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Designation of an Indicator for Flashover Prediction of Porcelain and Glass Insulators Based on Experimental Tests

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ABSTRACT
Flashover of polluted insulators in contaminated areas is one of the most important factors influencing the operation of transmission and distribution lines and finally line outages. Therefore, it is essential to prevent and detect flashover in the insulators. Hence, utilizing the insulator status monitoring systems and predicting their functions have absorbed a lot of attention over the recent years. In this paper, a new method is proposed for flashover prediction in porcelain and glass insulators. In this regard, a variety of experiments has been conducted on different types of insulators under different environmental conditions and analysis of their leakage current harmonics have been investigated. Fast Fourier Transform (FFT) analysis applied to the saved leakage current waveforms shows a strong correlation between the ratio of the third to fifth harmonic amplitudes by regarding the occurrence of critical conditions and degree of insulator ageing. Then, the third to fifth harmonic ratio of the leakage current (R3/5) has been proposed as an indicator of critical conditions in porcelain and glass insulators. The results of these experiments show that the mentioned harmonic ratio has a definite and constant procedure against the changes in the type of pollution and humidity rate. The results of experiments have indicated that increasing the index R3/5 to more than one represents a critical condition in the insulators and estimates a high probability of flashover. Also in whole the tests, value of the total harmonic distortion (THD) and flashover voltage are measured.

KEYWORDS: Insulators, Pollution, Leakage current, Flashover, Harmonic.

1. INTRODUCTION

The ageing of outdoor insulators can greatly threaten the reliability of transmission lines. Experiences from utilities have shown that 70% of the line outages result from insulator failure, and the cause of such failures is mainly ageing or contamination flashover. When these insulators are installed near industrial, agricultural or coastal areas, airborne particles are deposited on these insulators and the pollution builds up gradually, which results in the flow of leakage current (LC) during wet weather conditions such as dew, fog or drizzle. The LC density is non-uniform over the insulator surface and in some areas, sufficient heat is developed leading to the formation of dry bands. [1-8]. Several researchers have studied the behavior of the polluted insulators and presented various models for them. In [1], the model of the polluted insulator has been presented. In this model, the polluted insulator is shown as two serial resistors including the polluted layer resistor and the dry band resistor. Then, a mathematical model is presented for the critical voltage depending on the insulator profile and amount of pollution. In [2], presenting the circuit model of the polluted insulator, the electrical behavior of the polluted insulator is presented. In the paper, electrical arc constants were expressed dynamically and the function of the amount of pollution and insulator profile are introduced. In [3], a circuit model is presented for the polluted insulator. In this model, the polluted layer is modeled as a resistor in parallel with a capacitor. In this reference, by regarding the circuit model of the polluted insulator, a new mathematical model has been presented for the critical parameters (e.g., distance of the critical electrical arc, critical leakage current and critical voltage). In [1-6], by assuming identical level of pollution, the behavior of the polluted insulators is

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studied and modeled. On the other hand, in [7-8], the behavior of the insulators is investigated under the conditions that their surface pollution is not identical and electrical behavior of the insulators and their critical parameters are modeled under such conditions.

In addition to the mentioned cases, there is a variety of methods in which detection of the insulator conditions and prediction of flashover are suggested [9-17]. In most of these methods, studies on the leakage current and extraction of detection criterion of critical conditions from changes in insulator behavior are considered. In order to predict the imminence of flashover based on information collected from leakage current it is possible to analyze a few attributes of the signal such as the odd harmonics [9], the peak amplitude and rate [10]. These attributes are employed on laboratory tests for the definition of a criterion of flashover prediction but the great complexity of the real world situation makes it practically impossible to reproduce the conditions found on the field [10]. One of the most promising techniques for online measurements is the monitoring of leakage current flowing on the insulator's surface itself. For measurement of this parameter researchers use current transformers [9] and [11]. In [12], flashover is predicted by using the optical sampling of the leakage current signal of the insulator chain. In this paper, authors developed an optical system capable of monitoring the leakage current waveform on a high voltage insulator string. Because of the optical nature of the measurement, the approach is immune to electromagnetic interference. In this respect, many papers were carried out to predic flashover in the composite insulators as [13], in this paper, prediction of flashover occurrence is performed using the analysis of leakage current harmonics in the composite insulators. Tests on EPDM composite insulators showed that under discharge condition, the leakage current THD criteria should be combined with leakage current magnitude. The presented diagnostic parameter was the product of THD and Leakage current magnitude and its thresholds [14]. Yet, no quantified method was presented. In [15], a new method is presented to reveal a fault in the composite insulators by optical sensors. Also, the main effective factors of the wetting process of the pollution layer have been analyzed in [16]. Authors in [17] concluded that the analysis of leakage current bursts can be used to monitor the severity of pollution on the electrical network. Artificial neural networks (ANNs) have been utilized in issues requiring estimation, prediction, pattern recognition and classification, etc. In the field of high voltage insulators, ANNs have been utilized to predict a flashover [18], analyze surface tracking on polluted insulators [19], estimate critical flashover voltage on a polluted insulator [20] and forecast leakage current in silicon rubber insulators [21]. According to the above explanations, flashover occurrence in insulators leads to overvoltage of overhead transmission lines. Therefore, studying in this field is very important and useful for electrical engineers and a novel model or improved method can be presented.

In this paper, a new monitoring index (R3/5) is proposed to determine insulator condition under different situations, including clean condition, surface contamination and humid aging. The experimental tests have been performed on porcelain and glasses insulators to evaluate the ability of the proposed index for recognizing the operating condition of insulators. The results have shown the viability of the new index in insulators monitoring procedures. Investigation and discussion of the obtained results will give efficient ideas to the electrical engineers in order to easily analyze arrester conditions leading to effective maintenance schedule. This indicator makes it possible to predict the critical conditions of porcelain and glass insulators before flashover occurrence. The high value of the third harmonic than the fifth harmonic of the leakage current indicates the abnormal function of the insulator. By analyzing the data obtained from the leakage current signal, which is recorded at critical conditions, the critical range of the index resulting flashover appears when the third harmonic of the leakage current gets larger than the fifth harmonic. Meanwhile, to make more confidence and select critical range exactly, the experiments were frequently done on the other similar insulators and measurements were repeated. Other experiments indicated the obtained range can correctly be utilized to predict flashover. The other parameters of the leakage current waveforms, such as THD and the peak amplitude of leakage current and also flashover voltage in this research are measured.

2. EXPERIMENTAL PERFORMANCE PROCESS

2.1. Test objects

In order to perform experimental tests and measure leakage current and record the data, experimental setup is used according to Fig. 1.

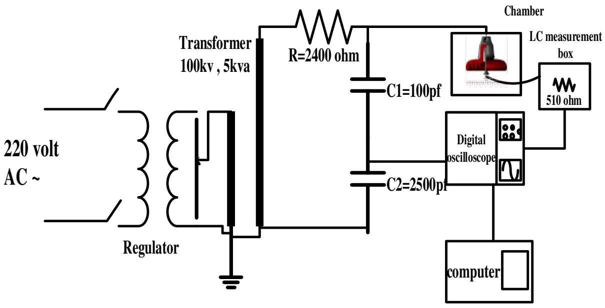


Fig. 1. A schematic of the experimental setup.

This setup, which is provided according to the standard IEC60507 [22] includes a clean fog chamber, a high voltage transformer, and a leakage current measuring system. For measuring the applied voltage to the insulator, a capacitor divider is used. The leakage current meter system and also oscilloscope are protected against the increase of current and voltage. The sampling of the leakage current signal is carried out by a digital oscilloscope and the data are stored.

2.2. Studied insulators

Fig. 2 shows investigated insulators. The insulator samples, whose characteristics are inserted in Table 1, are allocated to be tested under different artificial pollutions.

2.3. Polluting the insulators

In order to make pollution on the surface of porcelain and glass insulators, the solid layer method is applied. This method, in accordance with the standard IEC60507, is made to create uniform artificial pollution.

The standardized pollution levels are divided into 4 categories of light, medium, heavy and very heavy. Table 2 shows the amount of salt dissolved in 1 liter of distilled water and the corresponding pollution intensity. In order to make pollution at different levels, the needed salt with 40 grams of kaolin dissolves in 1000 ml of water. Figure 3 shows an insulator after settlement of pollution on its surface.

Fig. 2. Tested insulators.

Table 1. Characteristics of the tested insulators.

Characteristics \ Insulator Number	(1)	(2)	(3)	(4)	(5)	(6)
Spacing (H) (mm)	146	146	178	146	176	146
Creepage distance (L) (mm)	305	320	546	320	530	360
Max. diameter (D) (mm)	255	255	321	255	280	280
Electromechanical failing load (KN)	120	160	210	70	210	290

Table 2. Amount of salt in various solutions.

Pollution level	Light	Medium	Heavy	Very heavy
Salinity(gr/liter)	10-20	20-40	40-80	80-100

Fig. 3. Image of insulator in the polluted state.

2.4. Polluting the insulators

In order to measure the leakage current and record the data of the tested insulators in different levels of pollution, each insulator, after being polluted, has been tested in two states of dry and wet conditions. In dry state, the test is carried out in the humidity of the environment, and the wet state, the insulator is exposed to voltage in different humidifies which is provided by fog generator. Figure 4 shows a view of the experimental objects used in this research.

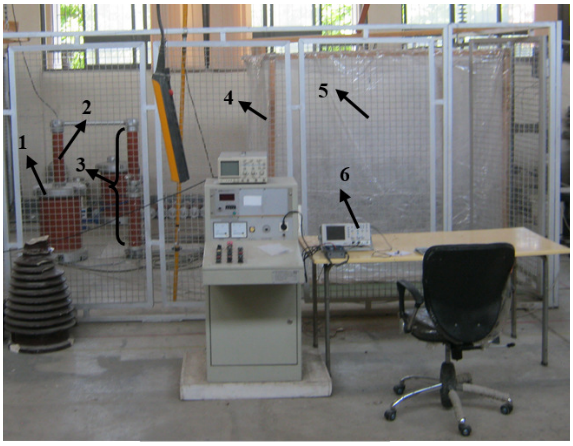


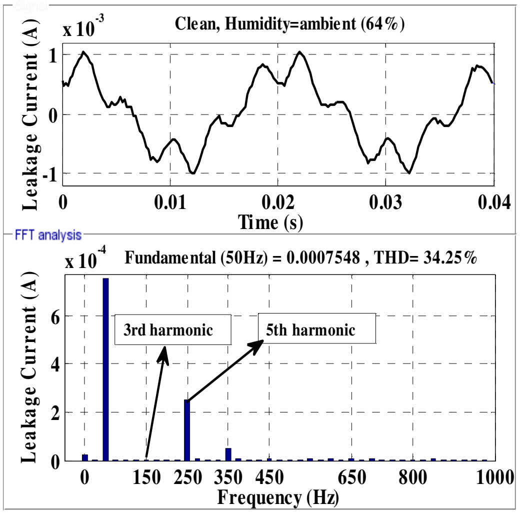
Fig. 4. Image of experimental setups.
1. HV transformer, 2. HV resistance, 3. Capacitive divider, 4. Fog chamber, 5. Insulator sample, 6. Oscilloscope.

4. MEASUREMENT RESULTS

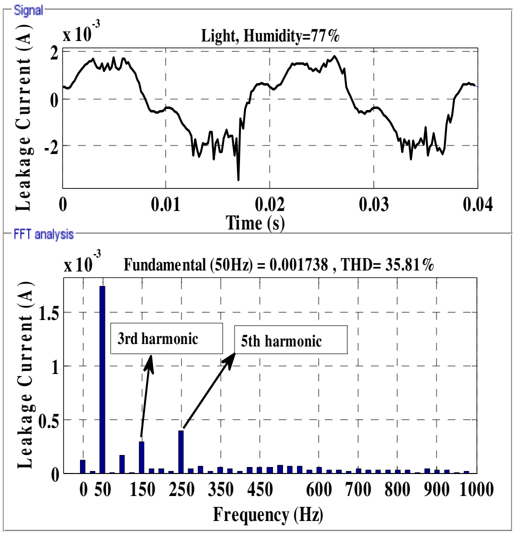
In the performed measurements, the leakage current signals are saved as CSV file by the oscilloscope. Sampling includes 4000 points of the leakage current signal in time domain. This data is transferred to MATLAB software and the complete features of the leakage current waveforms are extracted. For example, in Table 3 the data obtained from the analysis the wave shape of the leakage current of the insulator number 1 under the heavy pollution and different humidifies.

Table 3. Information obtained from the recorded leakage current of insulator number 1 in the heavy pollution.

Humidity% / LC Specifications	Ambient 64%	77%	85%	91%
	Value (mA)			
rms	0.55	1.1	1.1	0.94
1st	0.75	1.39	1.41	1.26
3rd	0.004	0.295	0.259	0.239
5th	0.242	0.247	0.194	0.339
THD%	34.25%	55.4%	64.59%	66.10%



a.



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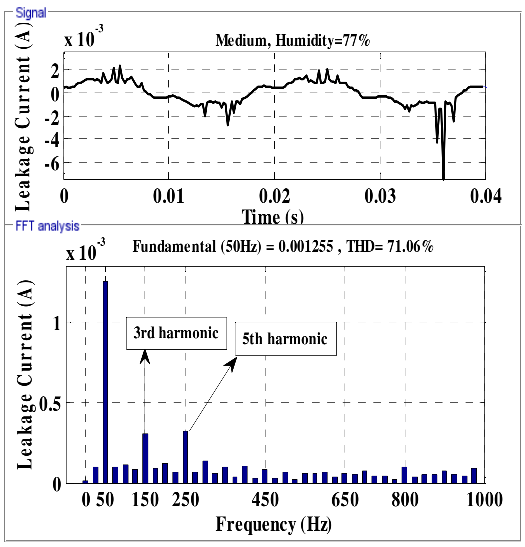


c.

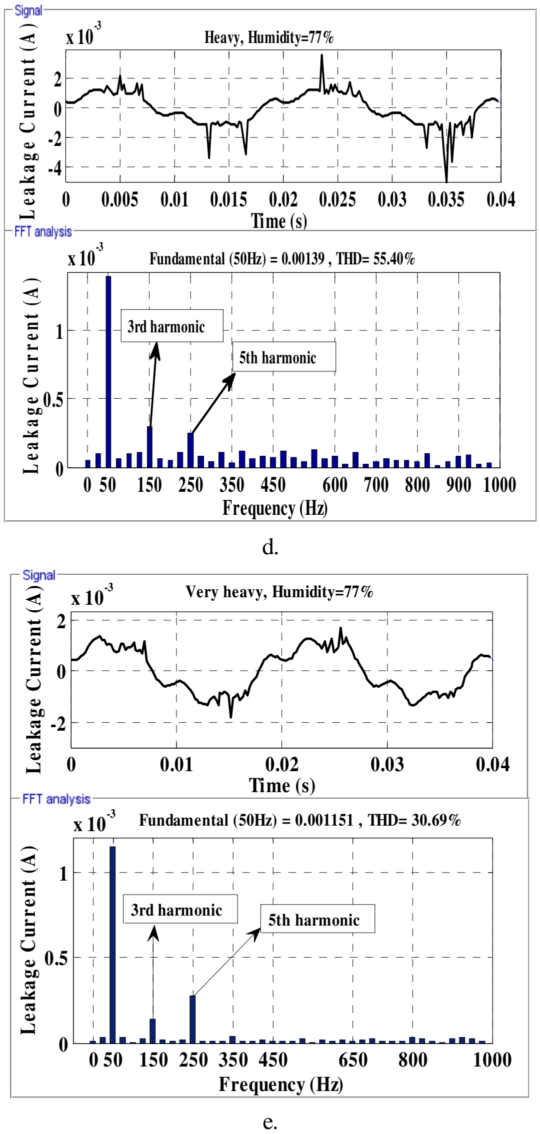


Fig. 5. Waveforms of the leakage current and FFT of insulator number 1 in various pollutions at 77% humidity.
a. Clean, **b.** Light, **c.** Medium, **d.** Heavy, **e.** Very heavy.

All insulators are exposed by different pollution and humidifies levels under the applied voltage of 40kV and 50 Hz. As an example, Fig. 5 shows the leakage current waveforms and their FFT for insulator number 1 at 77% humidity and different pollution levels.

In clean (normal) state, no flashover was seen in the experiments. The results indicate that the amount of the fundamental harmonic component of the leakage current increases considerably with an increase in humidity. In the polluted insulators and without fog, the fifth harmonic of the leakage current has always been more than the third harmonic. This case indicates the normal status of the insulator. The previous criterion to detect normal working status in clean insulators is also applicable for polluted insulators. Increasing humidity, the amount of the third harmonic increases and gets larger than the fifth harmonic. The effect of humidity on the leakage current waveforms is shown in Fig. 6. This figure shows that the peak of leakage current increases by applying fog. Figure 7 shows the variations of leakage current waveforms when the applied voltage changes. According to Fig. 7 the peak of leakage current and also the maximum of the third harmonic have increased by increasing voltage.

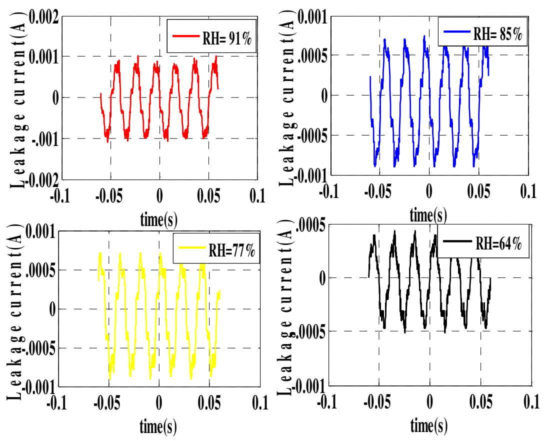


Fig. 6. Leakage current waveforms versus different levels of humidity (RH %) for insulator number 3.

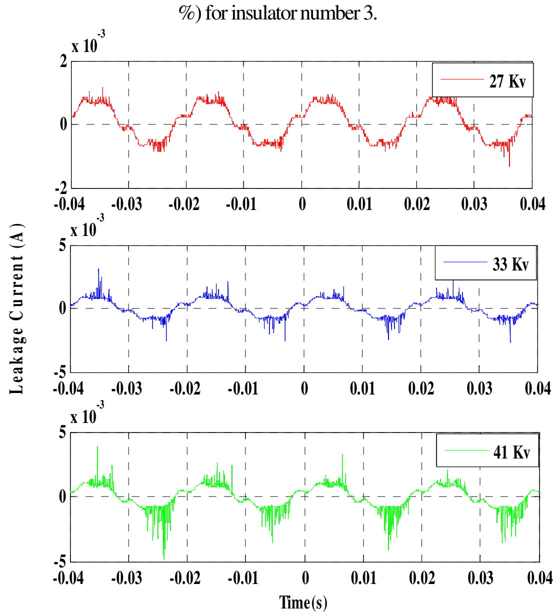
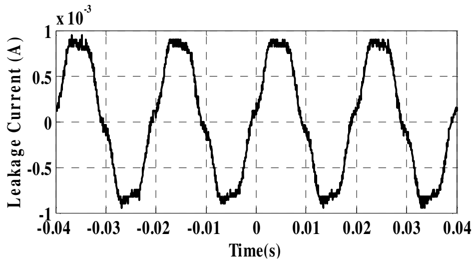


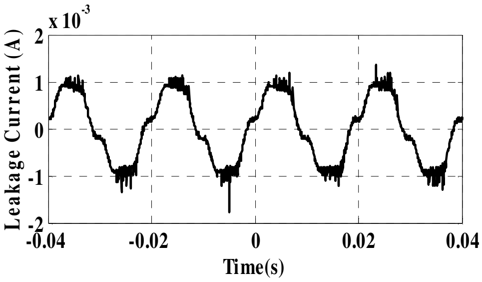
Fig. 7. Leakage current waveforms of insulator 1 in various voltage levels (27, 33 and 41 kV), humidity=77%, medium pollution levels.

3.1. Leakage current waveforms during flashover

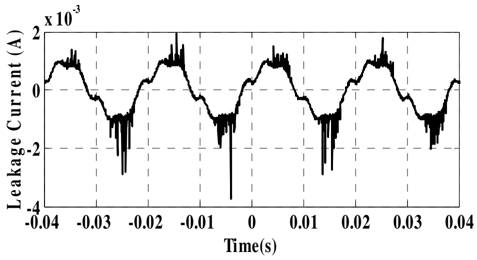
Figure 8 presents typical changes in the leakage current in the event of flashover occurrence against increasing voltage. Flashover occurs as four following steps.



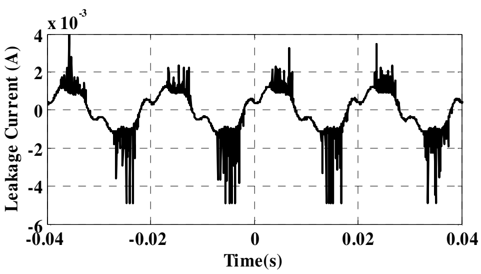
a). step 1



b). step 2



c). step 3



d). step 4

------------No waveform---------

e). step 5

Fig. 8. Shift of leakage current waveforms on to flashover occurrence for insulator number 1 (heavy pollution and humidity= 77%).

Discharge condition:

Step1: No discharge.

Step 2: Some visible point discharge with sound.

Step 3: Linear weak local arcs.

Step 4: Intermittent stronger local arcs (just before flashover).

Step 5: flashover.

Step 1: leakage current waveform seems like sine waves at the beginning of applying the voltage due to resistive current flow (almost wet surface layer, no dry bands, no discharge). Step 2: the tips of triangular waveform become sharper and lengthen when some visible point discharges occur ([23]), with a continuous sound near the cap on the upper surface (dry band formation occurs during stages 1 to 3). Step 3: the leakage current waveform becomes similar to the symmetrical wave in the presence of linear filamentary weak local arcs ([23]) in 5 or 6 spots near the cap on the upper surface. Step 4: in addition to the symmetrical waves at step 3 in the presence of intermittent, leakage current with a large peak value appears with strong local arcs on the bottom surface. According to the conducted tests, the third and fifth harmonics of leakage current are shown in Tables 4-9 in different levels of humidity and pollution for the tested insulators. The results of the aforementioned measurements reports that in the presence of wet on insulators, the third harmonic of the leakage current increases remarkably unlike the clean state. With growth in wet pollution, the third harmonic increases to the point which goes beyond the fifth harmonic such that at this time the electrical discharge occurs. A growth in humidity has a considerable effect on increase of the third harmonic of the leakage current and behavior variations of the insulator. As it is observed, in high humilities because of the complete wetness of the surface and decrease of the surface electrical conductivity, the leakage current gets more stable.

Table 4. Value of the third and fifth harmonics of the leakage current and their ratio in insulator number 1.

Humidity%	Severity pollution	3rdH (mA)	5thH (mA)	R3/5%
Ambient 64%	clean	0.0044	0.242	1.7%
77%	Light	0.295	0.387	76.28%
	Medium	0.3	0.316	96.36%
	Heavy	0.295	0.247	119.3%
	Very Heavy	0.21	0.3	70.7%
85%	Light	0.204	0.298	68.42%
	Medium	0.229	0.201	113.9%
	Heavy	0.259	0.194	133.5%
	Very Heavy	0.264	0.228	115.7%
91%	Light	0.176	0.3	58.58%
	Medium	0.124	0.205	60.54%
	Heavy	0.239	0.339	70.7%
	Very Heavy	0.247	0.221	111.4%

Table 5. Value of the third and fifth harmonics of the leakage current and their ratio in insulator number 2.

Humidity%	Severity pollution	3^{rd}H (mA)	5^{th}H (mA)	R3/5%
Ambient 64%	clean	0.026	0.243	11.05%
77%	Light	0.216	0.4	53.95%
	Medium	0.257	0.303	80%
	Heavy	0.313	0.296	105.7%
	Very Heavy	0.282	0.262	107.6%
85%	Light	0.101	0.365	27.69%
	Medium	0.496	0.476	104.2%
	Heavy	0.371	0.344	107.8%
	Very Heavy	0.545	0.454	120%
91%	Light	0.062	0.237	26.21%
	Medium	0.032	0.443	7.4%
	Heavy	0.382	0.341	112%
	Very Heavy	0.401	0.366	109.5%

Table 6. Value of the third and fifth harmonics of the leakage current and their ratio in insulator number 3.

Humidity%	Severity pollution	3^{rd}H (mA)	5^{th}H (mA)	R3/5%
Ambient 64%	clean	0.021	0.195	10.845
77%	Light	0.119	0.413	28.83
	Medium	0.112	0.541	20.72%
	Heavy	0.512	0.49	104.4%
	Very Heavy	0.345	0.328	105.1%
85%	Light	0.041	0.731	5.69%
	Medium	0.492	0.458	107.4%
	Heavy	0.531	0.527	100.7%
	Very Heavy	0.391	0.399	99.7%
91%	Light	0.037	0.733	5.16%
	Medium	0.063	0.595	10.57%
	Heavy	0.426	0.402	105.9%
	Very Heavy	0.425	0.424	100.2%

Table 7. Value of the third and fifth harmonics of the leakage current and their ratio in insulator number 4.

Humidity%	Severity pollution	3^{rd}H (mA)	5^{th}H (mA)	R3/5%
Ambient 64%	clean	0.055	0.261	21.56%
77%	Light	0.14	0.143	97.79%
	Medium	0.176	0.324	54.46%
	Heavy	0.181	0.247	73.33%
	Very Heavy	0.029	0.313	9.3%
85%	Light	0.097	0.109	89.5%
	Medium	0.358	0.343	104.3%
	Heavy	0.084	0.18	46.73
	Very Heavy	0.234	0.179	130.7%
91%	Light	0.147	0.133	110.58%
	Medium	0.199	0.32	62.13%
	Heavy	0.188	0.173	108.6%
	Very Heavy	0.211	0.196	107.6%

The increase of value the leakage current harmonic components due increasing pollution, unlike the clean state, indicates the effect of pollution on the electrical behavior of insulators. As can be seen, in high humidity level, due to the complete wetness of the surface and reduction of electrical conductivity of surface and flow of liquid drops from the surface of the insulator, the leakage current is more stable. The increase of amplitude and disorder of THD of the leakage current waveform, in the various pollutions compared to clean mode, is an indicative of impact of pollution on the electrical behavior of insulators.

Table 8. Value of the third and fifth harmonics of the leakage current and their ratio in insulator number 5.

Humidity%	Severity pollution	3^{rd}H (mA)	5^{th}H (mA)	R3/5%
Ambient 64%	clean	0.029	0.313	9.3%
77%	Light	0.081	0.34	23.96%
	Medium	0.035	0.488	7.36%
	Heavy	0.298	0.275	108.3%
	Very Heavy	0.561	0.546	102.7%
85%	Light	0.1	0.319	31.41%
	Medium	0.469	0.463	101.2%
	Heavy	0.281	0.239	117.5%
	Very Heavy	0.44	0.416	105.7%
91%	Light	0.125	0.279	44.87%
	Medium	0.084	0.465	18.16%
	Heavy	0.051	0.243	17.29
	Very Heavy	0.674	0.657	102.5%

Table 9. Value of the third and fifth harmonics of the leakage current and their ratio in insulator number 6.

Humidity%	Severity pollution	3^{rd}H (mA)	5^{th}H (mA)	R3/5%
Ambient 64%	clean	0.028	0.328	8.62%
77%	Light	0.049	0.195	25.32%
	Medium	0.347	0.367	94.55%
	Heavy	0.442	0.433	102.07%
	Very Heavy	0.394	0.383	102.8%
85%	Light	0.066	0.239	27.73%
	Medium	0.271	0.289	93.77%
	Heavy	0.474	0.428	110.7%
	Very Heavy	0.395	0.39	101.2%
91%	Light	0.086	0.28	30.82%
	Medium	0.084	0.288	29.23%
	Heavy	0.293	0.329	89.05%
	Very Heavy	0.343	0.329	104.2%

5. ANALYSIS OF THE LEAKAGE CURRENT HARMONIC COMPONENTS

Using the results of the leakage current measurements in the tested insulators in different conditions, it can be discussed:

5.1. Normal condition

In clean state, no flashover was seen in any of the experiments. The results indicate that the amount of the fundamental harmonic component of the leakage current increases considerably with increase in humidity. However, this increase is not so tangible in other harmonics. In clean conditions, the fifth harmonic of the leakage current is always larger than the third harmonic. Thus, it can be expressed that when the amount of the fifth harmonic is higher than the third, the insulators are clean and in normal working state.

4.5. Abnormal condition

In the light pollution, the amount of the fundamental harmonic of the leakage current decreases primarily, but increases upon the presence of fog and humidity and after a while its amount decreases again. Because of the wetness of the insulator surface and dissolution of soluble salts, surface conductivity increases suddenly, and finally, due to flow of the leakage current and creation of a dry band on the insulator surface, a slight discharge occurs on the surface. In some cases, slight discharges cause an electrical arc. After producing the fog and completing wetness of the surface of the insulator, salt dissolves in humidity. On the other hand, this humidity appears as small water droplets on the surface dripping down on the edges of the shed. This phenomenon causes reduction of salt on the surface and consequently decreases surface conductivity and makes the insulator more stable.

In the polluted insulators and without fog, the fifth harmonic of the leakage current has always been larger than the third harmonic. This indicates the normal status of the insulator. In fact, the previous criterion for detection of normal working condition in clean insulators is also applicable in polluted insulators. By applying fog and increasing of humidity, the amount of the third harmonic increases and gets larger than the fifth harmonic. Although the fifth harmonic increases, but increasing of the third harmonic prevails over it. Therefore, the third harmonic becomes higher than the fifth harmonic and the insulator status will be critical and probability of the flashover occurrence will increase. The other parameters of the leakage current waveforms, such as THD and the peak amplitude of leakage current cannot be considered as an appropriate criterion due to irregular changes in different conditions. Table 10 shows THD of the tested insulators.

Table 10. THD of the tested insulators.

Pollution / Ins. No	Clean	Light	Medium	Heavy	Very Heavy
	THD%				
1	34.25	35.81	71.06	55.4	30.69
2	34.63	30.69	19.51	20.08	18.25
3	32.47	9.14	12.68	9.72	14.18
4	26.9	27.04	32.09	32.58	28.67
5	35.71	29.3	36.95	32.6	32.76
6	36.21	36.21	31.72	34.37	31.83

With respect to the mentioned cases, the changes of third and fifth harmonics of the leakage current in relation to each other can be the basis of the judgment about the function of porcelain and glass insulators. According to the conducted experiments, it can be stated that the increase of the third harmonic of the leakage current is described as pollution and humidity of the insulator.

In this paper, regardless of the amount of humidity and environment pollution and only by measuring the leakage current and amounts of the third and fifth harmonics, a detection criterion for describing the status of porcelain and glass insulators has been presented.

5. MEASURMENT OF THE FLASHOVER VOLTAGE

In this research, two types of tests have been carried out. At the beginning, the test of insulators in voltage 40kV and in different levels of pollution and humidity was performed to observe the effect of pollution and humidity on the functional conditions of the insulators. The next test was conducted at different voltage levels. In the second case, the effect of voltage increase on the determined index and recognition of the endurable critical voltage were experimented. Table 11 shows the critical voltage of the tested insulators under different pollutions and humidifies. A sudden reduction of the endurable voltage level in the presence of pollution and humidity indicates their effect on the normal function of the insulators. In other word, increase in humidity and/or pollution causes flashover in lower voltage levels. As the measured amounts shown in Table 11, with increasing the amount of pollution, which results surface electrical conductivity, the critical voltage level decreases. In other word, because of the salt solution, the surface electrical conductivity increases and more leakage current passes on the insulator surface. An increase in the surface leakage current causes more electrical discharges. Humidity also has great effect on the increase of these electrical discharges.

Table 11. Critical voltage measured in the tested insulators.

Humidity	Pollution levels / Ins. NO	Light	Medium	Heavy	Very Heavy
		Critical voltage (KV)			
77%	1	66.4	60.3	45.1	52.6
	2	76.2	70.6	65.3	59.5
	3	75.6	63.5	56.2	41.5
	4	74.1	68	42.6	54.3
	5	70.1	65	42.8	39
	6	71.5	58	46	42.3
85%	1	66.7	42.2	59.6	46.5
	2	71	55.5	50.6	47.8
	3	66	53.3	54	48.5
	4	68.1	51.9	43.9	36.4
	5	61.8	51.9	48.6	42.7
	6	62.7	54.6	45.4	41.4
91%	1	68.6	64.7	61	63.5
	2	66	62.2	68.6	52.1
	3	70	52.9	56.2	50.4
	4	65.8	59.3	32.5	33.5
	5	57.6	50.9	49.6	43.4
	6	63.8	51.5	45.7	42.2

6. DISCUSSION ON THE INDEX R3/5

As stated before, through the leakage current analysis and harmonic component measurements of clean insulators in normal working conditions, it was determined that in these conditions for all insulators, the amount of the fifth harmonic is more than the third harmonic of the leakage current. Therefore, this criterion can be selected for detection of normal function conditions of insulators. Thus, whenever these condition changes, the insulator exits from its normal working state and enter the critical position.

Through the presented results of 78 tests carried out at voltage 40kV under various conditions of pollution and humidity, in 34 cases the amount of the third harmonic was larger than the fifth harmonic of the leakage current. In some cases, regarding the large amount of pollution, the flashover occurrence was expected but it did not happen. The response to this question can be found in non-linear property of pollution. Also, in high levels of humidity, due to complete wetness of surface which causes the solution to slow down the sheds and deduction of electrical conductivity on the surfaces, probability of electrical discharge becomes less than the lower humilities and the insulators would be in stable conditions. Among these 34 cases in which the third harmonic was more than the fifth harmonic of the leakage current, 28 cases culminated in electrical discharges and small sparks and finally occurrence of flashover. Generally, in the porcelain and glass insulators (under applied voltage of 40 kV) in which the flashover occurred, their third harmonic was totally higher than their fifth harmonic.

Hence, it can be stated that if flashover occurs, the introduced index will definitely be more than one (R3/5>1). Also, when the value of the index is larger than one, flashover occurs with probability of 82.3% (i.e., 28/34). Therefore, in all conditions that the amount of the third harmonic is more than the fifth, flashover will not occur. Nevertheless, continuing the work condition will be critical in insulators.

An increase in the applied voltage, under the polluted and humid conditions, has a great effect on the change of the normal working conditions. Table 12 shows the effect of voltage increase on the amount of the indicator for the tested insulators, considering constant level of pollution and humidity. The cases, in which the amount of the third harmonic was larger than the fifth harmonic, were extracted and in 15 cases this phenomenon occurred. Among these 15 cases which were mostly in high voltages, in 12 cases flashover was seen. In this test, the probability of flashover for 18 test cases is 80% (i.e., 12/15).

Therefore, in high voltages, the probability of the flashover occurrence increases remarkably. This indicates the effect of voltage growth on the increase in the particle discharges on the surface of the insulators.

Table 12. Indicator $R_{3/5}$ under different voltages, heavy pollution and humidity level of 77%.

Voltage level (kV) / Ins. No	30	42	50
	$R_{3/5}$%		
1	82.8%	113.6	110.2
2	101.6%	105.7	103.7%
3	104.3%	112.4	106.3%
4	92.6%	73.33	118.4%
5	107.3%	108.3	102.5%
6	103.7%	121.07	121.3%

5. CONCLUSIONS

In order to establish a method for on-line monitoring and diagnostics in aged insulators in-situ, based on surface leakage current harmonic components, transmission line insulators were investigated. The experimental results have been presented in this paper. The main findings are as follows:

- LC magnitude is not a good indicator of insulator ageing in porcelain and glass insulators.
- The amplitudes of the insulator leakage currents' odd harmonic components of transmission line porcelain and glass insulators have distinct features in respect to their degree of ageing.
- In clean state, the amount of the fifth harmonic is always more than the third harmonic. In the other word, if the amount of the fifth harmonic is more than the third harmonic of the leakage current, insulator will be in normal working state.
- In polluted insulators, particularly in medium and heavy pollutions with the presence of fog and humidity, the insulator exits from its normal working state. In this situation, the amount of the third harmonic gets more than the fifth harmonic and increase in the third harmonic is faster and higher than the fifth harmonic. Accordingly, the insulator state becomes critical and probability of the flashover occurrence enhances.

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