A Novel Database Format for Partial Discharge Monitoring and Evaluation, Based on the Information of Single PD Pulses

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Abstract: Numerous wide-band partial discharge detection and measurements have shown excellent results in order to diagnose and to evaluate high voltage apparatus. The shape of single PD pulses can be gathered with this method of measurement in time domain, if the signal is sampled and digitized with sufficient sampling frequency and resolution. There is a lot of information in these single PD pulses which can be used for evaluation diagnosis and monitoring of high voltage devices. As new monitoring systems based on wide-band partial discharge measurements are under development by many researchers and specialists a common format for data processing particularly for database systems is necessary. In this contribution a novel format for a database system for PD monitoring and evaluation systems is suggested. It is shown, that saving special features of single PD pulses not only causes a reduction of the huge amount of data to a limited value but also, that the real useful information of PD pulses can be reconstructed easily. A PD monitoring system operating based on this database format is introduced, as well as the advantages of this format for data reduction.

INTRODUCTION

Nowadays different PD measuring systems are available in the market. Most of the newly developed systems are equipped with computer and analysis software to process PD data. Conventional PD measuring systems work based on narrow band filtering so they measure two most important features of PD pulses that are the apparent charge at the terminals of the coils and the phase of occurrence. Because the route between PD origin and sensor system consists of various circuit elements such as resistors, inductors and capacitors, the shape of detected PD signal is different even for the same PD when originated from different locations. The measured shape of PD signals contains not only the information of PD charge and the medium but also the information of the route of the origin up to the decoupling point. Our pervious works with the goal of developing an on-line PD measurement system [1] revealed that various information found in the time signal of each PD pulse could be used to evaluate and localise the PD activities in a high voltage apparatus. Many information about PD pulses is generally used by the experts to evaluate PD activities in a high voltage device. This information summarised by the well-known PD patterns or PD fingerprints which was mainly the phase of occurrence according to power frequency cycle and the pulse amplitude or apparent charge. Each manufacturer suggests own format for the PD patterns and there isn’t a common structure or a standard for the evaluation of various PD features. In this contribution a format for PD features particularly for wide-band PD measuring systems is suggested, which is independent of the detector and tried to include all the information needed for high or low level analysis of PD patterns. This format could be considered to be used in modern PD monitoring systems.

PD MONITORING BASED ON SINGLE PD PULSES

By means of new digital systems sampling and recording of time signals with a high frequency rate is a simple task. The PD pulses originally have a very short time width so they have a wide frequency spectrum therefore to extract more information from the recorded PD signals, the sampling rate has to be high enough to achieve all the information included in the recorded samples. Conventional digital PD detectors digitise the input signal and search the data stream for pulses. If a pulse is detected the apparent charge and the phase of occurrence to the power frequency cycle are stored. The two saved features are used for various statistical analysis and graphs to evaluate PD. For each PD pulse there are only two features available although there is still a lot of information such as pulse duration and frequency characteristics that are eliminated. Our experiences in PD detection and evaluation based on wide-band measurement and high frequency sampling particularly for on-line and on-site application have shown that it is possible to save one record for each single PD pulse, which includes all useful information of PD while a small memory length is used. The features which extracted from a recorded single PD pulse are stored in memory after eliminating a huge amount of meaningless samples. In the evaluation phase the stored features can be used to reconstruct the time and frequency
characteristics of the original PD pulses. It is evident that for most high voltage devices multi channel PD detection is more suitable for evaluation and condition monitoring so the above mentioned PD recording system is also advantageous to summarise the PD features for different channels. Fig. 1 shows the whole data stream as well as a synchronous single PD pulse recorded by a four channel wide-band PD detector as an example.

SUGGESTED FIELDS FOR DATA BASE OF SINGLE PD PULSES

To confine the amount of data which have to be stored in the data base the selected PD features must be as raw as possible. That means the fundamental information have to be recorded and stored while the software which is developed as the viewer has to generate the graphs and statistical results that need a high volume of memory from the raw data at the time such information and reports are needed. All results of data processing are not necessary to be saved but they have to be generated from the summarised data which are stored in the data base. As mentioned earlier all the information of PD activity in a high voltage apparatus is included in the single PD pulses and its phase to the applied voltage. If the features of these pulses are extracted and stored they could be used for monitoring and evaluation as well as discrimination between noise and real PD. Fig.1 presents PD signals which are recorded synchronously for four channels, three for the phases and one for the neutral. Each data stream includes various single pulses. A capacity of about two MB per channel is needed to store the time signals for only one cycle of power frequency. At the first step only the samples for the single pulses are found and selected in data streams while all other data samples considering a pre-defined threshold are eliminated and therefore the volume of the data decrease considerably. If the samples related to the single pulses are considered for archiving, a big volume of storage is still needed while only the significant features of single PD pulses are required for PD evaluation. These features are described as follow:

1) **Triggering time**

   It is not possible to scan signals with a sampling rate of over 20 MS/S while all of samples recorded on a hard drive continuously. The sampling has to be executed for a predefined period of time. After flushing the gathered data to the hard drive another sampling procedure can be executed. It is necessary to save the start of each sampling period for reference.

2) **Charge level**

   The transferred charge (apparent charge) is the most important feature for each single pulse but a calibration procedure and also determination of a frequency width for filtering is required to calculate the charge level assigned to each single PD pulse.

3) **Phase of occurrence**

   In most conventional PD detectors the phase of pulse occurrence with reference to the power frequency cycle is an important feature. This parameter also has to be saved for each measured PD pulse.

4) **Time index** $K_T$

   A time index which is related to the shape of each pulse is a useful feature for clustering PD and recognition of noises [2]. This index for a sampled time signal $s(t)$ is calculated as follows:

   \[
   \tilde{s}(t) = \frac{s(t)}{\sqrt{\int_0^T s(t)^2 dt}} \tag{1}
   \]

   if $t_0$ is defined as:

   \[
   t_0 = \int_0^T \tilde{s}(t) dt \tag{2}
   \]

   then:

   \[
   K_T = \frac{\sqrt{\int_0^T (t-t_0)^2 \tilde{s}(t)^2 dt}}{\sqrt{\int_0^T s(t)^2 dt}} \tag{3}
   \]

5) **Frequency index** $K_F$

   Like the time index the frequency index also can be used together with the time index as a feature which presents the shape characteristic of PD.
\[ K_F = \sqrt{\int_0^\infty f^2 |S(f)|^2 df} \] (4)

6) **Pulse duration**
The pulse recogniser usually uses a threshold to find if a pulse is started in a sampled data stream. The triggered pulse is settled during a few micro seconds. The settling time can be detected using data processing techniques. The duration of each single pulse is therefore an important index to recognise the PD from the noise as well as to recognise the origin of the pulse.

7) **Pulse location**
For multi channel PD detection using some modelling and advance techniques [3] the location of PD pulse could be determined. An index of 0 to 100% may be considered to denote the probable origin of PD pulse along the winding.

8) **Instantaneous high Voltage**
The energy of PD pulse can be computed using the charge and the instantaneous voltage at the high voltage electrode. This voltage may be stored as a feature for a single PD pulse.

9) **Polarity**
The polarity of each single PD pulse also is an important index for evaluation so it is stored as -1 and +1 for each PD pulse.

10) **Pulse position in data stream**
Because the position of each pulse in the whole sampled data stream is needed for PD processing the start position of each PD pulse in the data stream is stored as an index.

THE SOFTWARE FOR PD ANALYSIS

Based on a four channel PD monitoring system for power transformers developed by the authors a software system with the mentioned structure for the database was implemented. The input signals are sampled with a high frequency four channel digitizer simultaneously in a predefined period (e.g. 40 milliseconds that is 2 cycle of power frequency is sampled with the rate of 25 mega sample per second in a 10 minute intervals). With the help of modern filtering techniques the noise suppression is carried out and then all the four data streams are searched for occurrence of pulses using data processing methods and if a pulse found the ten features which mentioned earlier are extracted and stored in the respective table in the database and the search process is continued for the remaining data. The main view of this software which presents the last PD level for each channel is represented in Fig. 2. As various features for each single PD pulse is available while a small volume of memory or hard capacity is required numerous statistical and analytical methods can be applied to diagnose the device under monitoring and also to recognise between the noise, interferences and the real PD signal.

![Fig. 2. The main view of the on-line PD monitoring system works based on the novel data-base structure](image)

**EXPERIMENTS**

For presenting the advantages of the suggested database the information which has been collected from a 20/400kV, 550 MVA power transformer by an on-line PD measuring system while was energised for about 5 hours for PD monitoring is illustrated in this section.

![Fig. 3. The 3-D phi-q-N pattern for phase U and V of a 550 MVA, 20/400kV power transformer](image)

Many 3-D and 2-D graphs and patterns can be used to evaluate data using this database. The difference between the conventional PD statistical analysis and the possibilities of this system is that there are ten significant features for each detected pulse and many other features may be calculated using this features or a combination so
numerous patterns can be achieved to help diagnosing the system while for the conventional systems only two or three independent feature are available. Fig. 3 presents the so called 3-D phi-q-N pattern for two channel U and V phase of the measured transformer. The raw data stream as well as a detected single PD pulse of these measurements was shown in Fig. 1 earlier. The 3-D graphs of Fig. 3 may be generated for other combination of features e.g. $K_T$-q-N or $K_F$-q-N (for $K_T$ and $K_F$ see equations 3 and 4). These kinds of patterns which reflect the shape of PD in patterns are not available in conventional PD detectors.

CONCLUSION

Each manufacturer suggests own format for the PD patterns and there isn’t a common structure for PD features. A novel format for PD features particularly for wide-band PD measuring systems is suggested, which is independent of the detector and tried to include all the information needed for high or low level analysis of PD patterns. Many features for each single PD pulse is available in suggested data structure while a small volume of memory or hard capacity is required so numerous statistical and analytical methods can be applied to diagnose and monitor the high voltage devices.

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