PULSE SEQUENCE ANALYSIS - WHAT DOES IT TELL US ABOUT MULTIPLE DISCHARGE SITES?

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Introduction

Partial discharge analyses are widely used to get relevant information on the actual state of high voltage equipment. The standard partial discharge analyses are based on the phase angle distribution of the discharges and do not include the correlation between consecutive discharges thus neglecting physically relevant information. The **Pulse Sequence Analysis** considers especially the correlation between consecutive discharges and thus enables a more sophisticated evaluation.

General remarks

Partial discharges occur when the local electric strength of a region in the insulation system is exceeded either because materials with different electric strengths are stressed and thus partial discharges occur within the material having the lowest electric strength, or because of a critical field enhancement that is limited to a small region of the electrode gap. In the first mentioned case the electron avalanche usually results in a more or less pronounced built-up of **local space charges** reducing the local electric field at the discharge site that ignited the partial discharge. In the latter case, which is usually valid for pure gas discharges, the field beyond a certain length of the discharge path is too low to sustain further growth of the electron avalanche and consequently the ionization processes will stop. The charge carriers will drift rapidly into low field regions resulting in a minor influence of these space charges on subsequent ignition.

Especially when solid dielectrics are involved, however, the built-up of space charges and surface charges at dielectric interfaces causes a superimposed local space charge field at the discharge site. In this case the resulting local field is no longer determined by the externally applied voltage only but also by the space charge field from previous discharge pulses. Consequently, the phase angle of the external voltage where the following discharge occurs is no meaningful parameter, because the phase of occurrence does not imply significant information on the magnitude of the actual local electric field.

Since the local field is the decisive parameter for the ignition of partial discharge pulses, a meaningful data set must be based on parameters that are correlated to the local electric field.

It was demonstrated in [1-4] that the Pulse Sequence Analysis is a powerful tool to investigate space charge dominated discharge processes. The main parameter this analysis is based on, is the **voltage difference between consecutive pulses** because this parameter is proportional to the change of the local electric field at the discharge site. With AC-voltages in polymers the decay of space charges or surface charges is usually negligible during the mean time between two pulses.

Correlated/non-correlated discharge processes

A suitable kind of evaluating partial discharge data is the application of the $\Delta u_n(\Delta u_{n-1})$ pattern, which describes the correlation of consecutive voltage differences between discharge pulses [5]. In [6] it was demonstrated that this pattern can be efficiently used to identify different sources of PD activity, since each data point in the $\Delta u_n(\Delta u_{n-1})$ pattern contains information on the sequence of three consecutive pulses, and these sequences are characteristic of the type of PD source.

Fig. 1 and **2** show these correlations for **electrical treeing** in an initial and in a late stage. It can clearly be

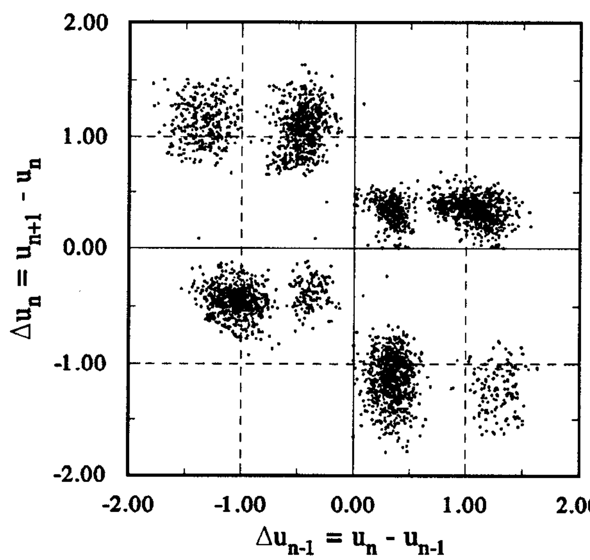

Fig. 1: Correlation of consecutive voltage differences between discharges (early stage of electrical treeing)

seen that a specific voltage change is necessary before the next partial discharge is ignited. When comparing the early and the late stage it is obvious that there is more scatter in the early stage. In the late stage of the electrical treeing there are only six well defined groups of $\Delta u_n(\Delta u_{n-1})$ points. In this stage electrical treeing is an almost deterministic process in which discharges occur only after well defined changes of the local internal electric field. Except during the short period of the actual discharge process a fixed correlation exists between the externally applied voltage and the local electric field.

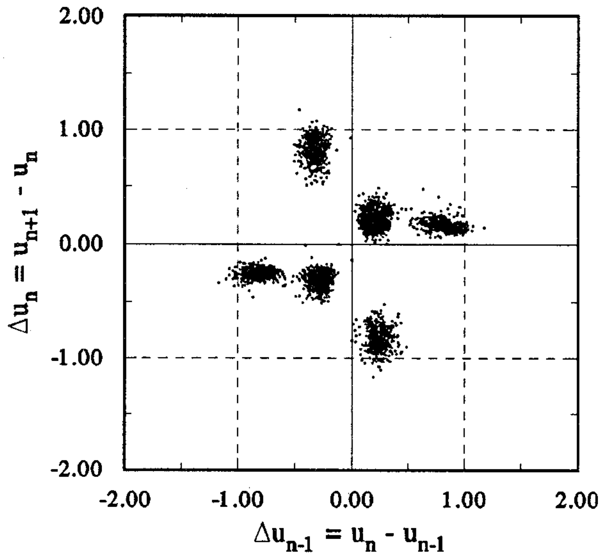

Fig. 2: Correlation of consecutive voltage differences between discharges (late stage of electrical treeing)

In the early stage of the electrical treeing process there are eight groups in which the six groups of the late stage can already be found. The two groups with the higher voltage changes belong to the situation in which only one discharge per half cycle occurs. In the late stage discharges usually occur after smaller voltage changes resulting in more than one discharge per half cycle. In addition to the influence of the actual ageing stage the number of discharges per cycle depends strongly on the magnitude of the applied voltage. Discharge sequences with only two discharges per cycle seem to dissappear with continuing tree growth. In the electrical treeing process usually a pronounced correlation of consecutive discharges can be found. Since voltage differences $\Delta u = 0$ do not occur for electrical treeing, the discharge activity is limited to only one tree channel at a given time and simultaneous discharges within different channels of the tree obviously do not exist.

In **Fig. 3** a typical pattern of a **surface discharge** is shown with a quite different location and shape of groups within the $\Delta u_n(\Delta u_{n-1})$ pattern. In the case of a surface discharge electron avalanches may usually start from different positions on the electrode along the insulator surface. Hence there are various sites and several independent discharges may occur at a given time, i.e. without any correlation, which results in external voltage differences $\Delta u = 0$.

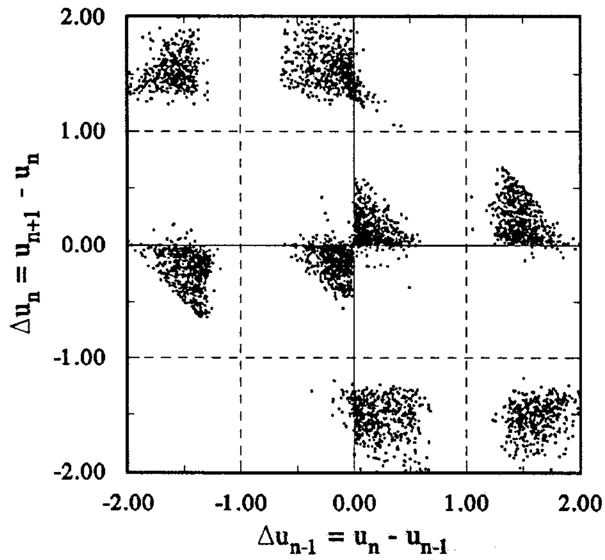

Fig. 3: Correlation of consecutive voltage differences between discharges for a surface discharge

The extreme situation of non-correlated events is shown in **Fig. 4**. This pattern represents that of a **stochastic discharge sequence** which was artificially produced with the random number generator of a computer. Consequently the discharge pulses are equally distributed along the phase angle axis and can therefore be regarded as random noise. In this case every possible Δu value occurs because no correlations between consecutive discharges exist.

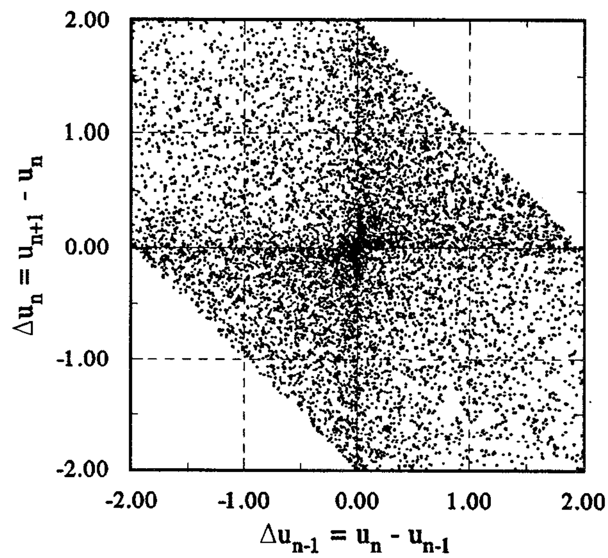

Fig. 4: Correlation of consecutive voltage differences for a stochastic discharge sequence

The examples presented here suggest that the application of the $\Delta u_n(\Delta u_{n-1})$ pattern allows to differentiate between correlated and non-correlated discharges. This information cannot be obtained when merely using the standard phase resolved discharge patterns of accumulated data, since, by definition, in these patterns partial discharges are treated like independed events.

Detection of single/multiple discharge sites

If the area where a discharge process can start is strictly limited to a small region of the discharge gap and solid/gaseous interfaces are present, the ignition conditions of a discharge pulse are determined by remaining space charges from previous pulses and thus a characteristic external voltage change is necessary to reattain the inception field. Consequently, voltage differences $\Delta u = 0$ can not occur, as shown for example in **Fig. 1** or **2** for electrical treeing. The superposition of two data sets from electrical treeing in polyethylene, both causing a pattern similar to **Fig. 2**, is shown in **Fig. 5**. A characteristically different pattern occurs. The high number of $\Delta u_n(\Delta u_{n-1})$ points near the origin of the coordinate system is a consequence of the high rate of about 20 discharge pulses per cycle.

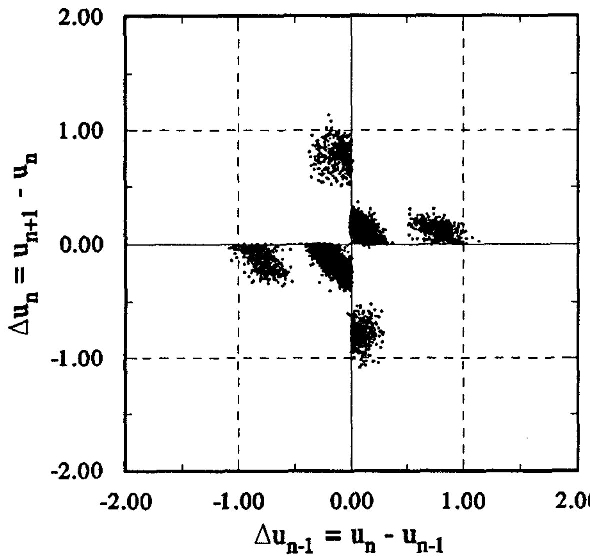

Fig. 5: Correlation of consecutive voltage differences for a superposition of two data sets from electrical treeing

Basic characteristics of the $\Delta u_n(\Delta u_{n-1})$ pattern for a process where multiple discharge sites are involved are shown in **Fig. 6**. The data from which this pattern is derived were gained from a superposition of two measurements performed with electrode bounded cavities.

Fig. 6 demonstrates that in the 'multiple site pattern' **line shaped regions** appear. These line shaped regions, which are either parallel to the axes or appear with an angle of 45°, cannot be found for processes with a pronounced correlation of consecutive discharges. The occurrence of these lines is a consequence of a discharge pulse that occurs randomly distributed either between, before or after two pulses that are correlated due to space charge influences. If there are two discharge sites acting in parallel, each pulse resulting from one of these sites can be viewed as a randomly occurring discharge for the second discharge site. Depending on whether this random pulse occurs before, after or between two correlated pulses from one of the sites, either the voltage difference Δu_n, the voltage difference Δu_{n-1} or the sum of these two differences will be constant.

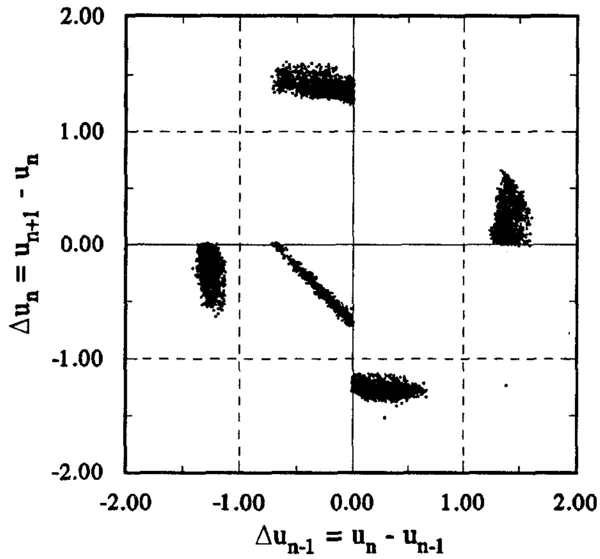

Fig. 6: Correlation of consecutive voltage differences for a superposition of data sets from two electrode bounded cavities

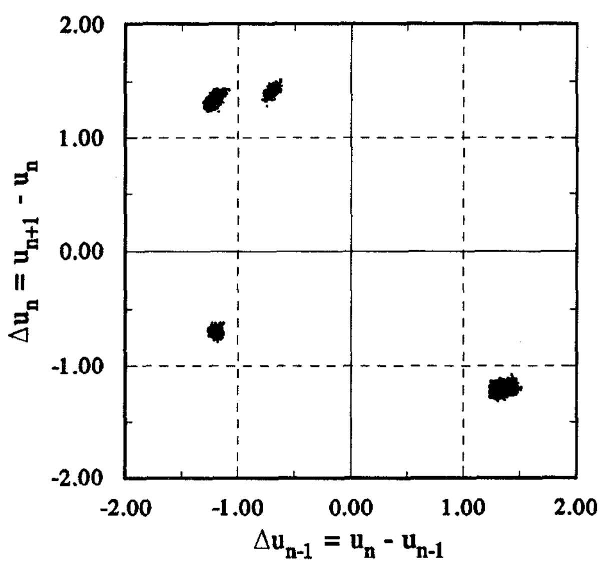

Fig. 7: Correlation of a single electrode bounded cavity

The original pattern of one of the two discharge sites (electrode bounded cavity) is shown in **Fig. 7**. In this case a positive voltage change between discharges is exclusively followed by a corresponding negative voltage change, whereas the negative ones are followed either by a further negative or a positive voltage change. This highly deterministic discharge behaviour was the same for both of the measurements that were used for the superposition.

Under certain conditions the original pattern of the defect types involved in a multiple site process can be reconstructed by means of the $\Delta u_n(\Delta_{n-1})$ pattern. Consequently, not only the information that there are more than two discharge sites acting simultaneously can be unambiguously obtained, but also the information on the specific type of discharge source. The procedure of reconstructing the original patterns, in order to extract the defect types that are involved in the discharge process, is currently under further investigation and will be published in the near future.

Conclusions

The examples show that the Pulse Sequence Analysis is able to differentiate between **correlated and non-correlated discharges** and is thus able to deliver information that is impossible to be gained by the standard phase angle correlated analysis.

With regard to the application of the Pulse Sequence Analysis to practical problems this means that in a high voltage apparatus we can find out whether there are **one or more defects**. With e.g. HV-generators or motors a certain amount of discharges may be acceptable as long as the magnitude is not too high and the discharges occur in those regions of the apparatus in which no critical continuous degradation occurs as a concequence of the discharges. Hence it may be of importance whether there is one big discharge source or many small ones.

The comparison of different correlation plots leads to the following statements:

- The more deterministic a partial discharge process is, the more concentrated are the voltage difference clusters.
- If a second process is superimposed, that is not correlated to the first mentioned deterministic one this leads to the appearance of line shaped regions. The orientation may be parallel to the axis or in an angle of 45°.
- If a high percentage of the data points is non-correlated a more or less area like appearance of the data points occurs.

Hence there are two indications for the existence of non-correlated processes. One is the appearance of very small voltage differences in the region of zero accompanied by an area like distribution. The other is a line shaped orientation which is a result of a deterministic sequence of discharges with a 'stochastic' discharge occurring between two discharges that are correlated.

References

[1] Hoof, M.; Patsch, R.: 'Analyzing Partial Discharge Pulse Sequences - A New Approach to Investigate Degradation Phenomena.' **1994 IEEE Int. Symp. on EI**, Pittsburg, USA, (1994), 327-31

[2] Patsch, R.; Hoof, M.: 'The Influence of Space Charge and Gas Pressure During Tree Initiation and Growth.' **ICPADM-94**, Brisbane, Australia, (1994)

[3] Hoof, M., Patsch, R.: 'Pulse-Sequence-Analysis: A New Method to Investigate the Physics of PD-Induced Ageing.' **IEE Proc.-Sci. Meas. Technol.**, Vol. 142, No. 1, (1995), 95-101

[4] Patsch, R.; Hoof, M.: 'Electrical Treeing - Physical Details found by the Pulse-Sequence-Analysis.' **ICSD'95**, Leicester, UK, (1995)

[5] Hoof, M.; Patsch, R.: 'Characteristics of Partial Discharge Pulse Sequences during Electrical Treeing in Polyethylene.' **ISH'95**, Graz, Austria, paper 5606

[6] Hoof, M.; Patsch, R.: 'Voltage-Difference Analysis, a Tool for Partial Discharge Source Identification.' **1996 IEEE Int. Symp. on EI**, Montreal, Canada, (1996)

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