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Study on Monitoring System for Partial Discharge of Electrical Equipment

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Abstract

The detection and fault identification of the partial discharge is the important aspect for the monitoring of the power equipment. For the lacks of the traditional detection methods, this paper analyzed the UHF signal characteristic parameters of the power equipment's partial discharge, and developed the UHF detection system of the partial discharge. The A/D technology of the gain equalization and quantization in the different bands is studied, and the fault diagnosis strategy of the partial discharge based on the UHF and AE is proposed. On the premise to ensure the integrity of the partial discharge signals, the acquisition, amplification, analysis and storage of the partial discharge signal is realized. The case-based reasoning technology determines the fault type and fault degree of the partial discharge to make the accurate judgment for the operational state of the equipment and improve the intelligence level and the operational reliability for the state diagnosis of the power equipment.

Keywords: *on-line UHF monitoring, fault diagnosis, partial discharge, electrical equipment, java software, dual orthogonal down-conversion*

1. Introduction

The partial discharge is the main cause of the insulation deterioration, is the important sign and manifestation of the insulation deterioration, and is also the important factor of the insulation failure for the power equipment. The insulation failure is the most main failure source of the power grid's distribution equipment. Partial discharge detection and fault identification is the important aspect on the monitoring of the power equipment. So the positive and effective detection and identification measures must be taken to prevent effectively the accidents of the power equipment. That plays a crucial role in the safe operation of the electrical power equipment. For the deficiency of the traditional detection methods, this paper analyzed the UHF signal's characteristic parameters for the partial discharge of the power transmission equipment, and developed independently the UHF detection system of the partial discharge. The paper integrated the non-contact high-voltage insulation testing technology, the arc fault monitoring technology, the environment parameter monitoring technology, the running fault monitoring and protection technology, the digital signal processing and information fusion technology, the intelligent embedded control technology and the network communication technology, and used the architecture of "the embedded LINUX operating system + the embedded IPC + the special acquisition and analysis board + the special analysis software". On the premise ensuring the integrity of the partial discharge signal, the acquisition, amplification, analysis and storage of the partial discharge signal are implemented. The case-based reasoning technology determines the fault type and fault degree of the partial discharge to make the accurate judgment for the operational state of the equipment, to improve the intelligence level and the operational reliability for the state diagnosis of the power equipment and to avoid the economic losses caused by the unnecessary blackouts check. The purposes of this study are as follows. One is that the UHF testing system of the partial discharge meets completely the requirements of the State Grid Corporation to the intelligent units of the partial discharge for the intelligent transformers and circuit breakers. The other is that the UHF testing system of the partial discharge makes the healthy evaluation for the electrical equipment to find and alarm the abnormities. That improves effectively the intelligent level of the state diagnosis and the operational reliability for the electrical power equipment.

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2. A/D Technology of Gain Equalization and Quantization in Different Bands

The partial discharge is an important factor leading to the insulation damage of the high voltage electrical equipment. The monitoring of the equipment in the running process must be strengthened. When the partial discharge exceeds a certain extent, the equipment should be repaired or replaced. Only the accurate detection of the partial discharge can protect the subsequent location process of the partial discharge.

When the partial discharge occurs, the electric pulse, ultrasonic wave, electromagnetic radiation, light and chemical reaction will be accompanied, and the localized heating phenomenon is caused. The paper used the ultrasonic detecting method to locate the partial discharge. The method has the simple and practical features, and is at large used in recent years. However, when the partial discharge occurs, the scattered ultrasonic waves have the different frequencies. The ultrasonic wave in the different bands implies the different information of the partial discharge, which requires the acquisition in the different bands. However, the acquisition program of the different bands is almost infeasible. First the existing filter circuits do not have the function dividing the frequency band in the ultrasonic frequency. Second the required A/D components and circuits are many, the sampling is complex, the cost is high and it is easy to generate the failures. The obtained sampling data are also under the different bands, do not have a unified standard of reference, and can not be used for the monitoring system of the partial discharge.

In response to these issues, this paper uses the balanced and quantitative methods of the gain in the different bands to sample the ultrasonic signals of the partial discharge. The equalization method is used to for the gain complementary method. That is to adjust the gains of the electronic amplifier and the acquisition system, so that the ratio of the output amplitude and the input amplitude is constant in the required spectrum. Then the analog digitals after the complementary processing are converted with the highly-resolution A/D elements and processing circuits, then are inputted to the concentrated control center for analysis and processing, thereby to improve the accuracy of the partial discharge monitoring.

3. Fault Diagnosis Strategy of Partial Discharge based on UHF and AE

The partial discharge process of the transformer or switchgear is always accompanied by the pulse current, electromagnetic radiation, as well as sound-light-heat and so on. The acoustic emission (AE) generated in the partial discharge process is used to judge and position the partial discharge. It draws the increasing attention in recent years. This is because when the partial discharge occurs in the medium, the intense impact of molecules, the formation and development of bubbles, the flow of liquid and the slight cracking of solid materials will produce a certain degree of acoustic emission signals. The study finds out that the sound signals generated by partial discharge have a certain correspondence with the level and type of partial discharge. Compared with the other detection methods, the acoustic emission method can serve the real-time and continuous monitoring of transformers from electromagnetic interference. Therefore it can be used in the very serious occasion of electromagnetic interference. In addition, the propagation characteristics of the sound waves in air or transformer oil can locate the partial discharge source. Figure 1 is the principle of partial discharge monitoring based on the UHF and the AE. The ultra high frequency (UHF) and the acoustic emission (AE) are internationally recognized as the most suitable detection for the on-site partial discharge. Their validity is agreed by the CIGRE Joint Working Group. This technology of high sensitivity and almost no interference has been widely used in the partial discharge monitoring or inspection work of the high voltage electrical equipment.

The paper applies the UHF and AE detection technology, and integrates the UHF and AE to incarnate fully the technical advantages of these two different detection methods. They can effectively solve the detection sensitivity problem of partial discharge signal on the on-spot interference environment, and are suitable in detecting and locating the partial discharge defects of GIS, switchgear, SF6 circuit breaker, cable termination as well as oil-immersed transformer, transformer under the operating conditions. Its main features are as follows.

(1) The powerful detection and analysis, flexible operation and powerful pattern analysis capabilities.

(2) Using the advanced variable bandwidth measurement technique can easily find the detection band of the optimal signal-to-noise ratio to ensure that the detection sensitivity of partial discharge is protected from the environmental interference.

(3) Without changing the measurement mode, the unique pulse capturing technology can also get all information of partial discharge analysis.

(4) The continuous pulse discriminating technology can automatically identify the communication signals in the UHF band and the continuous noise and vibration in the AE band to exclude the impact of the occasional interference signal on the partial discharge measurement.

(5) The UHF+UHF or UHF+AE signals can be measured simultaneously to do the correlation analysis of the two signals, and are easy to determine the sources and characteristics of the signals to improve the reliability of the test results.

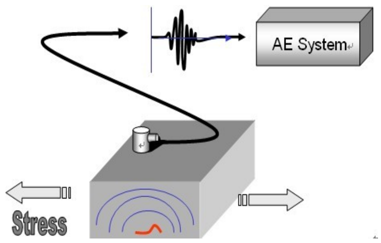

Figure 1. Principle of Partial Discharge Monitoring

4. On-line UHF Monitoring System of Partial Discharge

The core technology for the monitoring system of the partial discharge is the location method of the partial discharge based on the UHF and the AE principle. The AE detectors in the inside of the transformer or switchgear detect the UHF discharge signals. The equalized and quantized discharge signals of the different bands are sent to the information collection center to code. The coded signals are sent to the signal conditioning circuit which filters and eliminates the interference and noise signals. The filtered signals are sent to the processor. According to the arrival order of the respective detection signals, the processor uses the TOA (time of arrive) algorithm for positioning the discharge source to accurately and timely identify the location of the partial discharge, to improve the positioning accuracy of the partial discharge source, and ensure the accuracy and reliability of the positioning results. The functional block diagram for the monitoring system of the partial discharge is shown in Figure 2.

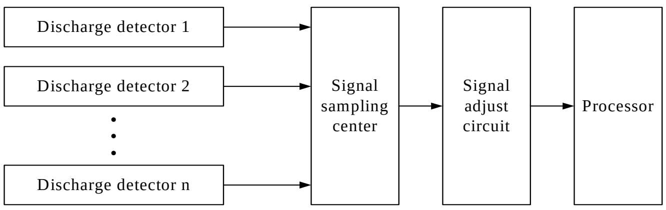

Figure 2. The Functional Block Diagram for the Monitoring System

The UHF signal's frequency generated by the partial discharge has reached the microwave band. If sampling directly, the sampling rate and memory depth for the acquisition device must be very high. The method extracting the signal envelope can lower the signal frequency, while retaining the premise that the enveloped peak and phase of the partial discharge signals are the same. That greatly reduces the technical requirement and difficulty for the hardware, and ensures the accuracy of the collection. The down-converter extracting the envelope traditionally will cause the spectral overlapping, because one way of the local oscillation signal is only mixed with the UHF signal. Therefore, we adopted the dual orthogonal down-conversion and the dual-channel AD to collect the partial discharge signal. Its principle is shown in Figure 3.

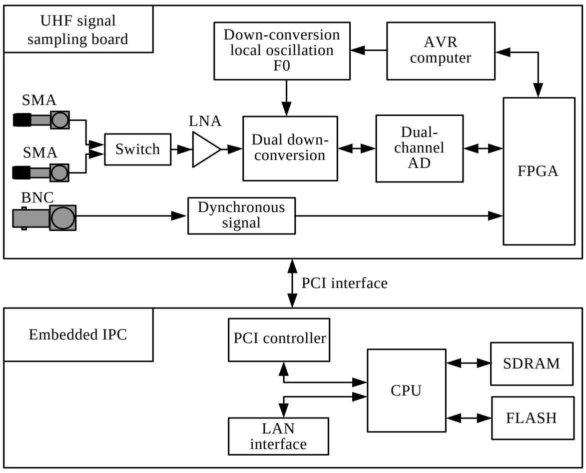

Figure 3. The Online Detecting System for Partial Discharge

According to the different discharge type and amount, the appropriate discharge voltage, the discharge electrode and the discharge electrode's gap are selected. The booster controls the voltage in the control platform. The program-controlled stepping device for the discharge gap adjusts the gap to produce the desired signal of the partial discharge.

The control principle of the discharge voltage is shown in Figure 4. First, the program-controlled high-precision variable frequency power supply generates the original signal of the partial discharge. Then the isolated transformer promotes the 50KV step-up transformer to amplify the partial discharge signal and to generate the required discharge voltage. The precise control of the program-controlled power supply can produce the partial discharge voltage in the transformer box. The traditional adjustment method is that the general regulator drives the boost transformer to produce the adjustable output voltage. The ratio of the primary input voltage and the secondary output voltage in the boosting transformer becomes nonlinear with the output power change. Therefore the program control of the output voltage in the step-up transformer is achieved according to the feedback of the PT signal. The precise programmable variable frequency power supply achieves the closed-loop control to the output of the high voltage power supply, and ultimately the accurate programmable control to the high-voltage output and the real-time data transmission.

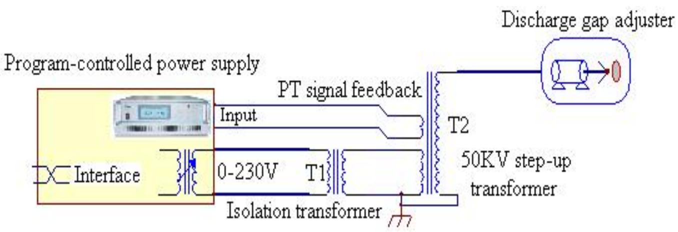

Figure 4. The Control Principle of the Discharge Voltage

The discharge electrode and the discharge gap of the analog discharge signal can be adjusted by the program-controlled stepping device installed in the fuel tank 1. The discharge electrodes may be selected in the five types of the air gap discharge, the floating potential discharge, the face discharge, the plate-plate discharge and the needle-plate discharge. The discharge amount is precisely controlled by adjusting the electrode gap. The maximum discharge amount is controlled from 10pC to 10000pC. The maximum discharge amount is adjusted by the resolution of 5pC.

The measurement principle of the partial discharge is shown in Figure 5. First, the partial discharge signal is monitored by the built UHF sensor of the partial discharge installed in the tank. Then the partial discharge signal is transferred to the digital partial discharge instrument by the detection impedance paralleled across the two ends of the discharge unit (with the standard coupling capacitor in series). The digital partial discharge instrument measures accurately the maximum discharge amount, the discharge phase and the discharge number of the partial discharge signal. Finally, the digital partial discharge instrument uploads the current discharge amount, two-dimensional and three-dimensional map to the upper server through the Ethernet interface in real time, as the basis for the transformer's condition assessment.

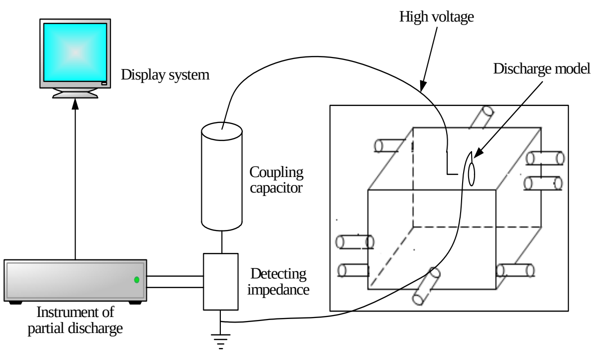

Figure 5. The Measurement Principle of the Partial Discharge

If only one way of the local oscillation signal is mixed with the UHF signal, the changes in the spectrum are shown in Figure 6. If using two ways of the orthogonal down-converter, the changes in the spectrum are shown in Figure 7 after mixing two ways of the frequencies orthogonally.

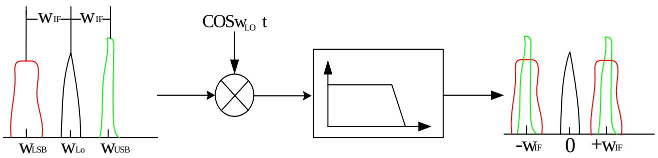

Figure 6. The Changes in the Spectrum After Mixing One Way of Frequencies

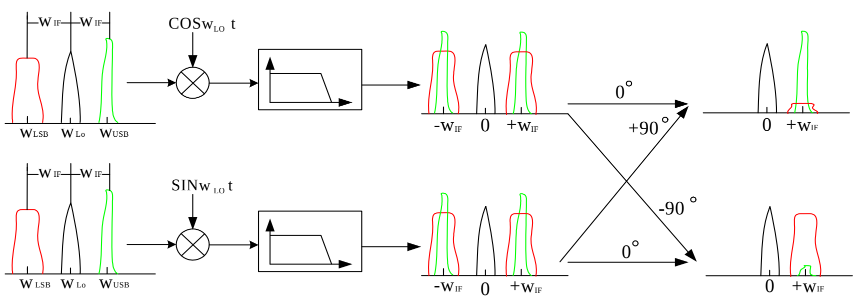

Figure 7. The Changes in the Spectrum After Mixing Two Ways of Frequencies Orthogonally

The optional mixing chip includes the variable gain amplifier, the two-way down-inverter, the phase separator, and the base-band operational amplifier. The local oscillation signal is separated by the phase separator to obtain the IQ local oscillation signal of the 90° phase difference into the down-converter. The IQ base-band operational amplifier uses the single-ended differential operational amplifier, two gains of which are 20 dB, to amplify the demodulated signal.

(1) The monitoring program workflow of the acquisition card

After power-up, to determine the measurement signal or the background noise. If the signal is the background noise, first the bandwidth is set up, and then the background noise in the various frequency bands is automatically scanned. After testing the background noise is completed, to automatically select the monitoring signal in the highest SNR band. If the signal is the measurement signal, the frequency band, bandwidth and gain of the monitoring signal are set and measured. If the measurement is completed, the interrupt is triggered to notify the IPC, and then to continue measuring. The workflow is shown in Figure 8.

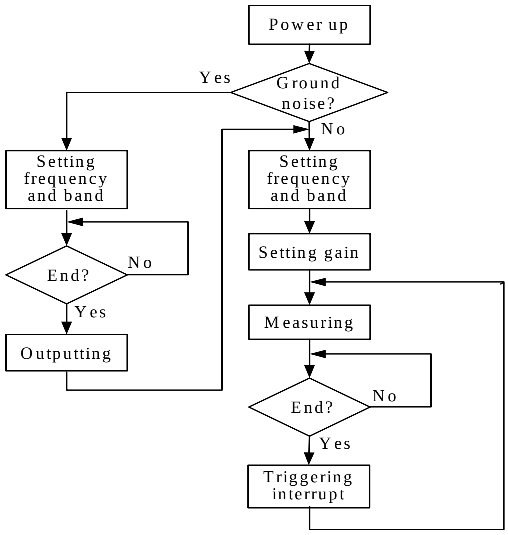

Figure 8. The Monitoring Program Workflow of the Acquisition Card

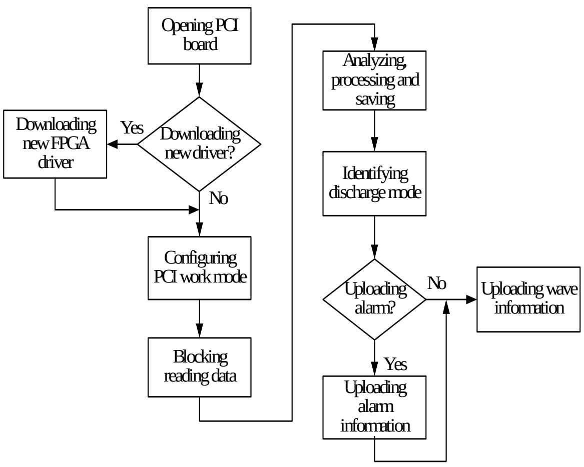

Figure 9. The Monitoring Workflow of the IPC

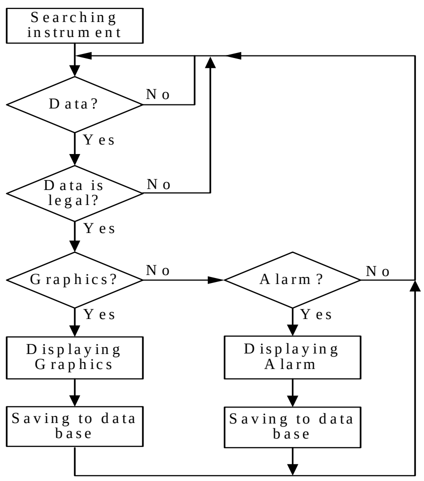

Figure 10. The Java Software Workflow

(2) The monitoring program workflow of the IPC

The monitoring program workflow of the IPC is shown in Figure 9. After the IPC's program runs, first to open the measuring board equipment to obtain the handle operating the measuring board. Then you check whether or not FPGA in the measuring board needs to upgrade. If a new monitoring program is to upgrade the measuring board, and configure the operating mode of the measuring board after the upgrade, and then the data are read. Once the measuring card's data are returned, then the returned data are analyzed, and the discharge type is identified to determine whether or not the partial discharge is abnormal. The abnormity starts alarming. Finally, all information is labeled as the Ethernet packet which is uploaded to the Java graphics software.

(3) The Java software workflow

The Java software workflow is shown in Figure 10. The Java software starts to search the detector of the partial discharge. After finding the detector of the partial discharge, the UDP port is monitored, and the UDP packet is received. The legal packet is received to judge that it is the graphic package or the alarm package, and the graphic or alarm window is respectively shown. Finally, the data are stored in the database for the future historical traceback.

5. Conclusion

The paper developed a high sensitivity UHF sensor. Using the integrated system of the lower variable-frequency and the signal conversion improved the sensitivity and stability for the partial discharge measurement. Using the intelligent fault-pattern recognition system and method based on the case-based reasoning technology for partial discharge improved the accuracy of the fault judgment. The IEC 61850 standard interface realized the online remote monitoring of the electrical equipment's state. The performances of the system reached the leading domestic level, and had the large technical advantages compared with the international similar products.

References

[1] ZHU Jie, CHEN Guo-jin, WANG Wan-qiang. Applying FPGA on Frequency Convert System of SVPWM. *Mechanical & Electrical Engineering Magazine*. 2005; 22(4): 22–25.

[2] CHEN Guo-jin, YAO Zhai-rong, SUN Hong. Realization of AC Motor Vector Control Based on DSP. *Mechanical & Electrical Engineering Magazine*. 2004; 21(6): 27–30.

[3] WANG Tao, CHEN Guo-jin, NI Jing. Design and application of electric control system on pattern drawing machine. *Journal of Mechanical & Electrical Engineering*. 2012; 29(4): 413–416.

[4] LI Yong-ning, YANG Hua, CHEN Guo-jin. Application of μC/OS-□ in digital welder control system. Journal of Mechanical & Electrical Engineering. 2011; 28(7): 827–830.

[5] CHEN Guo-jin, CHEN Hui-peng, CHEN Li-ping. Research on multidisciplinary modeling and robust control for electric power steering system. Advanced Materials Research 2011; 179–180: 179–185.

[6] CHEN Guo-jin, XU Ming, LIU Ting-ting, NI Jing, XIE Dong, ZHANG Yan-ping. Fault Pattern Recognition for Partial Discharge of Electrical Power Equipment based on Properties of Electrical Materials. *Advanced Materials Research*. 2013; 644: 105–109.

[7] CHEN Guo-jin, XU Ming, LIU Ting-ting, NI Jing, XIE Dong, ZHANG Yan-ping. Study on the Online Detecting Technology for Partial Discharge of Power Equipment with Mechanical Properties. *Advanced Materials Research*. 2013; 644: 51–55.

[8] CHEN Guo-jin, ZHU Miao-fen, WANG Wan-qiang. *Image identification based on the compound model of wavelet transform and artificial neural networks.* Proceedings–2010 6th International Conference on Natural Computation, ICNC. 2010; 3: 1438–1441.