation of fifth to third harmonic ratio versus applied for several pollution locations under heavy contamination level at different RH: (a) RH=55%, (b) RH=75% and (c) RH=95%.

According to the above, when the polluted discs located closer to the grounded side in the insulator string, the amount of third harmonic component increases noticeably but the variation of fifth harmonic component is negligible. So,  $K_{5/3}$  reduces with approaching the pollution to grounded side in both contamination levels.

#### 4. CONCLUSIONS

This paper describes relation between location of pollution and LC waveforms of porcelain insulator string under two contamination levels. The tests were also performed at different RH



and applied voltage. After performing laboratory tests, it was realized that there are close relationships between LC characteristics and the location of pollution. The results of experimental tests were examined in time and frequency domain. The main conclusions are summarized as follows.

1) It was found that the (peak value of LC) increases as the pollution deposited closer to grounded side in both contamination levels. Increment of LC lead to increasing of surface discharge number and finally, flashover will happen in lower voltage level. Also, the increases when the humidity and contamination severity increases.

2) Harmonic components of LC were correlated with location of pollution. Pollution location has significant impact on first and third harmonic component, so that the amplitude of them increase significantly with approaching the pollution to the grounded side, but it has a little effect on the fifth harmonic component. The increment of third harmonic is due to surface discharge occurrence.

3) THD of LC decreases, when the polluted discs located nearer the grounded side.

4) There is a strong correlation between location of pollution and (fifth to third harmonic component ratio of LC). This ratio reduces when the polluted discs get closer to the grounded side.

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