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論 文
49A - 8 - 4

Analysis of the Leakage Impulse Current in Faulty Insulators for Detection of Incipient Failures

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Abstract - Leakage impulse current of the contaminated insulators by using experiment data were studied. The impulse current in phase-time relationship was analyzed on line post insulators. Also, frequency components and crest factor of the leakage current were investigated to provide a scheme for an early detection of insulator incipient failure. The study shows that the phase-time characteristic is non-stationary and random and, non-harmonic component and crest factor can be promising parameters for detecting insulator leakage currents.

Key Words : Insulator, incipient fault, phase time, elliptic time base, crest factor

1. Introduction

The supply discontinuity and down time of the electric power is the main concern for power utility company and the customers. A variety of conditions can lead to supply interruptions during fair-weather conditions. One common cause of such interruptions for overhead feeders is broken or contaminated poletop line-post insulators[1]. The failure mechanism of the insulators starts from the insulator *contamination*. Contaminants can build up around an insulator and they have relatively high conductivity as compared to the normal surface of the insulator, and provide a path from the high voltage conductor to the insulator's metal pin and thereby allowing leakage current to flow.

Therefore, insulator leakage current measurements were believed to present information on the status of the insulator. Habib et. al. has developed a transformer arrangement for monitoring leakage levels of an insulator chain [2]. A toroidal coil placed on the string of insulators counts the number of bursts whose amplitude exceeds a critical level, and transmits an alarm when a dangerous intensity is reached.

Recently, an attempt for a substation-based monitoring for insulator status identification showed that the idea itself is positive as insulators failure have been observable at substation. However, it also showed that no single parameter has been found for substation-based detection at this time[3]. The objective of this paper, hence, is to characterize the leakage current in distribution insulators under dry and wet conditions and find substation-based detection parameters.

We investigated the behaviors of the leakage impulse currents of the faulty insulators through staged tests and sampled data analysis.

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2. INsulator Failures

1.1 Distribution Faults and Insulation Failures

A distribution fault statistic from Korea Electric Power Company in 1993 shows distribution equipment failures and their causes[4]. According to the report, most of the failures occur in the distribution line and the insulators.

And most of the insulator failures are caused by natural degradation of its integrity. Hence, the characterization study on the insulator failure behavior is essential to allow a utility to schedule and execute remedial action aimed at replacing failing insulators prior to the occurrence of overcurrent faults and service interruptions.

2.2 Insulator Breakdown Mechanism

The basic mechanism of insulator failures is still not very well understood because of the large number of non-linear parameters, however, it is relatively well known that factors such as moisture and contaminant significantly affect the failure process. Insulator failure is normally initiated as leakage current flowing over a wet

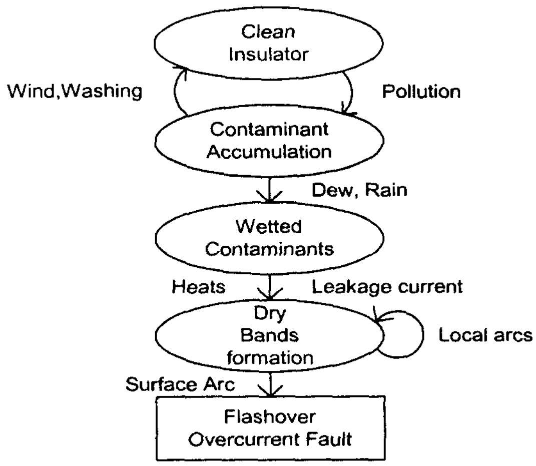

Fig. 1 Insulator failure mechanism

contaminated surface. A general insulator failure mechanism is illustrated in Figure 1.

When water from late-night condensation, dew, or rain, accumulates on the surface of a clean insulator, the water's surface tension tends to make it form individual beads. Between these beads of water will be dry sections of the insulator's surface which functions as a high-impedance gaps between water beads allowing the insulator to maintain its integrity.

Surface contamination limits the ability of the water to form beads, instead forming a more uniform coating of the insulator. This reduces the total dry length, thereby reducing the ability of the insulator to restrict current flow [5]. When the total dry length falls below a critical level, the line voltage is able to break down the insulating property of the insulator's surface and leakage current flows. And the heating from the current causes dry bands over which local arcs may be initiated.

The arcs may grow over the surface and, owing to partial discharges and rapid water evaporation, these arc currents may self-extinguish, continue sporadically, or increase to become destructive high-current flashover. This can lead to an overcurrent fault and a resulting interruption of service.

3. Leakage Current Signal Acquisition

3.1 Insulation Level Test of the Faulty Insulators

To do experiment and get the leakage current of the insulators, first, we collected insulators which were once failed and removed from the pole. And, we tested insulation levels of four sets of suspension insulators (SPs) of the type in which two are jointed together by a ball and socket, and four line-post pin insulators (LPs) using an M4000 Automated Insulation Analyzer[6].

Table 1 Insulation test results of the insulators

	Cur.(mA)	Loss(W)	Meas. (%PF)	Cap.(pF)
Normal SP	0.091	0.025	2.73	-
SP 1	0.303	0.261	8.62	80.0
SP 2	0.368	0.315	8.58	97.2
SP 3	0.074	0.433	-	16.0
SP 4	0.307	0.403	13.14	80.7
Normal LP	0.034	0.009	2.79	-
LP 1	0.238	0.187	7.86	63.0
LP 2	0.239	0.161	6.73	63.1
LP 3	0.304	1.197	39.36	74.1
LP 4	0.252	0.220	8.72	66.5

For the test, we chose 60Hz and 12kV to be applied to the top and the pin of a faulty insulator. The analyzer automatically measures and displays insulation current, loss, percent power factor, and capacitance. The insulation test results are shown in Table 1. By the insulation current, insulators SP3 is the least unsound insulator among the suspension insulators, and LP3 and LP4 are most and second-most unsound among the pin insulators, respectively.

3.2 Data Collection

The experiment for insulation leakage current data collection was done in July, 1997 at the Equipment Inspection and Testing Station of Korea Electric Power. The Station inspects and tests the distribution equipment such as insulators, transformers, and others from manufacturers for random sample test. The voltage used in the testing was stepped-up from 220V using a transformer and we gradually increased the testing voltage from zero to 13kV (which is the phase voltage of the Korean distribution voltage of 22.9kV) and stayed there for several minutes till the end of a test.

Figure 2 illustrates the experiment set-up and the paths by which insulator leakage current signal travels from an insulator on test-bed. We converted the high voltage and current signals to nominal 220-volt and 5-amp levels using CT and PT. The nominal levels of the signal were further reduced using smaller transformers. We recorded these conditioned currents and voltages on VHS video cassettes using a Racal V-Store 16 instrumentation recorder [7] configured with FM signal electronics. The National Instrument's Virtual Instrument software[8] was used to retrieve the stored analog signal to PC, via National Instrument's enhanced I/O interface board AT-MIO-16-E-1, from the tape and convert it to digital data. The sampling rate of the signal was 10kHz.

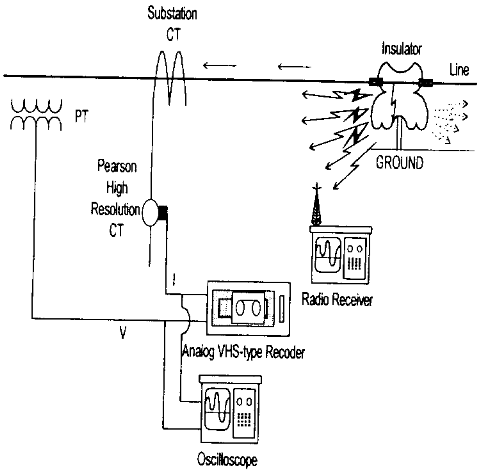

Fig. 2 Leakage impulse data acquisition set-up.

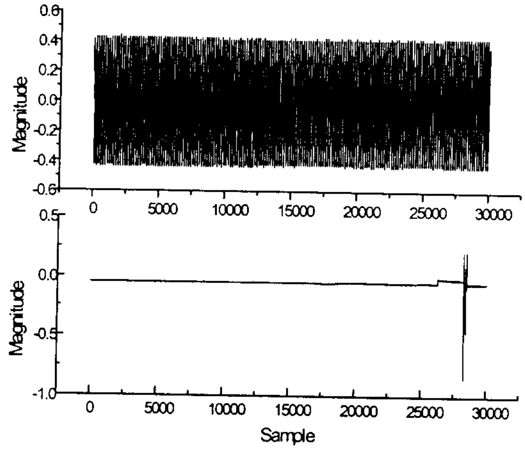

Fig. 3 Voltage and leakage current for LP3 in dry condition

4. Time-Phase Analysis

he leakage impulse currents can be displayed at a time base of the same frequency as the applied test voltage. In order to relate the timing of the impulses to the phase angle of the test voltage, the impulses are often superimposed on to the sine wave of the test voltage. This picture on an elliptical time base is even clearer[10]. The ellipse is situated in such a way that top and bottom coincide with the plus and minus crests of the high-voltage sine wave and the ends coincide with the zero crossings. The leakage impulse patterns as observed on phase-time may give a valuable indication to the status of the insulators.

In this analysis, we studied the insulator LP3 in dry and wet conditions. To make the insulator wet, we sprayed water over the surface. In both conditions, we could observe some strong impulse currents and also seemingly insignificant current pulses.

4.1 Insulator LP3 in Dry Condition

4.1.1 Strong impulse current

The voltage and the leakage current are depicted in Figure 3. The latter part of the data contains the leakage or flashover current. In Figure 4, we magnified the portion of the data having four pulses to see the phase-time information on the leakage current pulse, which is then illustrated on elliptic time base in Figure 5.

The leakage currents of the insulator are initiated near the positive and negative peaks, however, some impulse starts 1- 2 ms before the peaks. And the pulses last only 1/32 cycle or less.

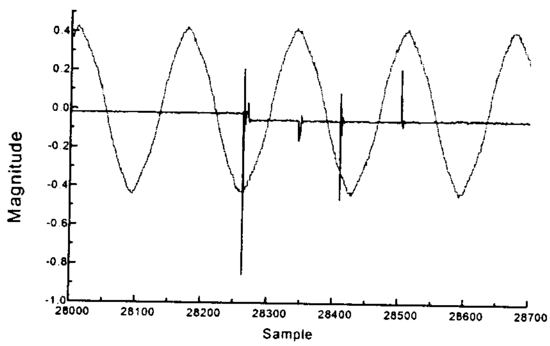

Fig. 4 Voltage and leakage current in detail

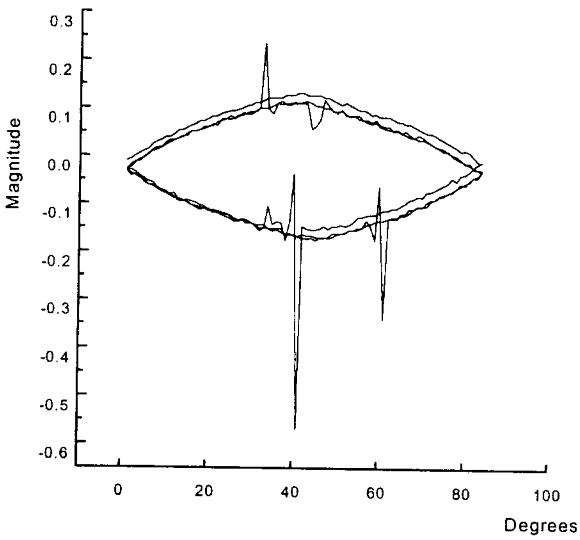

Fig. 5 Leakage impulse on elliptic time base

4.1.2 Weak impulse currents

In Figure 6 we depicted weak leakage current portion for LP3 in dry condition. The impulse magnitude is very low: the impulses are about 100 times smaller than those of strong ones. The phase-time diagram for a few leakage impulses is shown in Figure 7.

The phase-time relation of the weak leakage currents could not be well defined: the impulse is not clearly discernible. However, about 1/8 cycle length of impulses could be seen near the positive peak and 1/16 cycle pulses are seen near the zero crossing.

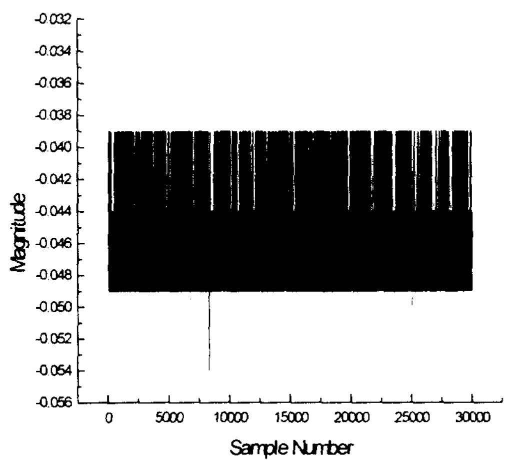

Fig. 6 Weak leakage current

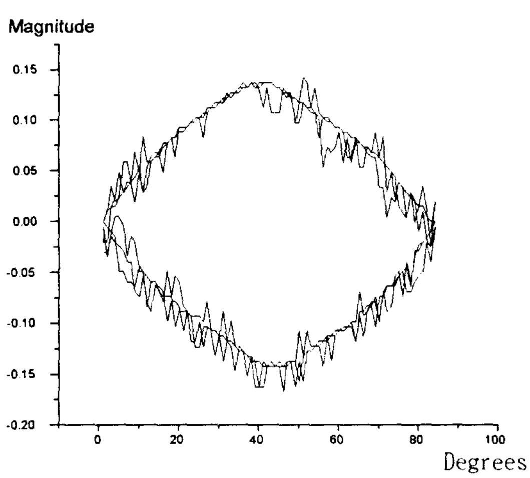

Fig. 7 Weak leakage impulse on elliptic time base

4.2 Insulator LP3 in Wet Condition

4.2.1 Strong impulse current

In the leakage pulse current shown in Figure 8, we could see that all the long duration pulses are dominantly negative impulses. From the phase-time plot of Figure 9, we could see that all the long impulses (1/4 cycle long) and three short pulses (1/32 cycle long) are in the quarter cycle before and or after the peak.

Also, we could see that, when the insulators are wet, the impulse lasts longer than in dry case. Since failure currents are easily initiated by moisture, it is expected that currents last long, and continue sporadically in short pulses, limited by the rapid heating and consequent evaporation of the moisture.

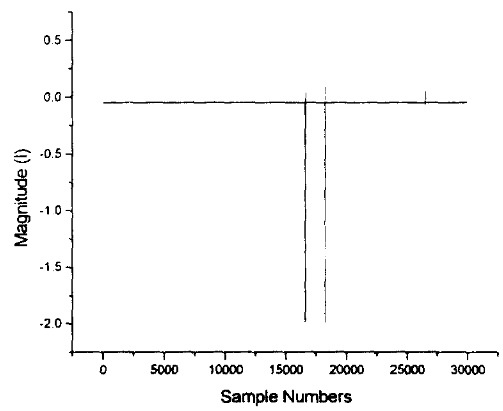

Fig. 8 Strong impulse current in wet condition

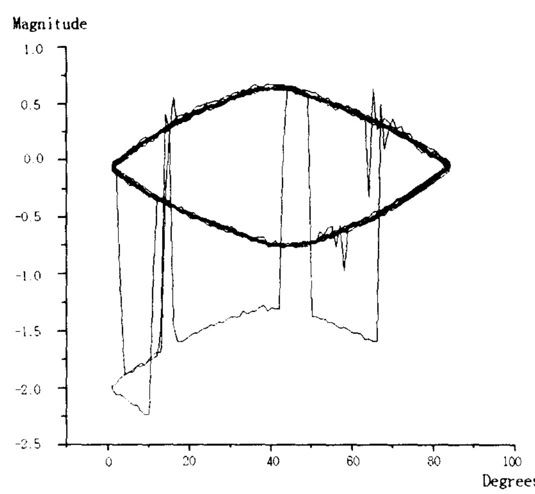

Fig. 9 Phase -time diagram in elliptic time base

4.2.2 Weak impulse current

The phase-time plot of the weak impulse current shown in Figure 10 is depicted in Figure 11. We could see long impulses (1/8 cycle) initiated at quarter cycle point past the positive peak.

4.3 Observations

Even though the data sets are not big enough to draw any conclusion on the phase time information of the leakage impulse, we could find one thing clear in contrary to the known fact that arc develops near the peak voltage, extinguishes, and then re-ignites, the insulator leakage impulses are initiated before and after the peak and even near the zero crossing point of the voltage. While acknowledging the lack of generality, we attempted to tabulate the behavior of phase-time characteristics of the insulator leakage impulses in Table 2.

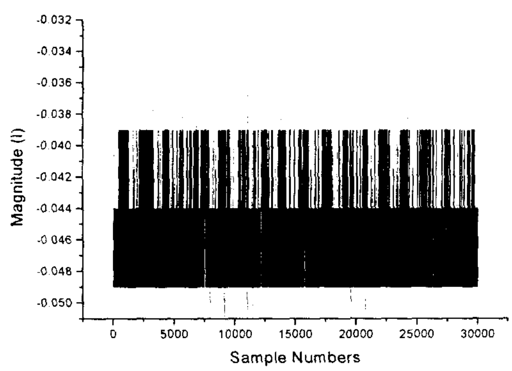

Fig. 10 Voltage - Current Wave form

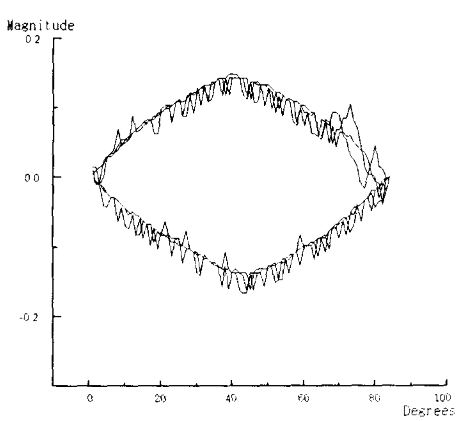

Fig. 11 phase-time relationship diagram in elliptic time scale

Table 2 Characteristics of the phase time of a faulty insulator

Insulator Condition and Impulse Types		Impulse Duration (cycles)	Impulse Initiation at
LP3 in dry condition	Strong Impulse	1/62 -1/32	near +/- peak
	Weak Impulse	1/16-1/8	near + peak and zero
LP3 in wet condition	Strong Impulse	1/8-1/4	quarter cycle point
	Weak Impulse	16/1-1/8	near zero crossing

5. Analysis of the leakage impulse detection

To detect the presence of the leakage impulses we analyzed harmonic contents and crest factors[11] using the experiment data on insulators LP3, LP4, SP3, and SP4. We did this analysis on two time-window basis, one with 2-cycle window, the other, with 60-cycle.

5.1 Leakage Pulse Detection Analysis in 2-cycle window

For every 2 cycles of sampled current data, we calculated harmonic components and crest factor to find detection parameters for incipient failure of insulators. For the harmonic components we investigated mainly non-harmonic non-stationary contents. The current data is 3 second long (or 180 cycles), so there are 90 resultant values.

5.1.1 Insulator LP3 in Dry Condition

Strong leakage impulse : The harmonic components and crest factor behavior is drawn in Figure 12 for the current waveform shown in Figure 3. All the harmonic components and crest factor show big increases at the leakage impulse points, however, in the voltage not shown here, none was significantly different at the impulse and other points.

Weak leakage impulse : Figure 13 shows the harmonic components and crest factor for the current waveform shown in Figure 4 which has weak impulses. We could see the impulse points coincide with, especially, crest factor.

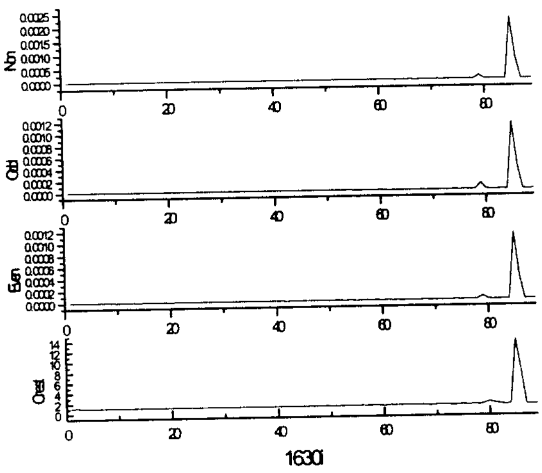

Fig. 12 Parameter variation of the waveform shown in Figure 3

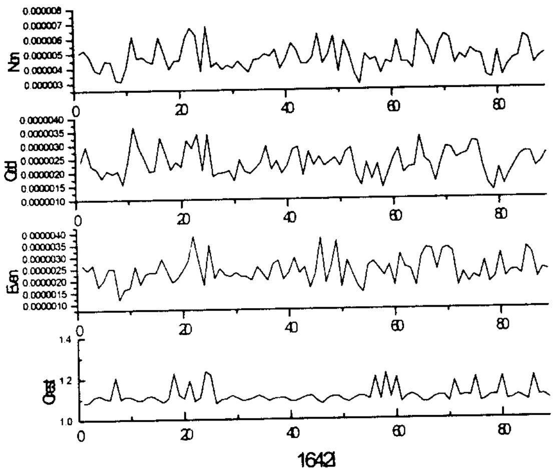

Fig. 13 Parameter variation of the waveform of Figure 4

5.1.2 Insulator LP3 in Wet Condition

Strong leakage impulse : Based on the above observation that non-harmonic and crest factor better coincide with leakage pulse, we indicated only these two parameters in Figure 14 for the current waveform of Figure 5. We see that crest factor closely represents the impulse.

Weak leakage impulse : In Figure 15, we could see that crest factor closely follows the weak impulse current of Figure 6. However, non-harmonic component randomly varies in this case.

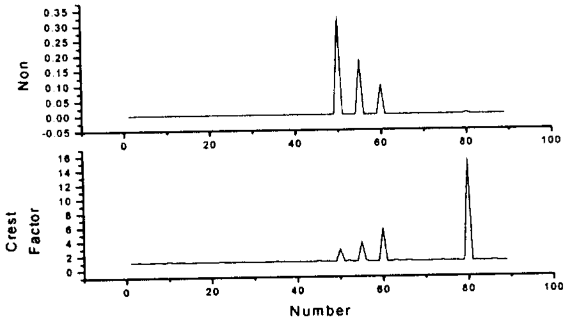

Fig. 14 Parameter variation of the waveform of Figure 5

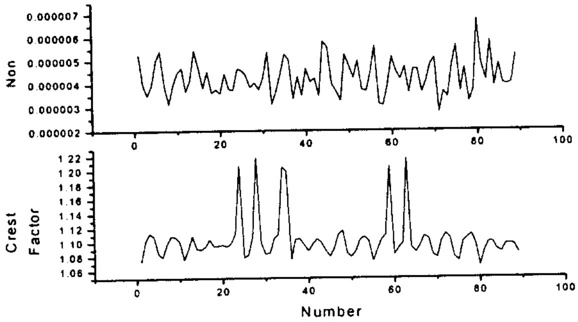

Fig. 15 Parameter variation of the waveform of Figure 6

5.2 Leakage Impulse Detection in 60-cycle window

From 2-cycle window calculation we found that non-harmonic component and crest factor coincide with leakage pulse currents. However, in a realistic situation of warning the imminent insulator failure, failure prediction should undergo a long process and it may not have to be checked by cycle-by-cycle base: rather it is acceptable and more reasonable to check the prediction parameters every second or minute. Hence, we investigated the two parameters in 60-cycle window. The current data we investigated are 5-minute long, therefore, there are 300 resultant values.

5.2.1 Insulator LP3 in Dry Condition

Since short and even long impulses are hidden in the 60-cycle window, we can see only one activity on both parameters in Figure 16. But this change indicates that the insulator undergoes a path to failure.

5.2.2 Insulator LP3 in Wet Condition

In wet condition, as depicted in Figure 17, non-harmonic components show more indications than crest factor which has only one. The wet insulator, as we expected, shows more and recurring leakage impulses.

5.2.3 Insulator LP4 in Dry Condition

Insulator LP4 is healthier than LP3, but contrary to an expectation, shows more activities of leakage impulse current. This is illustrated in Figure 18.

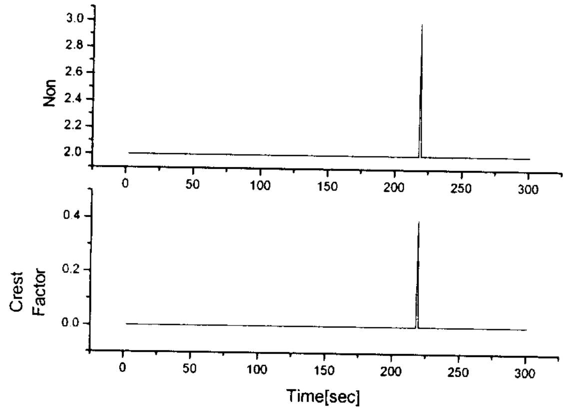

Fig. 16 Parameter variation for LP3 in dry condition

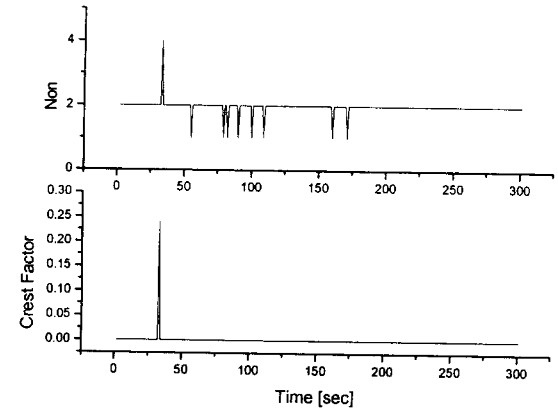

Fig. 17 Parameter variation for LP3 in wet condition

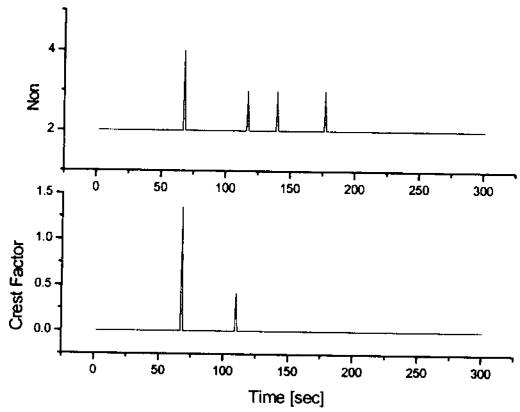

Fig. 18 Parameter variation for LP4 in dry condition

5.2.4 Insulator SP3 in Dry Condition

Suspension insulator SP3 in dry condition does not show any indication in both parameters as shown in Figure 19. Actually the SP3 is the least unhealthy suspension insulator.

5.2.5 Insulator SP3 in Wet Condition

However, in wet condition in Figure 20, SP3 shows very active indication of non-harmonic component while crest factor shows single indication.

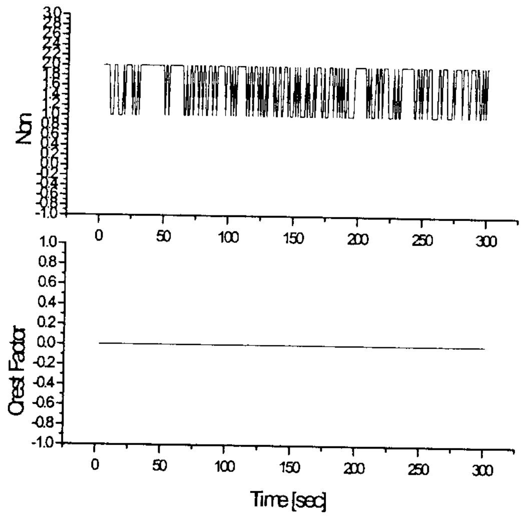

Fig. 19 Parameter variation for SP3 in dry condition

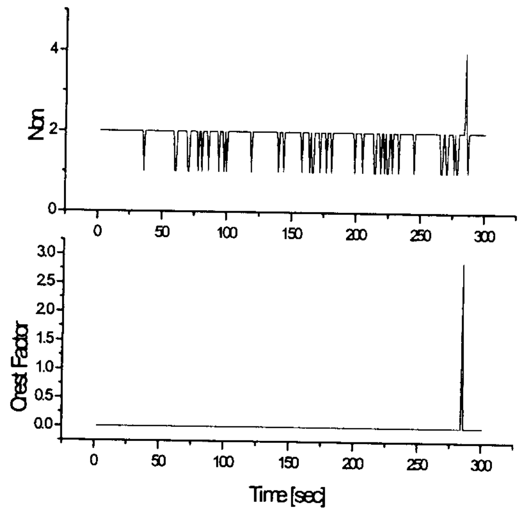

Fig. 20 Variable Variation for SP3 in wet condition

5.2.6 Insulator SP4 in Dry Condition

Insulator SP4 is the most unhealthy suspension insulators and its leakage characteristic is apparently very active and continues sporadically even in dry condition as shown in Figure 21.

5.2.7 Insulator SP4 in Wet Condition

In wet condition, the prediction parameters are very active and it seems the leakage continually re-ignites and continues sporadically, for almost 5 minutes, as shown in Figure 22.

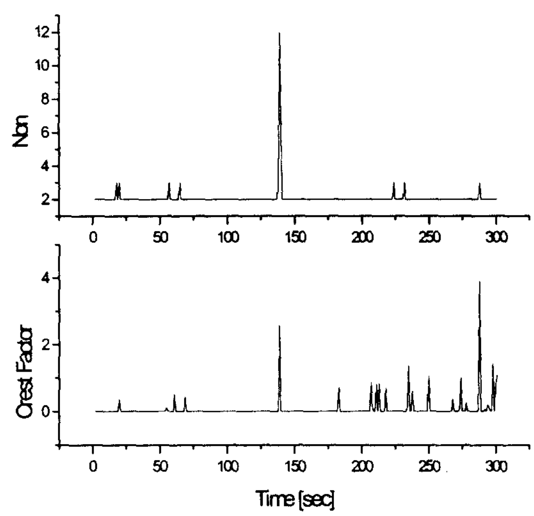

Fig. 21 Parameter variation for SP4 in dry condition

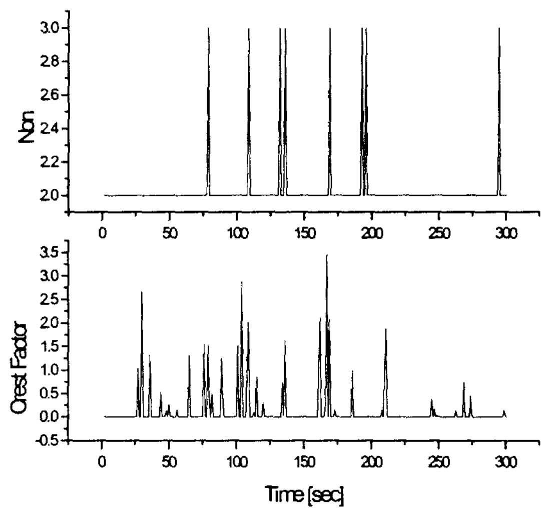

Fig. 22 Parameter variation for SP4 in wet condition

5.3 Observations

The found detection parameters for insulator leakage current, the non-harmonic component and crest factor, were applied to 60-cycle window calculation for four different insulators in dry and wet conditions. From the analysis, it was found that the behavior of the parameters, in terms of the magnitude and occurrence repetition, are getting more active as the surface condition is wet and the insulator itself is more unhealthy. This finding can be applied to predict the severity or harshness condition of the insulators in question.

However, practically, this finding cannot be applied because, on feeder line, there are many insulators in different conditions generating leakage impulses. Moreover, the finding was done in no-load situation, therefore, when load is present, there is no guarantee that the prediction parameters behave as they do with the data from the experiment. Hence, we expect to direct our effort to examine the prediction parameters in real situation in the next phase of the research.

6. Conclusions

Leakage current data obtained in experiment set-up on the insulators in different health conditions was analyzed to see the phase time relation and to find parameters for detection of incipient insulator failure. The phase time relationship of the insulator is not stationary but random. For detection parameters, non-harmonic component and crest factor are found to be promising. The more unhealthy and moisturized an insulator is, the more active the detection parameters are. This finding can be used to detect the failure and determine the severity or unhealthiness of the insulators in question. More research on real situation analysis is needed for a practical application of the findings.

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