The Effect of Severity and Location of Pollution on Leakage Current Characteristics of Porcelain Insulators under Different Humidity Condition

Ali Azizi Tousi Mohammad Mirzaie
Babol University of Technology, Iran
a.azizi@stu.nit.ac.ir, mirzaie@nit.ac.ir

Abstract: *Outdoor insulators used in transmission and distribution lines are subjected to environmental pollution. The pollution, especially combined with humidity, may reduce the surface resistance of insulator and may lead to flow of leakage current (LC) on the surface of insulators. Leakage current with large magnitude flowing on the surface for long period may cause degradation of the insulator performance.*
This paper reports the experimental results on the effect of severity and location of pollution on LC waveforms of H.V porcelain suspension insulator string under different humidity condition. Experimental data were analyzed in both time and frequency domain. Obtained results indicate that LC parameters such as peak value, harmonic components, total harmonic distortion (THD) and etc. are affected by severity and location of pollution. Also, the ratio of fifth to third harmonic component is presented as an effective parameter to study pollution effect in insulators.

Key words: *insulator, leakage current, pollution, relative humidity.*

1. Introduction

Outdoor insulators are widely used in power system since long time ago to isolate among live parts and between live parts and ground and as mechanical protector. The performance of insulators used in overhead transmission lines, overhead distribution lines, and in outdoor substations is one of the critical factors which govern the reliability of power delivery systems. These insulators are exposed to environment pollution such as salt, chemicals, dust, sand, etc. Contamination layers are progressively deposited on the insulators surface. Deposited pollution on insulator surface combined with humidity provides a conductive electrolyte and a conductive film for leakage current (LC). Because of rise in atmospheric temperature, this film of water evaporates and dry bands will form and finally, will lead to arcs on the insulator surface. 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 and distribution lines.

Monitoring of LC is one of the effective ways to assess the insulator performance especially under polluted condition [1-11]. LC parameters such as peak value of LC (I_h), phase difference between LC and applied voltage, pulse counts, correlation coefficient, harmonic components of LC, total harmonic distortion (THD) and etc. are employed to analyze the insulator operation [12-16].

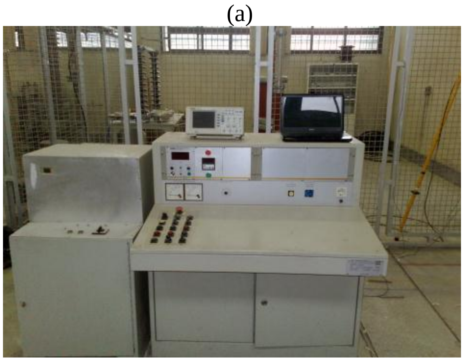
The LC characteristics are affected by parameters such as nature, severity, location and uniformity or non-uniformity of pollution. In this paper, the effect of severity and location of pollution on LC characteristics under different relative humidity (RH) has been investigated. In order to analyze the influence of pollution location, three adjacent discs of insulator string were contaminated and location of them changes along the insulator string from H.V side to grounded side. Also, experimental tests have been performed under two equivalent salt deposit density (ESDD) levels to assess the impact of contamination severity on LC characteristics. Besides, experiments were carried out under different relative humidity (RH) and various applied voltage. Then, the results of experiments were analyzed in both time-domain and frequency-domain. The results indicate that the LC parameters such as peak value, harmonic components and THD are affected by severity and location of pollution. The fifth harmonic component to third ratio ($K_{5/3}$) is also proposed as an important index to study pollution effect in insulators

2. Experimental test

2.1. Test arrangement

The experimental arrangements have been prepared according to IEC60507 as shown in Fig. 1. All experiments were performed 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. AC voltage up to 132 KV ÷ $\sqrt{3}$ = 76.2 kV_{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. In addition, the high-voltage terminal of power supply is connected to a capacitor voltage divider (C.V.D) with the divider ratio of 500:1. The LC waveform is measured from voltage drop across a specific resistor (470 Ω). All of the waveforms and their fast Fourier transform (FFT) are recorded and stored by digital oscilloscope (D.O). A sample insulator string used for the experiments includes 9 porcelain suspension insulators. The unit profile and its parameters are shown in table 1. The schematic of test circuit is shown in Fig. 2.

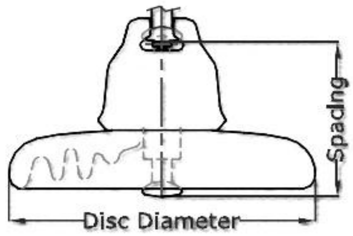
(a)



(b)

Fig. 1. Experimental setup: (a) power supply, C.V.D and fog chamber and (b) data acquisition system.

Table 1. Main dimensions, parameters and configuration of sample insulator.

Unit profile	
Disc diameter	255 mm
Spacing	146 mm
Creepage distance	295 mm
weight	5.2 kg
Rated failing load	120 kN

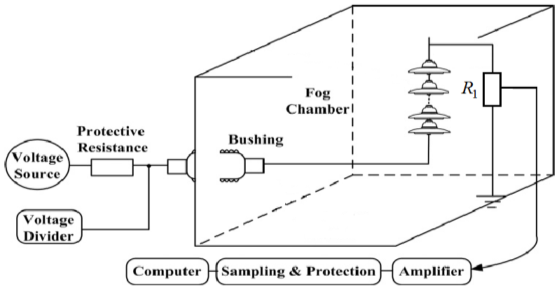


Fig. 2. Schematic diagram of test setup.

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.

In the next stage, pre-contaminated insulators were suspended vertically to dry out naturally for 24 hours before entering the fog chamber.

2.3. Test procedure

The purpose of the experimental tests is to assess the effect of severity and location of pollution on LC waveforms under different humidity condition. Two test procedures have been designed, their descriptions are as follows:

1. In order to study the impact of contamination severity, the tests were carried out under 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 $\frac{mg}{cm^2}$ respectively.

2. For investigating the influence of location of pollution, 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. 3.

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.

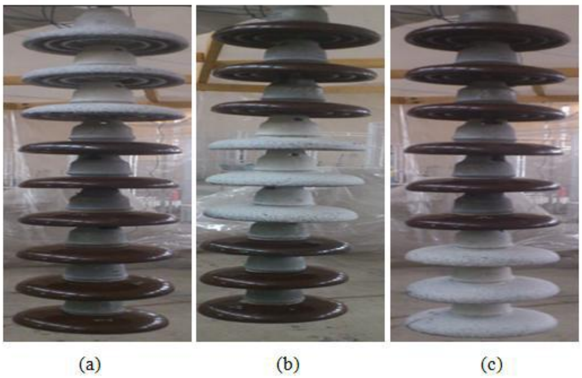


Fig. 3. Location of polluted discs: (a) near grounded side, (b) middle the string and (c) near H.V side.

3. Experimental results and data analysis

3.1. Characteristics when only the contamination severity changes

In order to investigate the effect of contamination severity on LC characteristics, two levels of ESDD were applied and the location of pollution was kept constant (near grounded side). For other pollution location, the trend is similar.

3.1.1. Time domain Characteristics

One of the important parameters considered in time domain and used in LC studies is I_h (the peak value of LC on surface of insulators) [17].

The experimental data indicate that I_h is affected by contamination severity. The relation between I_h and ESDD in different RH and applied voltage is shown in Fig. 4. Results show that the I_h increases when the contamination severity increases. Also, it can be seen that, the I_h has a direct relationship to the RH, so that I_h increases with the increase of RH.

3.1.2. Frequency domain Characteristics

Existing researches show the analysis of harmonic components of LC is an efficient and accurate way to study the behavior of insulators under polluted condition. Based on experimental tests, harmonic components of LC show good correlation with the contamination severity. As shown in Fig. 5, the amplitude of first, third and fifth harmonic components increases with the increase of both contamination severity and RH.

Surface discharges occurrence is the reason of third harmonic component increase. As mentioned above, when the severity of contamination deposited on the surface of insulator increases, 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.

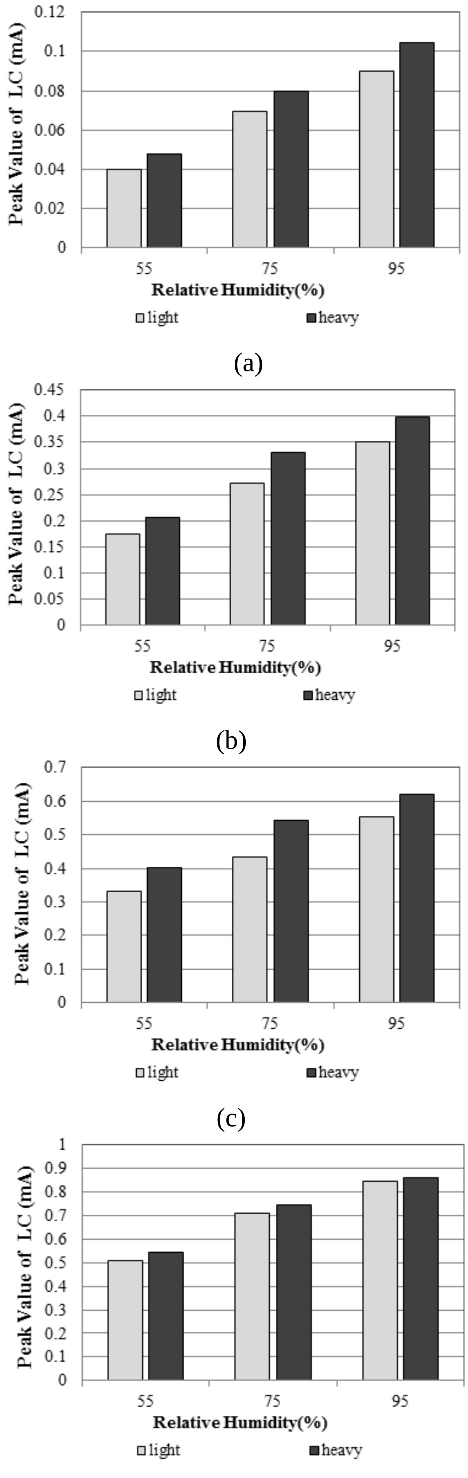


Fig. 4. The variation of I_h under two contamination level at different RH and various applied voltage: (a) 4.5 kV_{rms}, (b) 27.4 kV_{rms}, (c) 54.8 kV_{rms} and (d) 76.2 kV_{rms}.

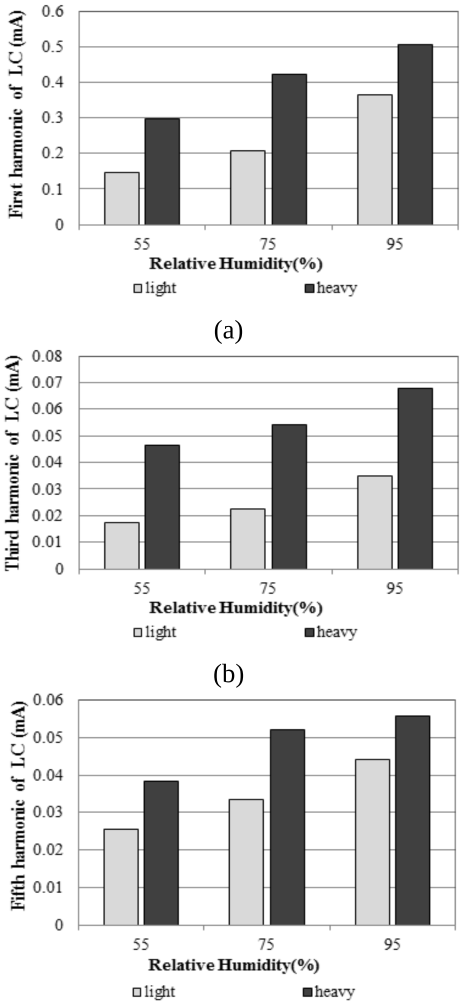


Fig. 5. The variation of harmonic components of LC under two contamination level at 76.2 kV_{rms} and different RH: (a) first harmonic component, (b) third harmonic component and (c) fifth harmonic component.

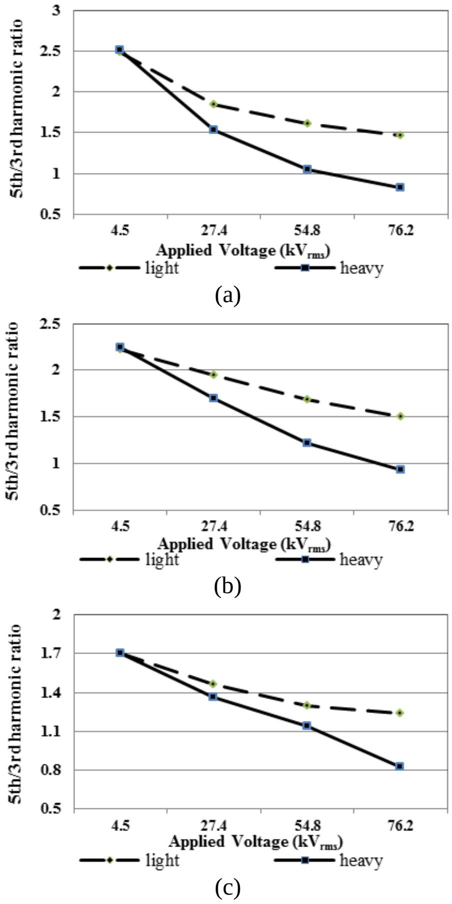


Fig. 6. The variation of fifth to third harmonic ratio versus applied voltage under two contamination level at different RH: RH=55%, (b) RH=75% and (c) RH=95%.

Another parameter is used in many LC studies to assess the insulator condition is $K_{5/3}$ defined as (1) [1,12].

$$K_{5/3} = \frac{5th\ harmonic\ component}{3rd\ harmonic\ component} \qquad (1)$$

The relation between $K_{5/3}$ and contamination severity is represented in Fig. 6. As mentioned above, when the contamination severity increases, third and fifth harmonic components will increase. However, the increment of third harmonic component is more than the one of fifth. As a result, the $K_{5/3}$ decreases with the increases of ESDD.

3.2. Characteristics when only the location of pollution changes

One of the other important parameters influencing LC and subsequently flashover process is location of pollution. For investigating the impact of pollution location on LC characteristics, the ESDD was kept constant at “heavy” and location of pollution has been changed along the insulator string as mentioned above. For light contamination level, the trend is similar to heavy.

3.2.1. Time domain Characteristics

According to experimental data, there is a strong correlation between the I_h and pollution location. Fig. 7 shows the variation of I_h for several pollution locations at different RH and applied voltage. It was observed that I_h increases when the pollution deposite closer to the grounded side. In high RH, the variation of I_h in three cases is noticeable, but as the humidity decrease, the one is slight.

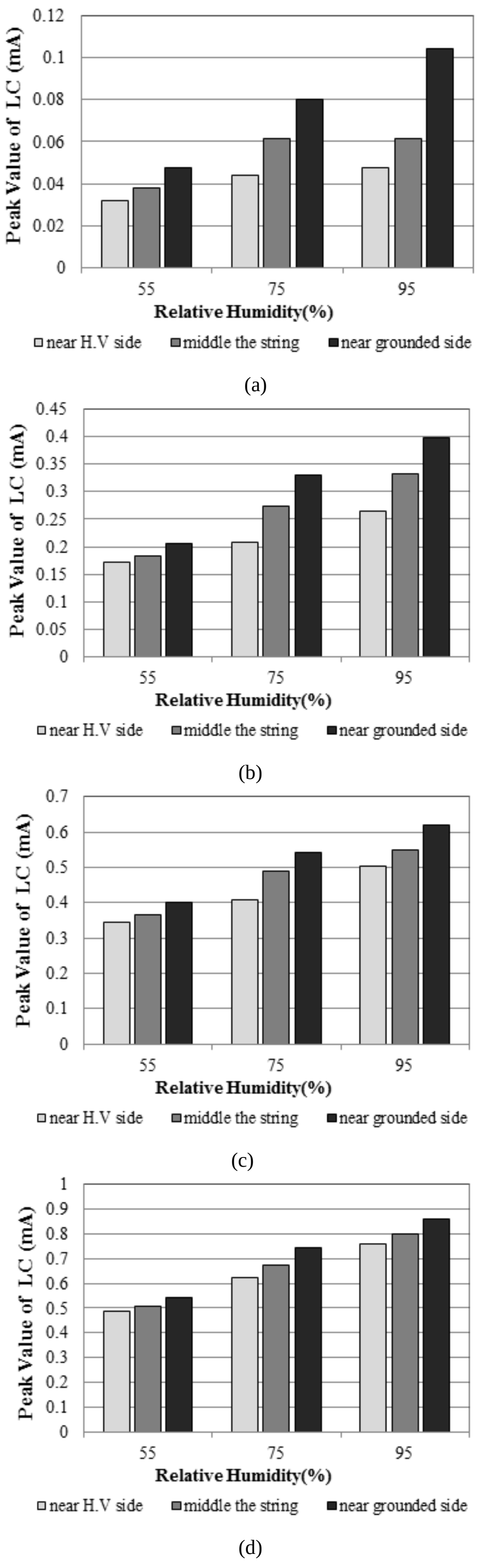


Fig. 7. The variation of I_h for different pollution location under heavy contamination level at different RH and various applied voltage: (a) 4.5 kV_{rms}, (b) 27.4 kV_{rms}, (c) 54.8 kV_{rms} and (d) 76.2 kV_{rms}.

3.2.2. Frequency domain Characteristics

Harmonic components of LC are also affected by location of pollution as shown in Fig. 8. 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 76.2 kV_{rms}.

As mentioned above, the increment of third harmonic is due to surface discharges. When the pollution get closer to the grounded side, LC increases and dry band forms. Finally, the LC waveform deforms and third harmonic component will be increased.

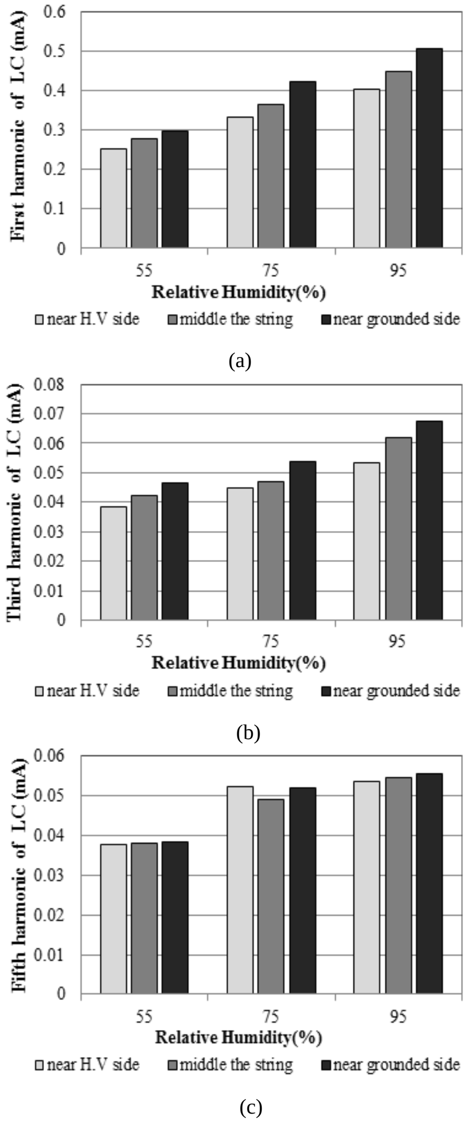


Fig. 8. The variation of harmonic components of LC for different pollution location under heavy contamination level at 76.2 kV_{rms} and different RH: (a) first harmonic component, (b) third harmonic component and (c) fifth harmonic component.

One of the useful parameter defined in frequency domain is THD (total harmonic distortion). The THD can be calculated using the (2).

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

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

The THD of LC was significantly correlated to location of pollution according to experimental results. The relation between THD of LC and location of pollution has been depicted in Fig. 9. It can be seen that THD decreases as the discs located closer to the grounded side were contaminated.

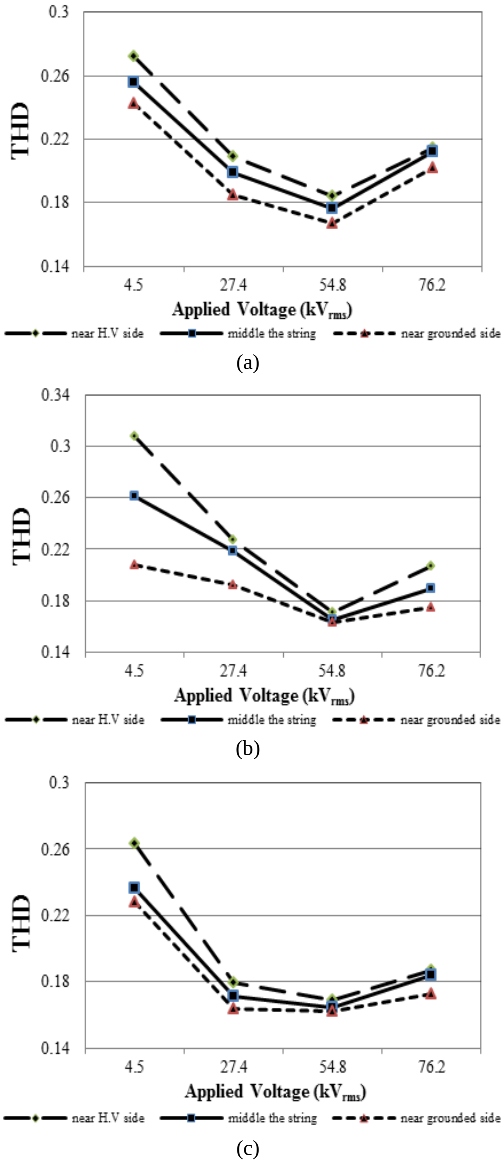


Fig. 9. The variation of THD of LC versus applied voltage for different pollution location under heavy contamination level at different RH: (a) RH=55%, (b) RH=75% and (c) RH=95%.

$K_{5/3}$, the fifth to third harmonic ratio is another parameter in frequency domain affected by location of pollution. Fig. 10 shows the effect of pollution location on $K_{5/3}$ at different RH and various applied voltage. According to 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.

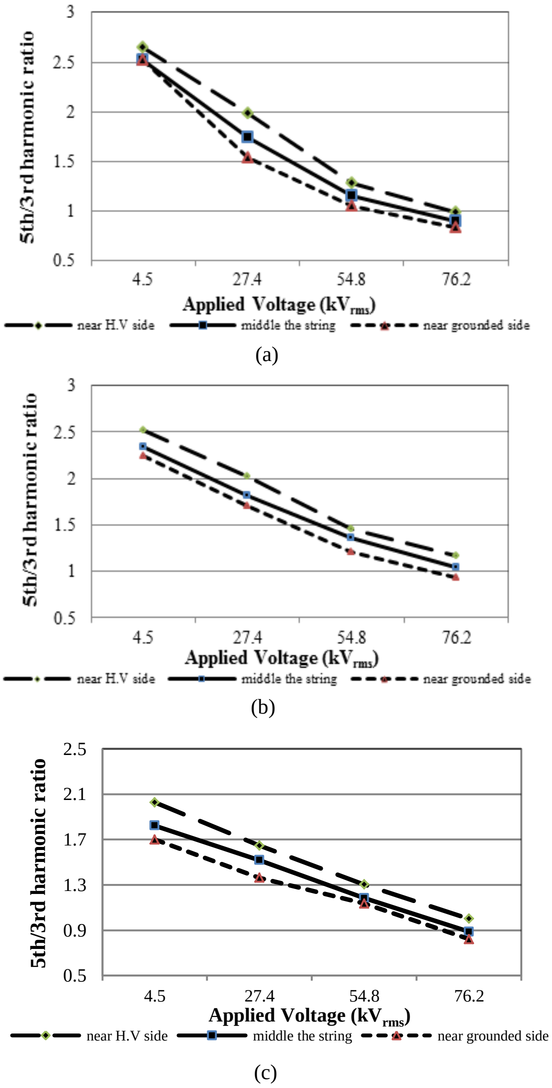


Fig. 10. The variation of fifth to third harmonic ratio versus applied voltage for different pollution location under heavy contamination level at different RH: (a) RH=55%, (b) RH=75% and (c) RH=95%.

4. Conclusions

This work reports relation between severity and location of pollution and LC waveforms of porcelain insulator string. For this purpose, two ESDD level were considered and location of pollution were changed along the insulator string. Experimental results show good correlation between LC characteristics and severity and location of pollution. The main conclusions are summarized as follows.

1) It was found that the I_h (peak value of LC) increases with the increase of contamination severity. Also, it was shown that when the pollution gets closer to the grounded side the I_h increases. Increment of LC lead to increasing of surface discharge number and finally, flashover will happen in lower voltage level.
2) There is a strong correlation between harmonic component of LC and severity and location of pollution. When the contamination severity increases, the first, third and fifth harmonic components of LC increase. Also, as the pollution deposited closer the grounded side, these harmonic components increase. In both cases, the increment of first and third harmonic component is noticeable, but the variation of one of fifth is slight.
3) $K_{5/3}$, fifth to third harmonic component ratio of LC was correlated with severity and location of pollution. As ESDD increases and pollution deposited closer to grounded side, $K_{5/3}$ decreases.
4) THD of LC decreases, when the polluted discs located nearer the grounded side.

5. References

[1] N. Bashir and H. Ahmad: *Odd harmonics and third to fifth harmonic ratios of leakage currents as diagnostic tools to study the ageing of glass insulators*, IEEE Trans. Dielectr. Electr. Insulat. 17 (2010), No. 3, p. 819-832.

[2] Hussein Ahmad, M. A. Salam, Lee Yi Ying and N. Bashir: *Harmonic components of leakage current as a diagnostic tool to study the aging of insulators*, J. Electrostat. 66 (2008), Nos. 3–4, p. 156-164.

[3] Ayman H. El-Hag: *Leakage current characterization for estimating the conditions of non-ceramic insulators' surfaces*, Electr. Power Syst. Res. 77 (2007), Nos. 3-4, p. 379-384.

[4] I. A. Metwally, A. Al-Maqrashi, S. Al-Sumry and S. Al-Harthy: *Performance improvement of 33 kV line-post insulators in harsh environment*, Electr. Power Syst. Res. 76 (2006), Nos. 9-10, p. 778-785.

[5] Ayman H. El-Hag, S. H. Jayaram and E. A. Cherney: *Calculation of leakage current density of silicone rubber insulators under accelerated aging conditions*, J. Electrostat. 67 (2009), Nos. 1, p. 48-53.

[6] Gerardo Montoya, Isaias Ramirez and Jorge I. Montoya: *Measuring pollution level generated on electrical insulators after a strong storm*, Electr. Power Syst. Res. 71 (2004), Nos. 3, p. 267-273.

[7] M. A. Douar, A. Mekhaldi and M.C. Bouzidi: *Investigations on leakage current and voltage waveforms for pollution level monitoring under wetted and contaminated conditions*, IET Sci. Meas. Technol. 5 (2011), Iss. 2, p. 67–75.

[8] T. Sorqvist and A. E. Vlastos: *Outdoor polymeric insulators long-term exposed to HVDC*, IEEE Trans. Power Deliv. 12 (1997), Iss. 2, p. 1041-1048.

[9] C. N. Richards and J. D. Renowden: *Development of a remote insulator contamination monitoring system*, IEEE Trans. Power Deliv. 12 (2005), Iss. 1, p. 389-397.

[10] S. Chandrasekar, C. Kalaivanan, A. Cavallini and G. C. Montanari: *Investigations on leakage current and phase angle characteristics of porcelain and polymeric insulator under contaminated conditions*, IEEE Trans. Dielectr. Electr. Insulat. 16 (2009), Iss. 2, p. 574-583.

[11] H. Homma, T. Kuroyagi, R. Ishino and T. Takahashi: *Comparison of leakage current properties between polymeric insulators and porcelain insulators under salt polluted conditions*, In: International Symposium on Electrical Insulating Materials ISEIM, 2005, Kitakyushu, p. 348-351.

[12] Hadi Hosseini Kordkheili, Hassan Abravesh, Mehdi Tabasi, Marzieh Dakhem and Mohammad Mehdi Abravesh: *Determining the probability of flashover occurrence in composite insulators by using leakage current harmonic components*, IEEE Trans. Dielectr. Electr. Insulat. 17 (2010), No. 2, p. 502-512.

[13] Amaldo, G.K., Geraldo and F.B.: *Leakage current monitoring of insulators exposed to marine and industrial pollution*, In: IEEE International Symposium on Electrical Insulation, 1996, Montreal, p. 271–274.

[14] Ramirez-Vazquez, I., Fierro-Chavez, J.L.: *Criteria for the diagnostic of polluted ceramic insulators based on the leakage current monitoring technique*, In: Conf. on Electrical Insulation and Dielectric Phenomena, 1999, Austin, p. 715–718.

[15] Xiangjun Li, Yong Feng, Khoi Loon Wong, Peter Sokolowski and Xinghuo Yu.: *Analysis of the leakage current on polluted insulators using correlation coefficient*, In: IEEE Conf. on Industrial Electronics Society Conference, 2011, p. 3338-3342.

[16] Xingliang Jiang, Yan Shi, Caixin Sun and Zhijing Zhang: *Evaluating the safety condition of porcelain insulators by the time and frequency characteristics of LC based on artificial pollution tests*, IEEE Trans. Dielectr. Electr. Insulat. 17 (2010), No. 2, p. 481-489.

[17] J. Y. Li, C. X. Sun and S. A. Sebo: *Humidity and contamination severity impact on the leakage currents of porcelain insulators*, IET Gener. Transm. Distrib. 5 (2011), Iss. 1, p. 19–28.