INVESTIGATING AND OVERCOMING THE NOISE AND DATA SIZE PROBLEMS IN LONG TERM FIELD LEAKAGE CURRENT MONITORING

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Abstract: Outdoor insulation is strongly influenced by local field conditions. Its performance is influenced by and related to surface activity, which is portrayed in the shape of leakage current. Therefore, field leakage current monitoring is widely employed to monitor and investigate the electrical phenomena experienced and overall insulations' performance. Two are the main issues concerning the efficiency of a field monitoring system: the influence of noise and the accumulated data size. In this paper, a number of 5000 leakage current waveforms recorded on porcelain and RTV SIR coated 150kV post insulators installed at a coastal HV Transmission Substation, are taken into consideration. The impact of field noise is investigated and four hardware applicable techniques are evaluated towards coping with the data size and noise problems. Results presented in this paper can be incorporated in the development of improved field leakage current monitoring systems.

1 INTRODUCTION

The performance of outdoor insulation is strongly correlated to surface electrical activity, experienced in service conditions. The main problem concerning outdoor insulation, which leads to a number of flashovers worldwide, is the pollution phenomenon, which is rather intense in areas located near the sea. Such a site is the Greek Mediterranean island of Crete, where the considered test site is located. Due to the island's coastal development, the main part of the grid, including High Voltage (HV) Substations, is located in a proximity to the sea coast and therefore is subjected to severe marine pollution. At such sites, porcelain insulators have to be washed regularly to avoid flashover, which is an expensive and time-consuming process. Polymer coatings are often employed in order to enhance the performance of porcelain insulators, especially when they can not be replaced with composite ones. A coating that is used extensively in the Greek Network is the Room Temperature Vulcanized Silicone Rubber (RTV SIR). Monitoring the performance of the different types of insulators and coatings employed, is an important task for the Greek Public Power Corporation (P.P.C.).

Leakage current (LC) is a widely implemented tool to monitor the electrical phenomena on the insulators' surface, and thus the insulators' performance. It is a method that can be employed on different types of insulators, and provide simultaneous and continuous measurements both in laboratory and field conditions. The advantage of field measurements is that they provide the actual view of the phenomena experienced during field service, under the specific local service conditions. The required long term monitoring, however, results to the accumulation of vast amounts of data.

The extraction of several values from the LC waveform has been proposed as an indication of the experienced activity. The peak value of leakage current is a parameter that has been widely employed, either as a single criterion [1, 2] or in combination with parameters such as the cumulative charge [3, 4, 5], the number of LC pulses that exceed certain thresholds [3, 4] and the frequency content [6, 7]. Calculated parameters from LC waveforms such as differential values [8, 9], time variation [10], the average LC value combined with measurement of Partial Discharges [11], characteristics of V-I curves [3] and the onset time and the distortion level [5] have been proposed. Level crossing analysis of LC envelope [12, 13], frequency and harmonic content [1, 3, 6, 7, 8, 10, 14-16], wavelets analysis combined either with pattern recognition techniques [17, 18] or neural networks [9, 19-20] have also been considered. However, it is not yet possible to define an extracted value that can be fully representative of the waveform shape, which means that the size of the accumulated data remains an issue. In addition, research has been targeted on waveforms that are portraying actual electrical activity, and the impact of noise is rarely considered. However, the noise problem could be rather significant in the case of field measurements due to the nature of the task.

In this paper, part of the obtained experience in field leakage current waveform monitoring is investigated. Typical waveforms and their correlation to surface activity, are illustrated. Field related noise is investigated and three different types of noise are defined. Hardware applicable techniques are employed and evaluated towards addressing the noise and data size problems. The study objective is to incorporate the results in the development of an improved leakage current monitoring system.

2 EXPERIMENTAL SET-UP

The test site investigated in this paper is the 150kV Transmission Substation of Linoperamata, which is located right next to the sea coast, in Heraklion, Crete. A large project that started in 1996 issued the application of RTV SIR coating on HV insulators. Gradually 100% of the substation's porcelain insulators were coated [21-22]. A total number of 5000 waveforms, recorded on porcelain and RTV SIR coated porcelain insulators, are investigated in this paper. An equal number of waveforms has been selected for each material. The monitored insulators are post insulators that are part of the grid.

In order to measure the leakage current, a collection ring is installed at the bottom side of each insulator and the current is driven through a Hall current sensor. The acquired data are transmitted to a central Data Acquisition System (DAS). Sampling is performed continuously and simultaneously for all insulators, at a rate of 2 kHz and resolution of 12bit. The waveform portraying the highest LC peak value in a user-defined time window is recorded. Each waveform recorded has duration of 480ms. The measuring system is shown in Figure 1.

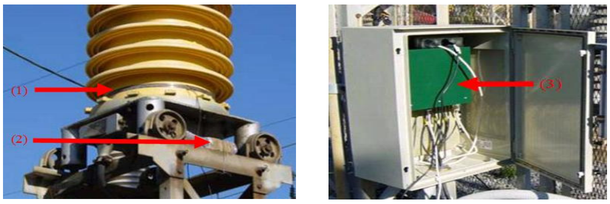

Figure 1: The measuring system: 1.collection ring 2.Hall sensor 3. the DAS

3 TYPICAL LC WAVEFORMS

The basic stages of activity and the corresponding LC waveform shapes are well documented in the literature. The basic discrete stages of activity consist of: sinusoid waveforms due to the presence of a conductive film on the insulator surface [3, 5, 6, 7, 9, 10, 23], distorted sinusoid waveforms as an intermediate stage [3, 6, 7, 10, 11, 15, 16, 23] and dry band arcing that causes a time lag of current onset [1, 3, 5-9, 12-15, 18]. Pulses due to local discharges are often superposed on waveforms at the maximum absolute value of half cycles [5, 7, 8, 14, 15, 23, 24]. A large number of LC waveforms in agreement to the typical shapes suggested in the literature have been recorded in the considered test site. The same basic stages are met on both materials, but it should be noted that surface activity is rarer on RTV SIR coated insulators and appears only during hydrophobicity loss periods [21-22]. Typical activity portraying waveforms are illustrated in Figure 2.

4 PROBLEM DESCRIPTION

Noise is a factor of significant influence in the case of field measurements. The monitored insulators and the measuring system are located in the field, subjected to various environmental stresses as well as to high voltage stress and several electrical events occurring during the operation of a HV substation (switching of heavy loads, opening and closing of switches etc). Further, since monitored insulators are part of the grid, access to the measuring system is limited and sensor or cable faults can not be immediately addressed.

Investigation of the recorded waveforms led to the identification of three different types of noise: typical noise, single point noise and dysfunction generated noise. Typical noise consists of a random amount of minor peaks of random but low amplitude, as shown in Figures 3A and 3B. Single point noise describes the recording of a single point far from the rest of the waveform as shown in Figures 3C-3F. It should be noted that such single points have been recorded superimposed on all types of waveforms: sinusoids (Figures 3D and 3E), dry band arcs (Figure 3F) and even typical noise (Figure 3C). Their time allocation is random, meaning that they do not always follow the current trend (Figures 3D and 3E). Finally, temporary dysfunctions lead to chaotic shaped waveforms (Figure 4).

Typical noise does not offer any useful information and adds significantly to the data size problem. Dysfunction generated noise can lead to erroneous results for any value extracted from the waveform. Single point noise can result to the extraction of erroneous values that are related to LC peak value, the slope of the waveform and the differential value of the current. It is evident that a noise removal/reduction stage is necessary in order to enhance the effectiveness of a field monitoring system. The techniques employed in this stage, should be fast and easily applied on hardware in order to be used on line in the field.

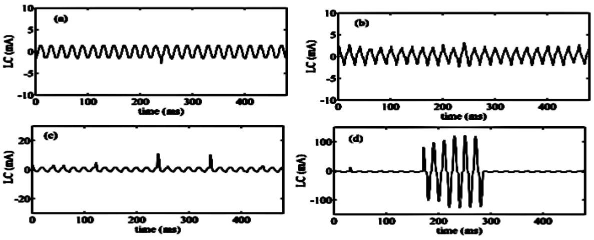

Figure 2: Field Measurements: Typical waveform shapes: a) sinusoid b) distorted sinusoid c) pulses superimposed at the waveform crest d) dry band arcing

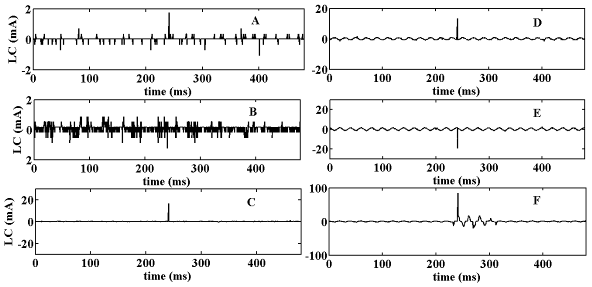

Figure 3: A-B Typical noise, C-F single point noise

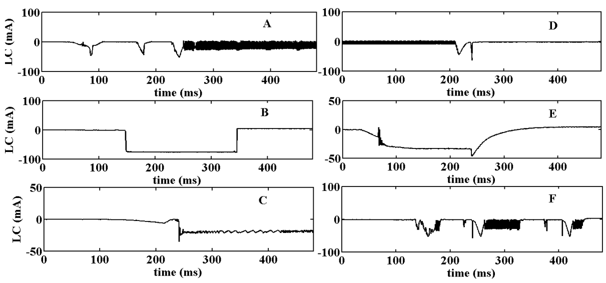

Figure 4: A-F. Dysfunction generated noise

5 EVALUATED TECHNIQUES

5.1 Time-window Technique

The time-window (T.W.) is a technique usually employed in long term field measurements [14, 25] to cope with the data size problem, and is incorporated in the DAS used in this paper. This technique applies a time window of pre-defined length and allows the recording of only one waveform during it. The waveform recorded is the one portraying the highest peak value. It should be noted that although continuous recording is not applied, the considered monitoring period in this case exceeds five years and therefore it can be assumed that the waveforms recorded, regardless the use of the T.W. technique, portray a reliable data set, representative of all types of experienced activity.

5.2 Fundamental Frequency Criterion

In order to identify dysfunction generated waveforms, a fundamental frequency criterion (F.F.C) is applied. The fundamental frequency of each waveform is calculated using the Fourier Transform and if found different that the fundamental voltage frequency (50Hz), the waveform is discarded as dysfunction originated. On the other hand, if the fundamental frequency is 50 Hz, the waveform remains intact.

5.3 Maximum & Minimum Point Smoothing

The Maximum and Minimum Point Smoothing (M.M.P.S.) technique is employed in order to investigate the single point noise problem. The maximum and minimum value of the waveform are detected and replaced by the value of the neighboring point that has the largest absolute value. As a result, single point peaks are removed while the shape of the waveform remains intact. Pulses as the one portrayed in Figure 2C are not removed due to their larger time duration, which correlates to more than one data points.

5.4 The Negligible Threshold Technique

The negligible threshold (N.T.) technique discards any waveform that portrays a peak value lower than a predefined threshold. This technique has been used in an accelerated test in the lab in order to discard noise and a low threshold of 0.05mA proved sufficient [5]. In the case of severe marine pollution, as the one in the considered site, a negligible threshold of 1mA has been proposed [26]. The main disadvantage of this method is that it does not allow the pre-calculation of the available monitoring time in reference to the available memory. In addition, in order to decide the threshold value one must take into account the field noise and the experienced level of surface activity. If the threshold is set too low, then recording of typical noise waveforms is probable and data accumulates rapidly. As the threshold value increases, the data size problem diminishes, but the probability of discarding waveforms that portray significant surface activity increases.

Therefore, various threshold values have to be employed and evaluated. Investigation of the available accuracy and the recorded activity are used to define the limits of the threshold area. Due to the digitization process, sinusoids of very low amplitude (lower than 0.1752 mA) are portrayed as squares, as shown in Figure 4. On the other hand, typical noise consists of spikes that exhibit amplitude in the area of 0.35 mA, as shown in Figure 5. That means that measurements in the area of 0.5 mA are usually incoherent. Therefore, the value of 1 mA has been selected as the lower threshold limit. The smallest recorded discharge portrayed a peak value of 5 mA and is illustrated in Figure 6. Therefore, the value of 2.5 mA is selected as an upper limit for the negligible threshold in order to minimize the possibility of discarding discharge waveforms.

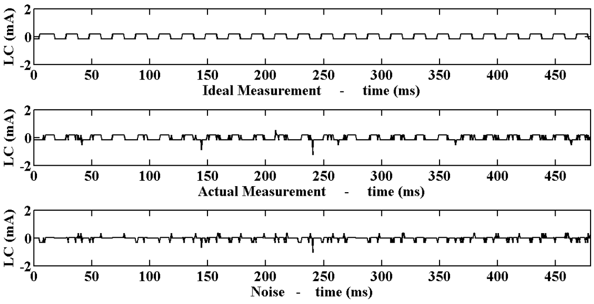

Figure 5: A LC measurement of low amplitude. The ideal (noise-free) measurement, the actual measurement and the extracted noise.

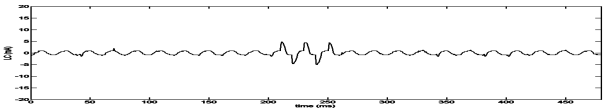

Figure 6: The smallest recorded discharge

6 RESULTS AND DISCUSSION

Investigation of the recorded waveforms showed that the majority portrayed low peak LC values. That was expected due to the nature of the phenomenon (rare short time periods of activity). Several different negligible thresholds in the range of 1mA to 2.5mA were applied and were also combined with the other techniques. Results are shown in Figures 7, 8. The number of waveforms portrayed in these figures is the number of waveforms that are not discarded after the application of each threshold value. It is shown that low threshold values do not offer an effective solution to the data size problem. The 1mA threshold, proposed in the literature for similar test sites, is proved insufficient for the considered test site. The value of 2.5mA offers the best results and therefore it is proposed in this paper as a negligible threshold. Further, it is shown that the efficiency of any negligible threshold value is enhanced with the application of the M.M.P.S. technique. It is found that a number of waveforms exceeded the predefined threshold by just a single point. The enhancement is rather significant in the case of 1mA and 1.5mA and smaller in the case of the 2.5mA, which is another reason that the 2.5mA is proposed as a negligible threshold.

It should be noted that the proposed techniques are supplementary to each other. For example F.F.C. can discard some typical noise waveforms but not all, since typical noise waveforms can exhibit a 50Hz fundamental frequency. An example is shown in Figure 9. The waveform portrayed in Figure 9a is discarded whereas the waveform portrayed in Figure 9b survives the F.F.C. The effect of F.F.C. application on waveforms under the 2.5mA threshold is portrayed in Figure 10. Consideration of Figures 9 and 10 shows that the F.F.C. technique can not identify all typical noise waveforms. Therefore it can not replace the N.T. technique. On the other hand, F.F.C. removes dysfunction generated waveforms of high peak value which survive the application of the N.T. technique, as shown in Figure 11.

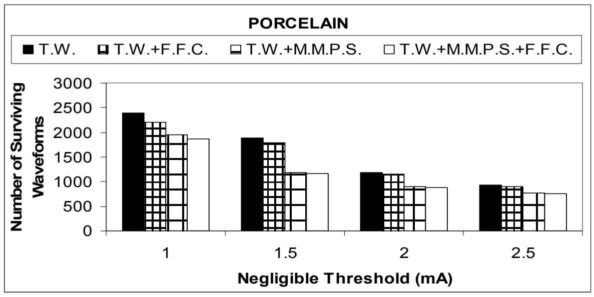

Figure 7: Results for various N.T. values

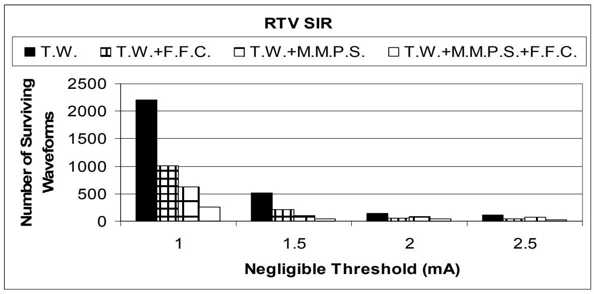

Figure 8: Results for various N.T. values

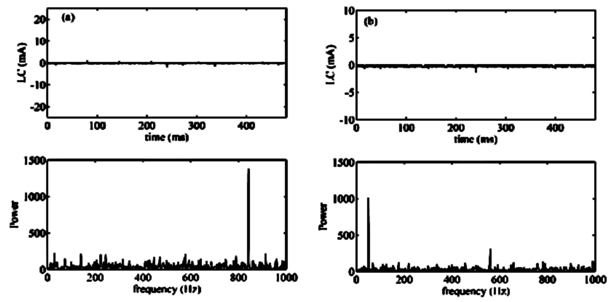

Figure 9: Two typical noise waveforms and their frequency content

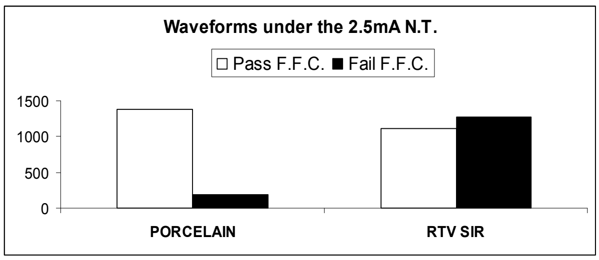

Figure 10: Applying the F.F.C. technique under the 2.5mA N.T.

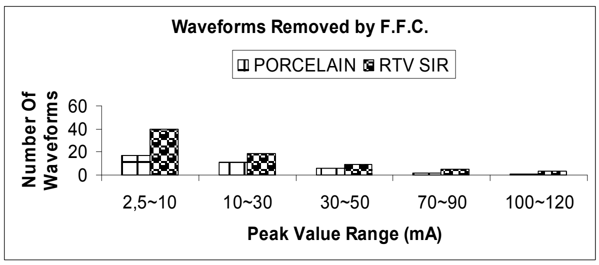

Figure 11: Peak Value Range Distribution of Waveforms Discarded by F.F.C. application

The combined use of F.F.C. and M.M.P.S. is also investigated. In order to evaluate the impact of noise, the number of waveforms that portray peak value in certain ranges is calculated before and after the application of the techniques. Results are shown in Figure 12. It is evident that the number of waveforms in every peak value range decreases after the application of the techniques. It should be noted that the number of activity portraying waveforms is significantly larger in the case of porcelain due to the hydrophilic surface of porcelain that favors surface activity.

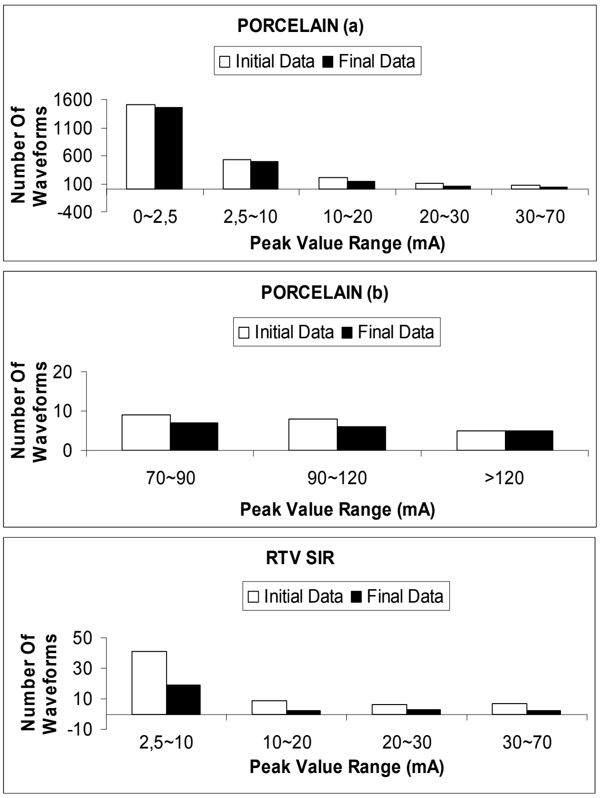

Figure 12: Peak Value Range Distribution of LC Waveforms

The combined application of all techniques offers an effective solution to the data size problem as shown in Figure 13. Considering the nature of the problem, the combined use of all techniques is proposed as an effective solution to the data size problem, which will allow the setting of smaller time-windows or even continuous recording.

It is shown that combined use of the investigated techniques can have significant success in addressing the data size and noise problems and it is proposed that these techniques should be incorporated in advanced field monitoring system either combined with the time-window technique and allowing the setting of significantly smaller time windows, either by replacing the time-window technique and allowing continuous recording of LC waveforms. It should be noted that the proposed techniques are easily implemented on hardware and therefore can be incorporated in advanced LC monitoring systems even at a prerecording stage.

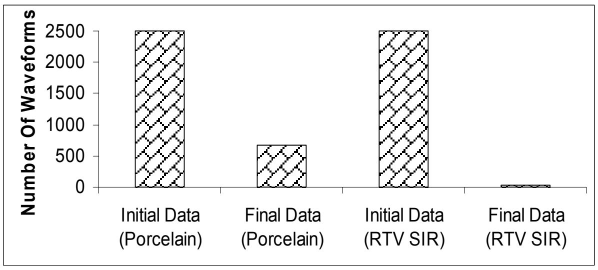

Figure 13: Addressing the data size problem

7 CONCLUSIONS

In this paper, a number of 5000 leakage current waveforms recorded in the field, during a period exceeding 5 years, are investigated in order to obtain an exact image of expected data and problems during long term field monitoring. Two problems emerged concerning the effectiveness of any field leakage current measuring system: the data size and the impact of noise. Four techniques are evaluated in coping with the data size and noise problems. It is shown that that the proposed techniques are supplementary to each other and that the combined use of all techniques is most successful. The results presented in this paper can be incorporated in advanced field LC monitoring systems.

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