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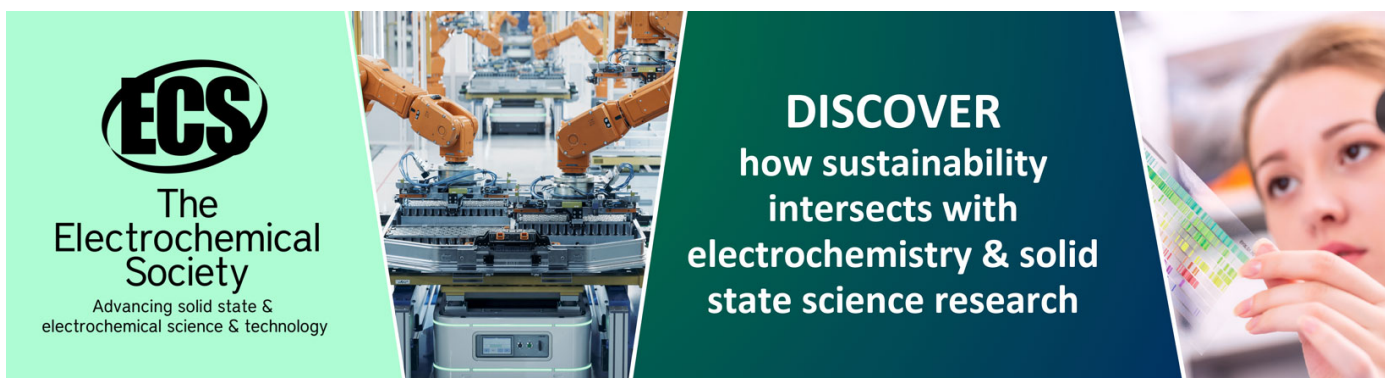
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Design and Implementation of a Multi-sensor PD Online Monitoring System in GIS

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Abstract. This paper makes a detailed introduction of the software system which is used to detect the partial discharge in GIS online and describe its superiority with open and robust features in distributed network acquisition as well as its great real-time performance. The introduction can be divided into two parts: design and implementation. Based on multi-sensors adopted and the distributed framework, the signal collection and control, feature extraction, feature storage, analysis and evaluation of the diagnostic function of PD can be realized in the system. The stability and reliability of the system has been verified by the field operation experience, which can satisfy the need of GIS online monitoring.

1. Introduction

GIS is one of the most popular power equipment in the power system, which has been extensively applied in the grid because of its great advantages [1-4] showing as below:

(1) GIS has a small occupation area, small volume, light weight, and all components are sealed without environmental interference.

(2) The operating mechanism is oil-free and gasification-free, with high operating reliability.

(3) GIS is transported by the whole block, which is convenient for installation, with short cycle and low installation cost. Short maintenance time. All three - phase mechanical linkage is adopted in the box GIS, with low mechanical failure rate.

(4) Superior breaking performance -- the circuit breaker adopts the self-energy arc extinguishing chamber (the hybrid structure of self-energy thermal expansion and auxiliary compressor) based on the new arc extinguishing principle, making full use of the energy of the arc itself.

(5) Low loss and noise -- the inductive magnetic field on the GIS enclosure is very small, so the eddy current loss is very small, reducing the loss of electrical energy. The adoption of spring mechanism makes the operating noise very low.

By monitoring PD signals in it online, insulation defects can be detected and stable operation can be guaranteed. Based on the UHF and ultrasonic detection methods, an on-line software system used to monitor PD in GIS is designed in this paper, which can analyze PD signal as soon as the system accepts signals. In this paper, the detailed introduction of the software system which is used to detect



the partial discharge in GIS online and describe its superiority with open and robust features in distributed network acquisition as well as its great real-time performance has been made. The introduction can be divided into two parts: design and implementation. Based on multi-sensors adopted and the distributed framework, the signal collection and control, feature extraction, feature storage, analysis and evaluation of the diagnostic function of PD can be realized in the system. The stability and reliability of the system has been verified by the field operation experience, which can satisfy the need of GIS online monitoring.

2. Structure of the software system

The structure of the online software system used to monitor PD signals is shown in figure 1, which consists of four sections: data transmission, data collection, data transmission and the processing and analysis of data.

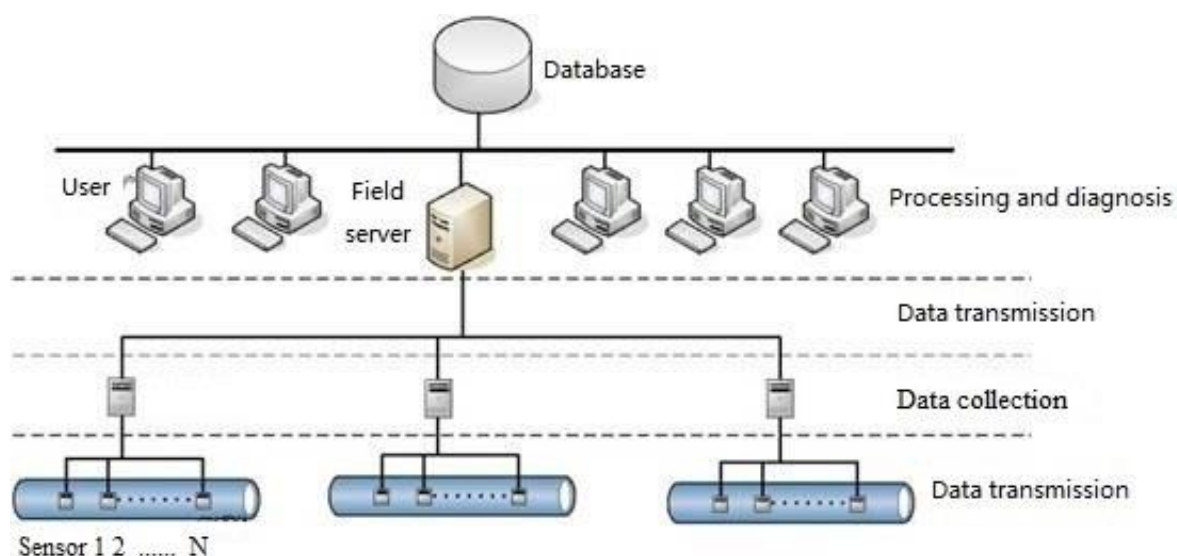


Figure 1. Structure of the system

UHF sensors and ultrasonic sensors are used to detect PD signal, which is the key of data transmission. In the data collection section, high-speed DSP is used as front-end equipment to collect data. After that, the envelope detection of the collected signals can be used to obtain the data from envelope and phase of UHF signals as well as ultrasonic signals with low sampling frequency [5]. According to the Ethernet protocol, the data transmission section is built on the basis of the structure of distributed system. Repeaters in the section are used to achieve the aim of long-distance transmission (the largest of which is 500 meters) in order to satisfy the demand of the substation [6]. At the same time, the processing and diagnosis section is achieved by the software system. In this section, the front-end is controlled by the software to collect and store data. And then, the data will be analysed and made comparison of UHF signals and ultrasonic signals. The analysis results are contributed to identify the insulation defects and make severity evaluation. In addition, a server is used to connect multiple DSP front-ends to build the distributed framework.

With the whole design ideas, it can be realized that an enormous number of GIS in a substation can be monitored at the same time by the system.

3. Design and implementation of the software system

The software system is designed on the basis of the principles of instantaneity, effectivity, expandability and modularization. The system is modularized into five parts: signal collection, signal preprocessing, feature extraction, signal analysis and user interface. Client/Server connection mode is

applied to the system. Several test devices are used as collection front-end to make all the computers connected through the Ethernet/fiber network. With the overall design, the performance of the system to resist interference can be improved and remote monitoring is supported.

To ensure the openness and robustness of the distributed network acquisition, Ethernet is used to make all the front ends connected to the server in this system. In order to add a new monitoring front end, the workers only need to add a monitoring element to the network. The software is able to identify new devices automatically and add them to the list of test devices. Each front end is independent to another, which ensures the stability of the system. When one of the front ends fails and has to exit the network, the rest can still work normally. The software is also able to automatically identify the exit device and remove it from the list.

The implementation of the software system is on the basis of NET Framework. 2003 Windows Server is applied as the operating system. SQL Server 2005 is used as the storage platform. Use Visual C# as the language to program.

3.1. Signal collection module

The signals are collected by UHF and ultrasonic sensors which are the DSP front ends, and then these signals will be sent to the server through Ethernet. The signal collection module is set to control data transmitting between the server and DSP processors to complete the following steps: firstly, the server provides DSP front ends for UDP sampling broadcast packets on the basis of sampling interval to make sensors synchronously detect PD signals. Secondly, the server sends data requests to DSP to collect signals from sensors through TCP protocol. The collected UHF and ultrasonic signals DSP sends to the server are shown in figure 2. This module implements several tasks such as data acquisition and transmission and other functions at the same time.

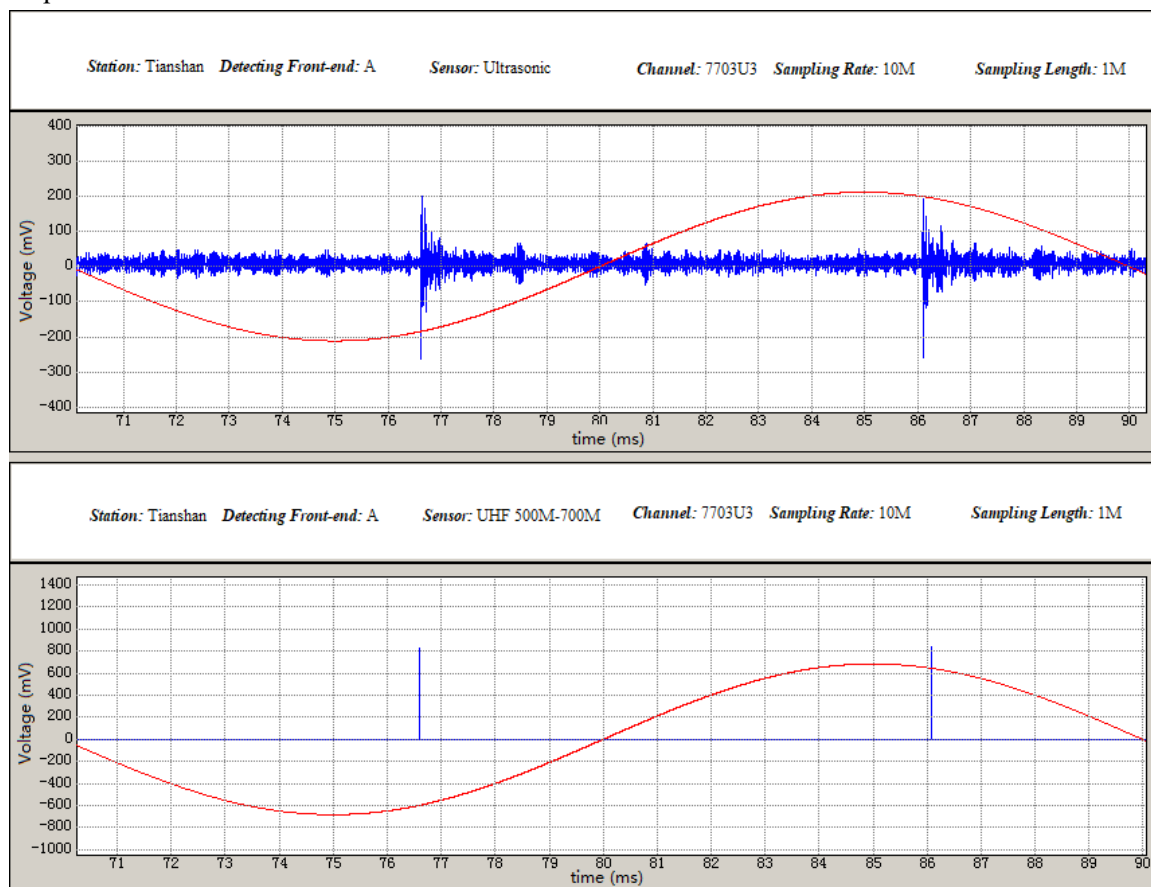


Figure 2. System interface of UHF and ultrasonic signals collection

3.2. Signal preprocessing module

Before analysing the data transmitted to the server from DSP front ends, they have to be preprocessed, which means that the software needs to read data and extract effective discharge pulses to reduce noise interference.

Since the field where PD signals are collected is not noiseless at all, it is unavoidable that collected signals are contaminated with noise. The most popular method to remove noise interference is to filter the signals based on Fourier transform and extract pulse based on the principles of wavelet transform and two scale wavelet transformation, which is applied in the software designed.

The algorithm should extract the waveform of each pulse completely and contain all the time-domain characteristics of pulse waveform without distortion. It needs to separate the signals at first. In the system, the separation of PD pulse signals is on the basis of the width of the interval between pulses. To determine the interval, some principles have to be followed:

- 1) The peak of the pulse must be higher than the threshold that has been set.
- 2) The width of invalid data whose pulse are lower than the threshold must be larger than the interval width that has been set.
- 3) The width of continuous invalid data in each pulse should be less than the interval width that has been set by users.

3.3. Feature extraction module

Three-dimension map ϕ -q-n is drawn for PD signals in order to extract pulses. To be clear, ϕ represents the discharge phase. q represents the quantity of partial discharge. And n is the number of times that partial discharge occurs per second [7]. ϕ (0° to 360°) and q are divided into several intervals respectively. Record the number of times the discharge occurs at specific phases and intervals so that the ϕ -q-n map of PD signals can be generated. And then statistical parameters can be extracted from the map, which includes the maximum and average discharge quantity and discharge times, the maximum and average voltage amplitude and energy of each discharge.

Characteristic parameters of PD maps include statistical parameters extracted from both two-dimension maps and three-dimension maps including the pulse number, maximum discharge capacity, and skewness, projection, and standard local peak number, asymmetry degree of the discharge in positive and negative half perimeter, correlation coefficient and other so on [8-9], which are used for PD signal diagnosis.

The extracted features can interact between ADO.NET in .NET Framework and SQL Server database, which makes it simple and convenient to store and retrieve data.

3.4. Signal analyzing module

After the system designed analysing collected UHF and ultrasonic signals and extracting features from them, it will display the map of the signals which contains discharge signal, as well as the type of discharge and diagnostic confidence. Both UHF and ultrasonic sensors are set at each point so that the system can also compare the signals from different sources and make an accurate judgement. By this move, the system can improve the accuracy to locate the source of partial discharge. At the same time the system will search characteristics data and analyses the data trend from each sensor based on history data in the database. Then the data from different sensors will be compared in the same equipment to make the results more accurate.

3.5. Interface module

The connection diagram of the sensor-based installation is displayed on the main interface of the software system, as shown in figure 3. Both UHF sensors and ultrasonic sensors used to detect GIS are installed on the flange of each GIS.

From figure 3 it can be found that there are three colors of lights. Yellow light represents phase A. Green light means phase B. The last one, red light means phase C. When a sensor detects PD signals in the GIS, the corresponding GIS node on the schematic will flash and alert to the workers. At this

point, the power company staff can click the GIS node on the interface to view the detection results of any sensor of the GIS, which includes the figures of PD parameter trends, maps of historical data so that workers can analyze the recent trends.

The three-dimension map and two-dimension map of PD signals displayed on the interface are shown as figure 4 and figure 5. The system will be able to continuously display three-dimension maps and two-dimension maps of historical PD data in order to allow the users directly understand the features of typical PD. The system is also able to allow users import typical PD data to improve the performance of the diagnosis of PD.

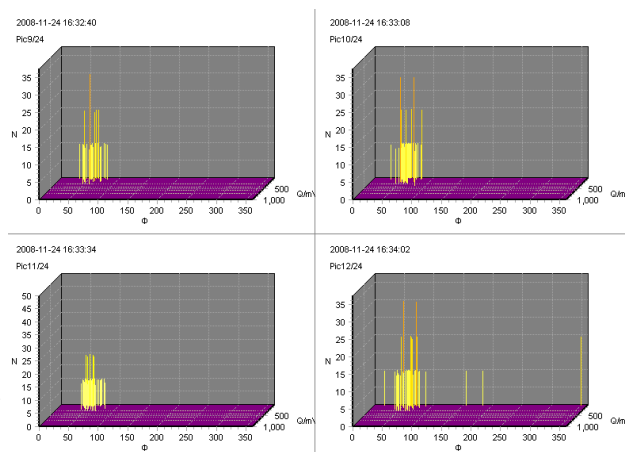
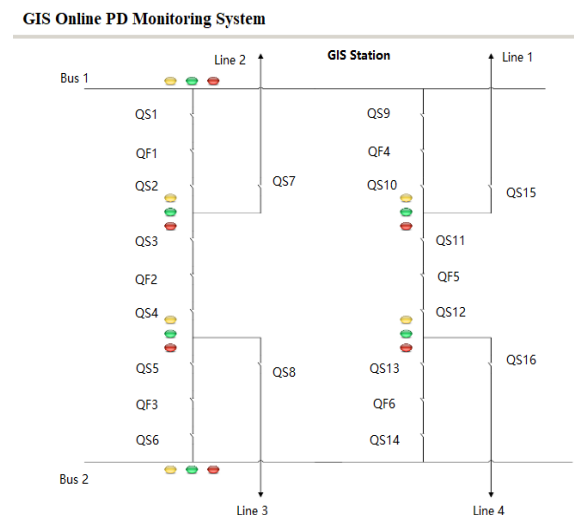


Figure 3. Main interface of the software system **Figure 4.** Interface of three-dimension map display

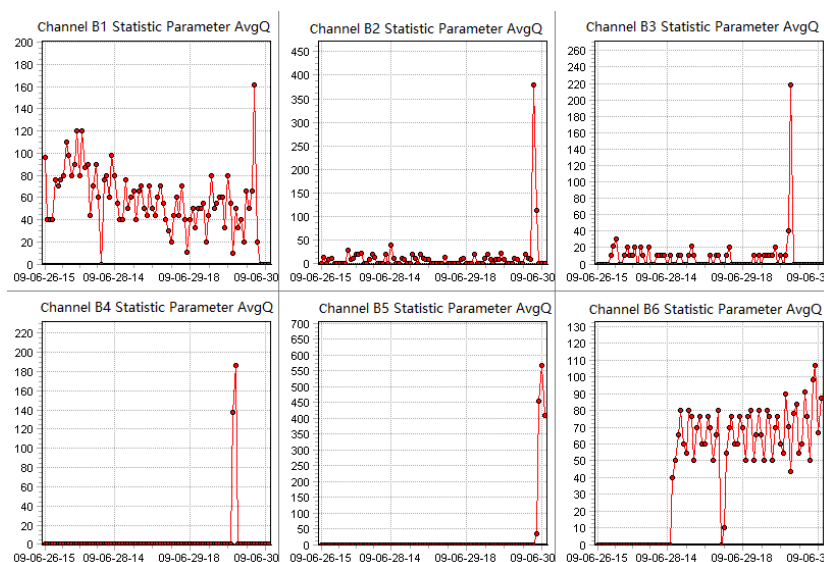


Figure 5. Interface of two-dimension map display

Just as figure 5 shows, the channel and statistic parameter can be chosen to display all the trend images of the parameter at different sensor, which is the two-dimension map. In figure 5, channel 1 to channel 6 were chosen to show their maps and the chosen parameter is AvgQ which represents the average quantity of partial discharge.

4. Summary

The system uses combined detection method which includes ultrasonic sensors and UHF sensors to monitor the insulation defect of GIS. The system is built based on the distributed framework to realize the monitoring of PD signals in the whole power equipment. The functions of the system include parts as below:

1) Signal collection and control. Signals are collected by UHF and ultrasonic sensors which are the DSP front ends, and then these signals will be sent to the server through Ethernet.

2) Signal pre-processing. Before analysing the data transmitted to the server from DSP front ends, the software needs to read data and extract effective discharge pulses to reduce noise interference and enhance the differences of original signals.

3) Characteristics extraction. Three-dimension map ϕ -q-n is drawn for PD signals in order to extract pulses. And then several statistical parameters can be extracted from the map by the software.

4) Data storage and analysis. Characteristics extracted from each map are stored and can be searched by the system. The system analyses the data trend from each sensor based on history data in the database and makes a comparison of the trends from different sensors in the same equipment to improve the results more accurate.

5) Results display. The connection diagram of the sensor-based installation, three-dimension map and two-dimension map of PD signals can display on the interference of the software. The channel, the trend of different statistic parameters can be chosen to show according to the choice of users, which makes the interference of the system more convenience.

The system has great performance on opportunity, scalability, diversity and expandability, which has been verified by long-term operation experience on field. The system is qualified to diagnose the insulation defects of GIS, which satisfies the demand of the grid.

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