Laboratory investigation of the impact of air pollution on partial discharge inception voltage of insulators in a specific region

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Article Info

Article history:

Received Sep 7, 2020
Revised Apr 12, 2021
Accepted Apr 26, 2021

Keywords:

Conductive layers
Inception voltage
Insulators
Partial discharge
Pollution

ABSTRACT

Studying the discharge characteristics of transmission line insulators in the presence of pollution, particularly when the contaminated layer is wet by rain, fog or condensation, is necessary for selecting the proper insulation. Therefore, identifying the major air pollutants as well as the most effective ones on the discharge performance of outdoor insulators is mandatory. A systematic approach has been proposed to evaluate the impact of dominant air pollutants of an area on partial discharge (P.D) inception voltage of specimen insulators. Based on the suggested method, determining the pollution constituents, defining the dominant pollutant of the area, finding the most commonly used insulators for medium and above distribution voltages within the geographical boundaries of the Central Province of Iran, as well as examining the effect of dominant air pollutant of the region on partial discharge inception voltage of designated insulators by laboratory measurements, are the necessary steps toward a comprehensive study of the subject.

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1. INTRODUCTION

Based on the definition which has been presented in IEC 270 [1], a partial discharge is an electric discharge that only partially bridges the insulation between conductors. Partial discharges often occur locally and are caused by an intensification of the electrical field and consequent air ionization on an insulator's polluted or damaged surface. Although this phenomenon releases not much energy, it will gradually develop and lead to flashover and break down the insulator. Even if the partial discharge does not end to flashover, it will degrade the insulator's dielectric property [2], [3].

According to reliable statistics, a high percentage of service interruptions are caused by moisturized outdoor insulators' contamination. Nowadays, air pollution is a problem in industrial countries and developing areas of the world [4], [5]. Air pollution constituents, in rain or fog conditions, cause the formation of a conductive layer which leads to flow of leakage current and discharges on transmission line insulators surfaces [6], [7]. Several investigations for various air contaminants and in different parts of the world have been performed and reported in many articles in the literature [8]-[12].

Nevertheless, most of them have focused on examining one kind of air pollution constituent on selected specimens' discharge behavior.

Present work, however, is based on a detailed study of all major air pollutants of the area of interest and the probable impact of dominant and the most effective one on partial discharge inception voltage of commonly used insulators in a specific region [13]. Furthermore, a new systematic approach to the problem has been suggested and has been presented in a flowchart diagram in Figure 1. In This experiment, we only measured the partial discharge inception voltage, and other quantities such as the number of charges, discharge power, discharge current, are not covered.

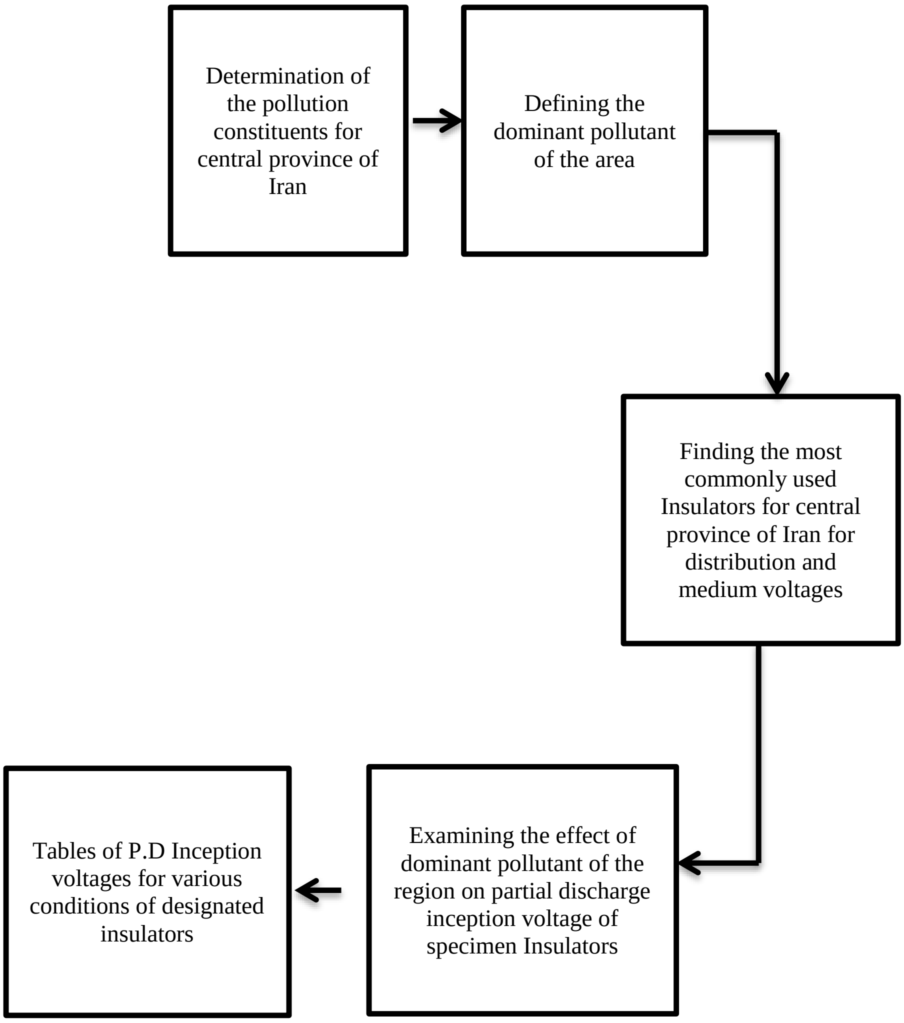


Figure 1. Flowchart of suggested method of investigation

2. CLIMATE EVALUATION AND DETERMINING THE DOMINANT AIR POLLUTION CONSTITUENT

According to the information from seven stationary stations and eight mobile measuring groups, suspended particle matters (Spm), sulfur dioxide (So_2), and carbon monoxide (Co) were the major air pollutants throughout the region. The measurement period was one year, from April to the end of March, 2017. The percentage of each, has been graphically shown in Figure 2.

Figure 3 and Figure 4 So_2 and Co are in gas forms, and their solubility in water is very limited. On the other hand, they hardly would be sedimented on the insulator surface. Therefore, a mix of (SPm) and salty dust, originated from MIGHAN Salt Lake and its surrounding desert, which is located 5 km northeast of the biggest city of the province, identified as the dominant air pollutant for the district under study [14], [15]. Consequently, a sample from the aforementioned mixture was gathered to be used as a substance for artificial pollution tests.

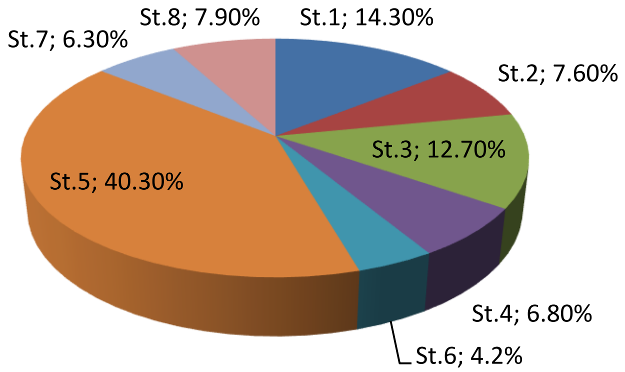


Figure 2. Percentage of (CO) measured in different stations (24 hours average)

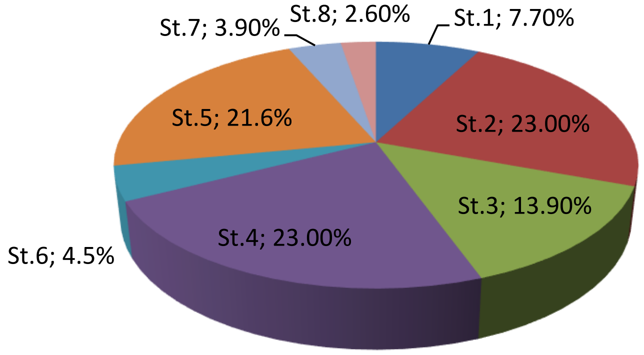


Figure 3. Percentage of (SO_2), measured in different stations (24 hours average)

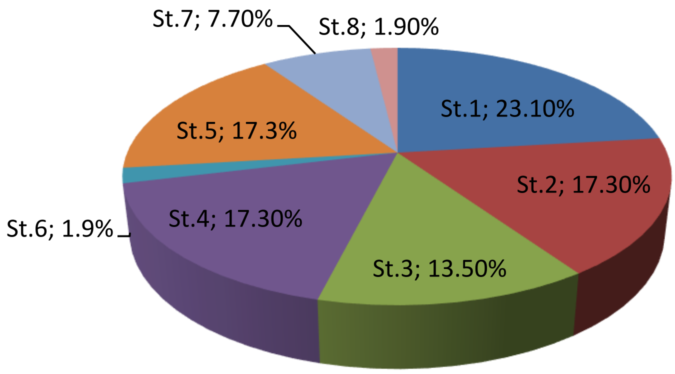


Figure 4. Percentage of (SPm), measured in different stations (24 hours average)

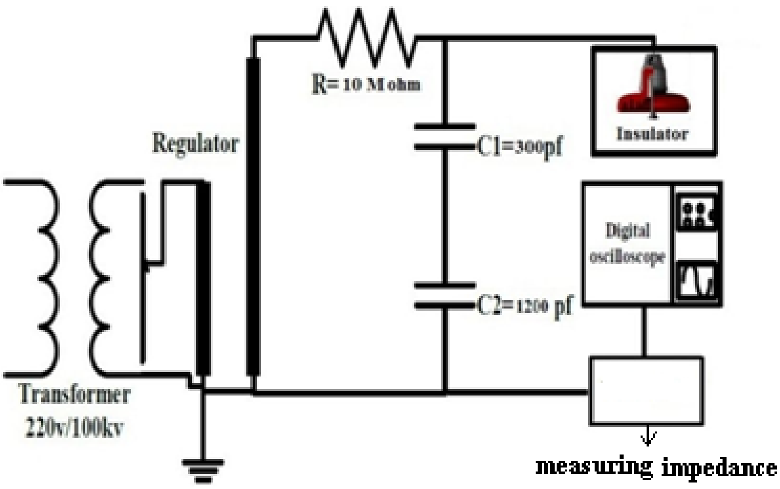
3. MATERIALS AND METHODS: TEST FACILITIES, CIRCUITS, SPECIMEN AND PROCEDURE

Experimental investigations were performed in the laboratory of the Science and Technology University of Iran (center for high voltage researches). The power was supplied by a 100 KV, 200 KVA pollution test transformer as shown in Figure 5. The coupling capacitors which were used in the test are shown in Figure 6. The test voltage shall comply with the requirements of IEC 60-1 [16], the alternating current (AC) pollution test requirements recommended by international electrotechnical commission (IEC) standards 60507,60815 and partial discharge measurement requirements recommended by IEC 270 [17], [18].

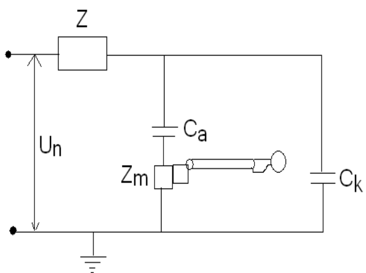
Figure 5. High voltage source transformer

Figure 6. Coupling capacitors

Test circuit is shown in Figures 7(a, b, c, d and e). Where "Ca" is the test object, "Z_m" is an impedance that connects in parallel with the measuring instrument. "Z" is an impedance that could be substituted by a 10 MΩ resistor to prevent discharge pulses from being by-passed through the high voltage supply and to reduce interference from the source.



(a)



(b)

(c)

(d)

(e)

Figure 7. Test circuit; (a) actual test circuit for (P.D) inception voltage measurement, (b) test circuit recommended by IEC 270, (c) picture of test circuit in Lab, (d) picture of test circuit with the test object, (e) partial discharge detector

The purpose of the test is to measure the inception voltage (U_f), according to subclasses 3.5.1, IEC 270. Therefore, we gradually increased the voltage from a lower value at which no discharges are observed, till the lowest voltage (U_f), at which partial discharges exceeding a specified intensity are observed. Wetting time in order, for the pollution layer, to be solved in water, should at least be 20 minutes in case of glass and porcelain insulator, and 30 minutes for composite-polymer insulators. However, in the above tests half an hour wetting time was considered for all insulators [19]. The specimens were the most commonly used types of insulators in transmission lines of the central province of Iran. Profiles, dimensions and basic parameters are shown in Figure 8 and Table 1. Where D is the diameter, L is the creepage distance and H is the height of the insulators.

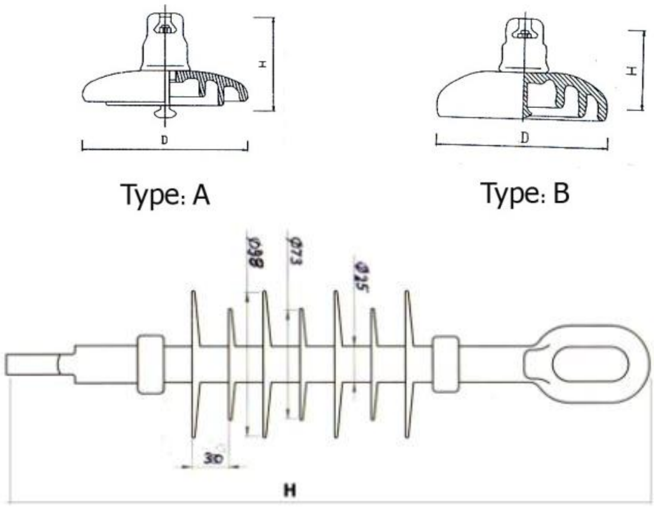


Figure 8. Profiles of tested insulators

Table 1. Parameters of tested insulators

Type	Materials	H(mm)	D(mm)	L(mm)	Max.Tensile (Mechanical), KN
A	Porcelain	146	255	295	70
B	Glass	146	254	292	70
C	SIR	480	98/73	670	70

4. RESULTS AND DISCUSSION

Following the standard procedure, P.D inception voltage of specimen insulators when they were dry and clean and polluted by the area's dominant air pollutant was measured. The test results in different pollution severity (PS), a different angle of rain, and different uniformity of pollution materials are shown in Tables 2-4. Which are mostly comparing with those existing in the literature [20]-[24]. The results of artificial pollution tests are slightly different from what the insulators will be exposed to, in field and service, but according to many types of research and experiences [25]-[27], the difference would at most be less than 8%. So that, the results of lab tests are reliable for the design and selection of outdoor insulators in locations of interest [28]-[31].

Table 2. Results of the tests on porcelain insulator (Type A)

P.D inception Voltage	Type and severity of pollution and rain condition	
25 kv	Clean and dry	
25 kv	Dry and polluted	
19 kv	Uniform pollution	Medium PS,
18 kv	Non uniform pollution	Vertical rain
17 kv	Uniform pollution	Heavy PS,
16 kv	Non uniform pollution	Vertical rain
18 kv	Uniform pollution	Medium PS, rain with the angle of 45°
17 kv	Non uniform pollution	
16 kv	Uniform pollution	Heavy PS, rain with angle of 45°
15 kv	Non uniform pollution	

Table 3. Results of the tests on glass insulator (Type B)

P.D inception Voltage	Type and severity of pollution and rain condition	
20 kv	Clean and dry	
20 kv	Dry and polluted	
19 kv	Uniform pollution	Medium PS,
17 kv	Non uniform pollution	Vertical rain
16 kv	Uniform pollution	Heavy PS,
14 kv	Non uniform pollution	Vertical rain
18 kv	Uniform pollution	Medium PS, rain with the angle of 45°
16 kv	Non uniform pollution	
15 kv	Uniform pollution	Heavy PS, rain with angle of 45°
13 kv	Non uniform pollution	

Table 4. Results of the tests on polymeric insulator (Type C)

P.D inception Voltage	Type and severity of pollution and rain condition	
30 kv	Clean and dry	
29 kv	Dry and polluted	
26 kv	Uniform pollution	Medium PS,
24 kv	Non uniform pollution	Vertical rain
23 kv	Uniform pollution	Heavy PS,
21 kv	Non uniform pollution	Vertical rain
25 kv	Uniform pollution	Medium PS, rain with the angle of 45°
23 kv	Non uniform pollution	
22 kv	Uniform pollution	Heavy PS, rain with angle of 45°
20 kv	Non uniform pollution	

5. CONCLUSION

From The test results, the following conclusions can be presented: Increasing the pollution severity will decrease the P.D inception voltage. P.D inception voltage will be affected by the wetness degree of the pollution layer. Therefore, the voltage was recorded after making sure that the layer was saturated by moisture. Non uniformity of pollution layer has a significant impact on P.D inception voltage and generally will decrease it. If the ratio of the windward area of an Insulator's surface to the Leeward area is W/L, then a reduction of this ratio will reduce the inception voltage. Therefore, the abovementioned factor, should be taken into account in calculating the overall creepage distance and in the selection and designing of insulator string in windy and desert locations. Narrowing the rain angle from the vertical position will slightly increase the partial discharge inception voltage, in other words vertical rain is preferred in regard to P.D inception voltage. In general, polymeric insulators have higher (P.D) inception voltages and better discharge characteristics than the glass and porcelain insulators under pollution conditions.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. Kourosh Apornak who assisted in conducting this work and the environmental protection office of central province of Iran for providing useful information.

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