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On-line Monitoring System Based on Principle of Electro-acoustic Monitoring for Transformer Partial Discharge

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Abstract: Partial discharge inside a transformer is mainly responsible for the insulation aging and damage of the transformer. However, partial discharge is usually accompanied by external signals like sound, light and electrical signals and detectable physical phenomena such as characteristical gas and dielectric loss. Therefore, it is of great significance to monitor online the external signals and phenomena formed during partial discharge of the transformer when the transformer diagnoses faults. This paper gives a comprehensive overview of the electro-acoustic joint monitoring principles and its monitoring systems and the judgment skills concerned, on the basis of which the monitoring system is designed. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Transformer, Accident, Partial discharge, On-line monitoring.

1. Introduction

Power transformer is considered as one of the most important equipment of the electric power system. Its insulation condition directly affects the security and stability of power system operation. Statistics show that insulation fault is one of the most important causes of transformer accidents, whereas partial discharge inside a transformer is mainly responsible for the insulation aging and damage of the transformer. Therefore, it is of great significance to monitor partial discharge inside the transformer to ensure its safe operation.

Partial discharge inside a transformer will give rise to some external and perceivable signals like electrical impulses and ultrasonic waves. Then the electro-acoustic joint monitoring system can be used to identify discharge position by monitoring the signals reflecting partial discharge condition to achieve the purpose of monitoring the insulation condition.

2. Electro-acoustic Principle and Structure of Joint Monitoring Systems

1) Principle of pulse orientation discrimination: pulse current detection can be used to measure the grounding impedance, detect the end of transformer bushing screen wire, shell grounding line, the iron core grounding line, as well as due to the partial discharge pulse current in the winding, to get the apparent discharge capacity.

2) Ultrasonic measurements: mainly used for qualitative judgment of whether, as well as a combination of electrical pulse signal or a direct physical position using ultrasonic signal source of the game [1, 2]. In partial discharge online monitoring,

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ultrasonic measurements is the main auxiliary measurements. With in-depth study of ultrasonic measurement of partial discharge, it is possible to quantitatively analyze the discharge strength and insulation deterioration degree. With the further development of acoustic-electric transducer, ultrasonic measurements might be a primary means of measurement; it can also be partial discharge pattern recognition, than formed the failure criterion similar to the oil chromatographic analysis.

The monitoring system uses a pulse and ultrasonic partial discharge monitoring principle, the simultaneous detection of partial discharge ultrasonic signal and the electrical pulse signal, by processing the "fingerprint" of parameters to obtain the PD, such as the discharge amount, discharge frequency, and to determine the discharge location. The electro-acoustic monitoring system block diagram is shown in Fig. 1.

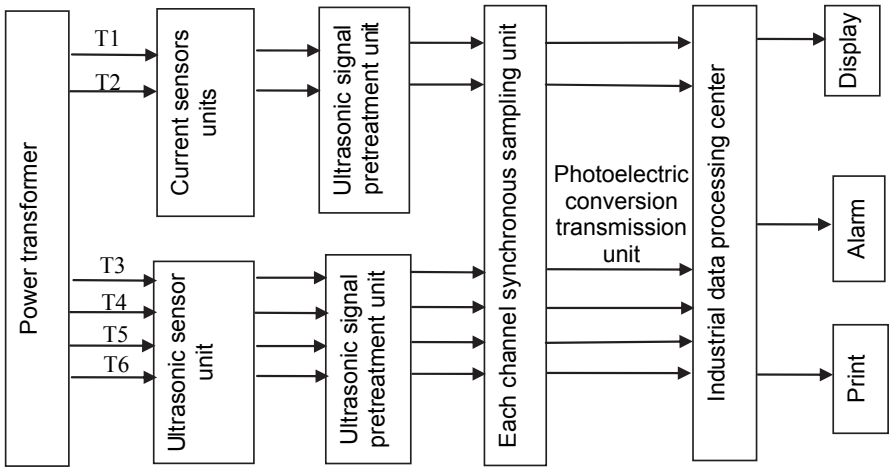

Fig. 1. The structure diagram of the electro-acoustic joint monitoring system.

T1, T2 are broadband pulse sensors. T1 sets in the transformer neutral point grounding line. T2 sets the grounding line of the tank shell. If the neutral point ungrounded, can the T1 PD signal coupling between the high voltage bushing last one umbrella skirt and flange, T2 sets of deflectors on the screen end of the high pressure casing.

Due to the PD pulse rise time and duration time is very short, about nanosecond pulse, its equivalent frequency domain bandwidth up to 200 MHZ, so the sensor should use broadband to make it pulse with high enough resolution, gets enough Council information for software anti-jamming, especially apply operations to remove external groundwork discharge pulses, increasing the effectiveness of online partial discharge detection.

T3, T4, T5, T6, are ultrasonic sensors, there is enough bandwidth to ensure the accuracy of ultrasound localization algorithm.

The data collection frequency of the sampling unit for the 2 MS/s, 12-bit, 8-channel simultaneous sampling, the sampling frequency bandwidth of 500 KHz, the center frequency of taking 200~500 KHz.

2.1. The LD Driver and Modulation Circuit

1) T1, T2 monitoring of electrical pulse signal generated by PD, and the use of pulse current in the same direction, the internal partial discharge pulses in opposite directions in the two mutual-inductor on the principles of outside interference in these two mutual-inductor to distinguish between inside and outside the discharge, effective suppression of external interference.

2) The use of ultrasonic sensors monitoring of partial discharge acoustic signal generated in the transformer shell. This approach strong resistance to electrical interference, not only can exist based signal transformer inside the discharge and transformer internal discharge can be measured, will be arranged according to the geometrical principles of optimal ultrasonic sensor in transformer shell.

3) Detection of partial discharge; use of the acoustic signals detected by the computer regularly, that is, whether repeated in a certain period of time.

4) Positioning: When the transformer partial discharge current pulse signal, it produces a current pulse signal was immediately detected. Ultrasonic detection of the signal than electrical pulse signal delay in time. Integrated ultrasonic delay will be able to determine the location of sensors with discharge. When the present system of transformer internal discharge resulting ultrasonic measurements, mainly used for qualitative judgment of partial discharge signal exists or not, and combination of electrical pulses and reach the source of ultrasonic probes the difference game points position [3, 5].

The tests showed that peak oil of partial discharge ultrasonic spectrum distribution between 70~150 kHz. PD ultrasonic sound source is very small, after

conversion by the ultrasonic sensor and the signal is weak and ambient noise, for which we selected the broadband type detection bands selected between 70~200 kHz to avoid the transformer body vibration caused by the ultrasonic noise [4, 6]. Specific operation is as follows, ultrasonic sensors fixed on the transformer casing, the use of piezoelectric crystal transducer as the acoustic-electric, acoustic signals are converted to electrical signals, and further amplified by a cable sent to the monitoring system. Between the monitoring system in order to avoid the transformer casing, the electrical connection between the ultrasonic sensor and transformer enclosure, engineering plastics are separated. Meanwhile, in order to match the acoustic impedance and sound detection sensitivity between the transformer casings filled with transformer oil in the piezoelectric crystal.

Take advantage of the difference principle (Fig. 2) to determine the partial discharge signal there and on the source position. First to synchronous sampling signal, when moments later pulse signals and ultrasonic signals and slack, Ti meet $T_{min} \leq T_i \leq T_{max}$, and then integrated the signaling time difference of ultrasonic sensor unit accepts to determine whether this is a transformer internal discharge.

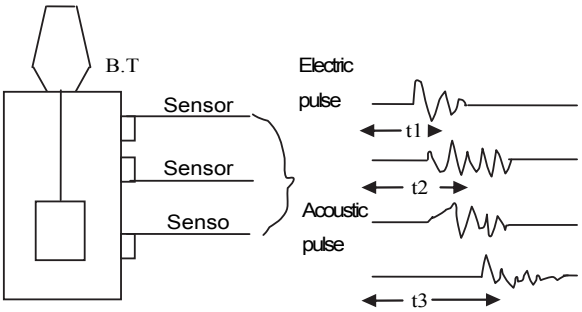

Fig. 2. The working principle of ultrasonic detection system.

Uses related operation can determines the ultrasonic sensor accept of signal of slack two apart set for d, received of signal respectively for q1 (t) and q2(t) = Aq1(t + Δt), Δt is source of ultrasonic reached two accept sensor of produced of delay, with digital performance, signal respectively for q1(n) and q2(n), delay as Δn, set up a signal amplitude of 1, A for another signal of ranges attenuation factor. Fast correlation algorithm using FFT.

Signal operation:

$$\gamma 12(j)=1/N\sum N\text{-}1N=0Aq1(n+\Delta n+j)$$

Because the two signals from the same random noise source, the two signals only at the same time as related, j=-Δn will produce meaningful output APav, Pav is the average power of the source signal,

$$Pav=1/N\sum N\text{-}1N=0q12(n).$$

2.2. The Anti-jamming Technology

1) Adjustable "threshold" set in the identification system can remove those able to significantly distinguish the higher the intensity of the interference pulse signal.

2) Use of electronic switching circuits. When the arrival of the interference pulse from the ground network, electronic door instantaneous shut down, eliminating the amount of influence.

Because transformers running sites there are a large number of radio signal interference and high frequency communications interference. In order to suppress these disturbances, the monitoring system using some digital signal processing software for inhibition.

2.3. The Pulse Current Sensors and Ultrasonic Sensors Unit

1) PD ultrasonic signals have a very wide frequency band, mainly concentrated in the 50~300 kHz, the ultrasonic sensor output under different discharge capacity discharge signal level in tens of micro volts ~ tens of mill volts. Ultrasonic sensors require broadband; the frequency attribute should match the signal spectrum.

2) Measurement points on the transformer housing.

3) Current pulse signal detection field wiring unit. The unit consists of a preamplifier, differential amplifiers and filters. Facilitate software filtering the signal into the computer, broadband electrical pulse sensor can be used for anti-jamming differential balancing circuit and pulse polarity discrimination circuit, both the basic idea of the method is based on internal transformer partial discharge pulse and ontology of external interference pulses in transformer grounding line offset or difference in flow direction on identification of external interference signal.

4) Ultrasonic signal field wiring unit. The conversion of the ultrasonic sensor signal is weak, and on-site environmental noise is large, can constitute the integration of the back of electron converter of the unit and ultrasonic sensors, place inside the good shielding shell. The terminal unit includes two low-noise amplifiers [7] and a low-noise filter [8], high-pass filter cutoff frequency is 60 kHz.

5) The photoelectric conversion and light signal transmission (Fig. 3).

Two light: a while sending four-channel signal, a root to time division multiplexing transmission of digital signals.

6) Data acquisition. If the center frequency of the electrical pulse sensor is 1 MHz, broadband 500 kHz, according to the sampling theorem and digital signal processing requirements of each sampling time length should be greater than two frequency cycle, than the center frequency fc: fc=500 kHz, Bw=500 kHz.

The sampling frequency fs=2 MHz, the amount of data is approximately 80 K.

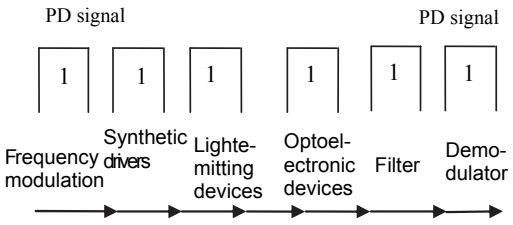

Fig. 3. Photoelectric conversion and the light signal transmission.

2.4. High-speed Data Acquisition System

1) Design method of partial discharge signal acquisition system [9, 10].

According to the characteristics of the detection site and interfere with the weak signal, acquisition and processing host away from the power transformer, can greatly reduce the interference of the strong electric field. At the same time, the ultrasonic sensor and preamplifier should design into an integrated structure, and good electromagnetic shielding. Pre-class collection, processing between hosts using fiber optic cable transmission signal to avoid the interference of strong electromagnetic fields of transmission lines, this measure can greatly improve the anti-jamming capability of the device. Excellent design of the filter, making it band to match the signal's spectrum. The filter's role is to inhibit various types of interference. Frequency characteristics of Ultrasonic sensors should match the signal spectrum, so ultrasonic sensor should be designed into a broadband type. To adapt to the dynamic range, as well as signal amplitude characteristics of ultrasonic ranging sensor signal strength, each channel should be set independently adjustable attenuator.

2) The composition of the partial discharge signal acquisition system

It consists of four-channel signal acquisition system, interface, computer and processing software components, respectively, to complete the points of acceptance ultrasonic signal acquisition, data processing and locate the point of failure. For determining the discharge point, ultrasonic sensor to accept array requires at least three modules, primitive must rely on transformers shell. The system uses a four-element, as shown in Fig. 4, four-channel works.

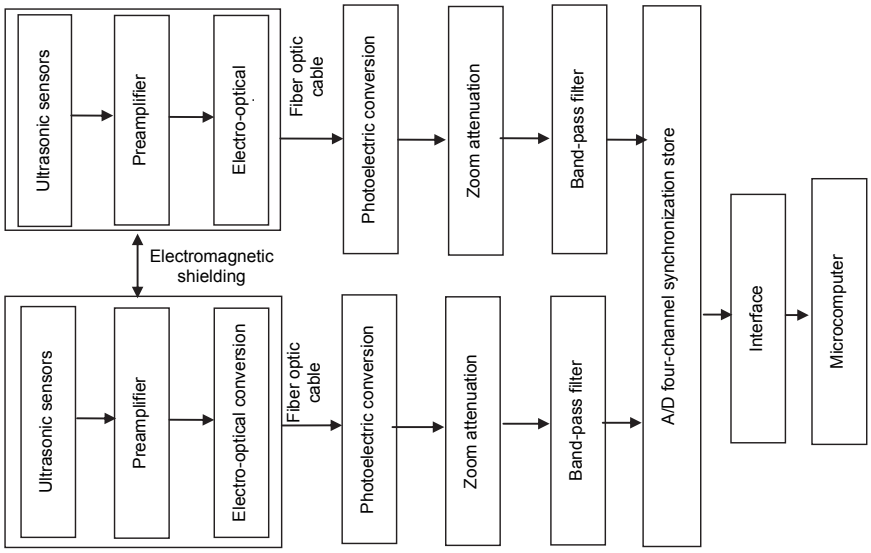

Fig. 4. System USES four units, four channel way to work.

1) Front-end device.

Part of front-end device consists of the ultrasonic sensor, preamplifier, electro-optical converter and other components, place it on electromagnetic shielding shell constitutes a integrated structure, with good electromagnetic shielding integrated structure is to reduce the work-site strong power frequency interference important measures.

Preamplifier includes bipolar low-noise amplifier and a low noise active high-pass filter. High-pass filters cutoff frequency of 60 kHz. It can effectively inhibit frequency interference and low frequency sound interference to prevent interference in the preamplifier stage limiting the loss and it is a useful signal overlay, this filter must be placed between the two-stage amplifiers. Front-end amplifiers use low noise of MAX410 or MAX412. It is vital to reduce the noise of the system.

2) A/D conversion [11, 12] and data storage.

Discharge ultrasonic signal highest frequency components up to 300 kHz above, the sampling frequency is taken 2 MHz. ADC uses 8-bit parallel processing-shine A/D converter CA3318. It has the characteristics of high-speed, low-cost, easy to use, due to the synchronization of four-channel A/D converter, each channel set channel buffer memory

acquisition after the end into the price according to the channel order. CA3318 three-state output structure to simplify the circuit structure of the data transmission. A/D converter and channel buffer storage and feeding units of storage data under the control of controller, and is given by the address counter deposit, take the address of the unit. When the channel buffer cache content, address counters count pulse is given by the controller, the counting cycle is consistent with the A/D conversion cycle, when the fetch, count pulses from the address of the computer plus a pulse. Number of deposit and access is started from the starting unit, taken one at a time plus 1 data to address, until taking out all of the data.

3) Acquisition start.

The power transformer partial discharge can be divided into continuous discharge gap discharge. Serious failure occurs when the continuous discharge; fault is not serious from time to time gap discharge. Continuous discharge can be collected at any time. Gap discharge phenomenon occurs mostly near the peak of the power signal.

4) Interface.

The computer interface using the search work. After collection start each channel at the same time for acquisition and storage, microcomputer in the query State. Acquisition storage controller issued to the computer after the end "data ready" signal. Computer began to channel buffer memory fetch. Computer so that the controller after each removal of a data address plus 1, and so take the number up to take complete all the data of a channel. When the program determines the data at the end, turn to the next channel data, all four channels until the transmission is completed.

2.5. Technologies of Computer and Related Judgment

The transformer insulation performance is good or bad is to rely on a number of parameters of the two assays, and then integrated by computer to determine. It is not only able to judge the internal transformer is not a disruptive discharge, but also its growth rate is generally named its harmful levels of insulation. For example: during the detection process, computer – if you find that some data had changed, and make sure that is not caused by external interference is considered PD in transformers. If detected by the ultrasonic signal is found relatively fixed, high repetition rate, and in a certain range, determining the partial discharge of transformer internal. In addition, several alarm set respectively in the detection system. As above, once the electric pulse monitoring system found exception starts an alarm signal. If the ultrasonic detection system is abnormal, then start another alarm signal. If two signals simultaneously, we can sure that internal insulation of transformer that an exception has occurred. In addition, through the various parameters of the computer output, such as the average current of discharge, discharge, discharge n-p map and the ultrasonic signal propagation delay can be made on the discharge hazards assessment. The device in transformer runtime detection of partial discharge signals out about 2000 pc.

1) The performance of the PD pulse indicator is the discharge pulse current instantaneous and discharge rate exceeds the limit value and the development should be alert. Meanwhile, according to the partial discharge of a certain frequency range and amplitude changes in the ultrasonic signal and the pulse current signal time difference to determine whether the transformer within the PD. There are ultrasound signal after the transient pulse signal, and the time difference Yi meet $T_{min} \leq T_i \leq T_{max}$, it certainly for internal the PD.

2) Multi-point receiving method of ultrasonic signal based on the time delay between the point and electro-acoustic method to determine the relationship between digital models can determine the location of transformer PD points, thus it is helpful for maintenance find PD points of failure, cleared in a timely manner.

3. Conclusions

Transformer in the system status is very important, but its structure compared to other electrical equipment is relatively complex. In the long-running process of the transformer, need to use a variety of technical means, including regular and characteristic experimental periodic monitoring of electrical properties, combined with online monitoring methods and other projects in order to make a more comprehensive transformer insulation performance, objective and comprehensive evaluation. Cannot rely solely on an item on the line, and the dielectric strength of the decline depends on the combined effects of various factors, and is random. Therefore, should also carry out planned preventive tests. A variety of test methods, testing a variety of performance parameters of defect caused by electrical changes, to determine its insulation, arrangements and guided repair. In order to ensure safe operation of transformers.

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