대용량 터빈 발전기에 사용되는 온라인 부분방전 관측 시스템에 관한 연구

論 文
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The Study on a PD On-line Monitoring System Used for Large Turbine Generators

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Abstract - This paper describes a partial discharge (PD) on-line monitoring system used for large turbine generators. The system consists of a broadband current transducer, a computer-aid PD measurement system. By using a programmable fabricate band pass filter and an adaptive digital filter, the system can suppress the noise and extract PD signal from the intense noise surroundings successfully. Two simulated PD sources, which often exist in the large generators, were simulated and detected. At the end of this paper, some field test results, obtained from a 200MW generating set, were presented and discussed.

Key Words : partial discharge, on-line monitoring, broadband current transducer, band pass filter, adaptive digital filter

1. Introduction

Recently the development tendency of power equipment is high voltage, large capacity. During operation, the electrical, thermal, and mechanical stresses, along with environmental factors, can combine to degrade the electrical insulation. Therefore the insulation system is deteriorated during equipment operation. Thus the measured trend in PD activity from periodic testing over the life of the equipment can indicate if insulation deterioration is occurred. This facilitates scheduling of preventive maintenance prior to failure. The study of PD test especially for on-line monitoring becomes important and popular [1-3].

Generally, electrical noise can be categorized into two types: thermal and external. Thermal noise is the more fundamental and results from thermally induced current fluctuations in amplifiers and detection impedance. However, external noise tends to be much more severe during the PD testing of HV equipment. In many cases, external noise can cause false indications, reducing the credibility of on-line and off-line PD tests [4]. The external noise sources include follows [5, 6]: (1) PD and corona from the power system which can be coupled directly to the apparatus under test(in on-line test) or radioactively coupled (in on-line or off-line test); (2) radio transmissions and power line carrier communication systems; (3) arcing from slip ring and shaft grounding brushes in rotating machinery, arcing between adjacent metallic components in an electric field where some of the components are poorly bonded to ground or high voltage; (4) thyristor switching; (5) other pulse interference, for example, arc welding, relay switching, thunder.

A lot of PD on-line monitoring systems were developed since 1980s. Because of the complexity and difficulties of interference suppression in the generator, most of their research concentrated on how to suppress noise and extract PD signal correctly. The most famous among them are PDA [7] and TGA [8]. PDA was developed by M. Kurtz in the early years of 1980s. The sensor used in this system was coupling capacitor. The coupling capacitor was fixed at the output terminal of a differential amplifier. It could detect PD in hydraulic generator with suppressing the noise successfully. However, when it was used for turbine generator, it could not be applied satisfactorily. Because the noise inside turbine generator is much higher compare to hydraulic generator, sometimes noises are hundreds of times than discharge signal. The capability for PDA to suppress noise is only 10 times. Meanwhile, PDA require circle bus at least 2 meters or longer. As for the turbine generator, there is

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no such structure. Therefore, PDA can not be applied to PD on-line monitoring of large turbine generator. Another system which was called TGA was developed successfully in the beginning of 1990s. The sensor used for TGA is called Stator Slot Coupler (SSC). The principle for TGA to recognize discharge and noise is the pulse shape. The system was on the basis of high-speed data acquisition and waveform analysis. The disadvantage of TGA is that SSC must be installed in the generator stator slot. In this case, the safety problem of generator itself must be considered seriously. This is the reason why the system can not be applied widespread.

In this paper, a new PD on-line monitoring system was developed and presented. It is a computer-aided PD on-line monitoring system. The system is composed of a broadband current transducer system, and a digital partial discharge analyzer. It can be used for both on-line and offline test of large turbine generators. Some typical defects, which often exist in the large generator stator bar, were simulated and detected by using new system. Some field test results are also given and discussed at the end of this paper.

2. System Description

The block diagram of the system is shown in Fig.1, which was mainly composed of two parts: PD coupling circuit and PD detection circuit. PD coupling circuit is used for coupling the PD signal. PD detection system is the core of total system. It is used for acquisition of the signal which coupled by the sensor and displaying the detection results after signal processing.

2.1 PD coupling circuit

The sensor used in this system was a broadband current transducer system (BCTS). This transducer system was composed of a high-frequency current transducer, a preamplifier. The ground lead was chosen as a good measurement location because it was at a low potential about ground and PD current at any location in the test sample caused current pulse flowing in the lead. This kind of transducer was worked by way of magnetic coupling. Therefore the measurement circuit and the HV circuit had no direct electrical contact. It was safe to use especially for HV equipment on-line monitoring.

As we have known, the stator winding of generator is a distribution parameter component. Stator winding are embedded deeply in the stator slot. As for the electromagnetic coupling among each coil and circle, it is so weak that the capacitor among different windings can be ignored. Therefore, the transmission line theory can be

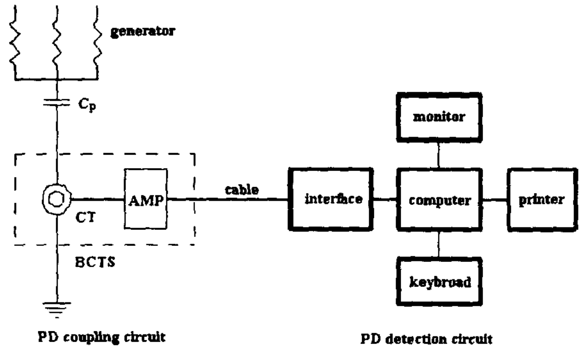


Fig. 1 Test circuit of PD on-line monitoring system for large generators

applied to analyze the characteristics of PD pulse along the stator winding [9, 10]. Former research results have shown that high frequency component of the PD signal has obviously attenuated. The attenuation also depends on the transmission distance. Therefore, the main frequency component of the signal at the neutral point of generator is beyond the frequency range of 10MHz. Therefore, the upper limit of BCTS, which is applied, is 20MHz. As for the lower limit, the frequency should be much higher than the frequency of power supply in order that the resonant component of power supply could be avoided. But it should not too high. Otherwise, it will affect the reappear of impulse waveform. Therefore, bandwidth of BCTS that is applied in this system is from 10kHz to 20 MHz.

This transducer system also met the following requirements:

- Fast transient response (establishing time is in the range of a few ten nanoseconds);
- High sensibility (the minimum PD pulse magnitude which can be coupled is 2mV);
- Linearity within the range of detection PD pulse currents (in the dynamic range of 2mV to 2000mV, no distortion);
- Stability in use (installed at the generator neutral point which is in zero potential, the transducer has good fixing and shielding).

Therefore, the new developed BCTS can be applied for coupling of PD signals of large generators.

2.2 PD detection circuit

Block diagram of PD detection circuit is shown in Fig.2.

To extract the discharge parameters for computer analysis, some form of signal processing and digital conversion was necessary. In this system, the hardware consisted of a program controlled attenuator, a

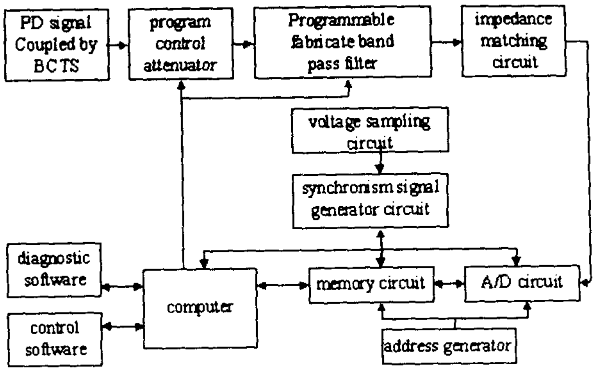


Fig. 2 Block diagram of PD detection circuit

programmable fabricate band pass filter, a impedance matching circuit, and an A/D converter to digitize the PD pulse.

Program controlled attenuator was designed for judging the signal scope. According to the obtained original signal, computer gave the corresponding response to adjust signal magnitude, thus the PD signal can be enlarged (or attenuated) to a suitable scope. The dynamic range of this circuit is 40dB. Then the signal entered a programmable fabricate band pass filter. In this system, three filter band was designed, which was from 10kHz to 100kHz, from 10kHz to 2MHz, and from 10kHz to 10MHz, respectively. As for this system, different filter band was designed in order to satisfy different kinds of requirements of field test. After attenuation, filtering and impedance matching circuit, PD signal was flowing into the AD conversion circuit. Meanwhile, the voltage signal was sampled and converted to square wave, which could provide the information of phase position. In this system, the high speed AD converter worked by way of parallel comparison method. The maximum sample rate is 20Ms/s. Demultiplier circuit was designed so that the low sample rate could be obtained up to 25ks/s. AD conversion bits is 8. Hardware logic generation circuit was also adopted to support hardware address code and control logic. Due to the high-speed conversion, high-speed memory circuit was also required. Therefore, high-speed static flash memory was applied. Bi-address buffer was adopted to detract the requirement for memory speed. In order to observe the PD signal in one cycle of power supply, AD conversion length was required at least one cycle of power supply signal. As for 20Ms/s sampling rate, 400k Bytes memory caches was required at least. After AD conversion, digitized data was stored in a mass storage device such as hard disk or floppy disk. System inter control was operated by control software. Diagnostic software was used for analyzing and displaying the acquired PD signal.

An adaptive digital filter was also applied in this system which was shown in Fig.3.

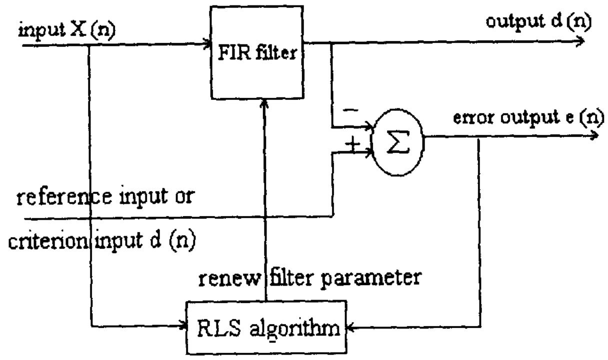


Fig. 3 RLS adaptive digital filter

It was a FIR structure, RLS algorithm adaptive digital filter. This filter has the following features: (1) Structure is simple, phase shift is steady and linear, waveform would not distort. (2) RLS has fast convergence speed, it can follow the tracks of PD signal well when the signal appeared, then adjust its FIR structure. The noise-suppressing ratio of this filter was 40dB.

3. System Application

3.1 Simulated test

3.1.1 Specimen

The internal discharges and slot discharges, which always exist in the large generator, were simulated. The discharge sample was made by using a few stator bars, which was cooperatively produced by electrical machinery works.

In case of internal discharge, the pre-arranged cavity was located in the insulation layer. The electrode system and test sample was treated deliberately in order that only internal discharge exists during the discharge process. The internal discharge sample is shown in Fig.4.

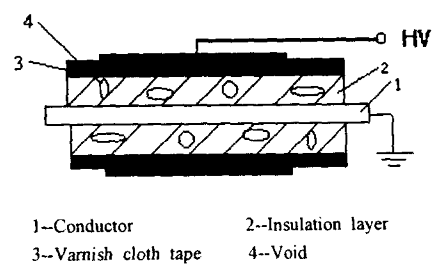
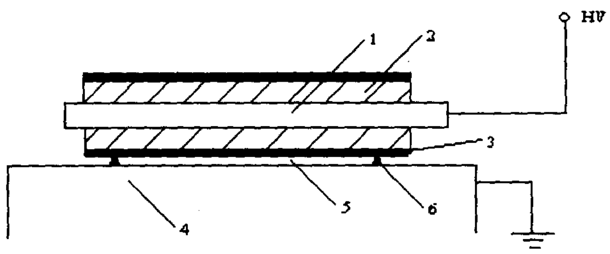


Fig. 4 Test sample of internal discharge

As for the slot discharge, the stator bar was put into a simulated stator winding, which had many pre-arranged defects on the winding surface. The slot discharge sample is shown in Fig.5.



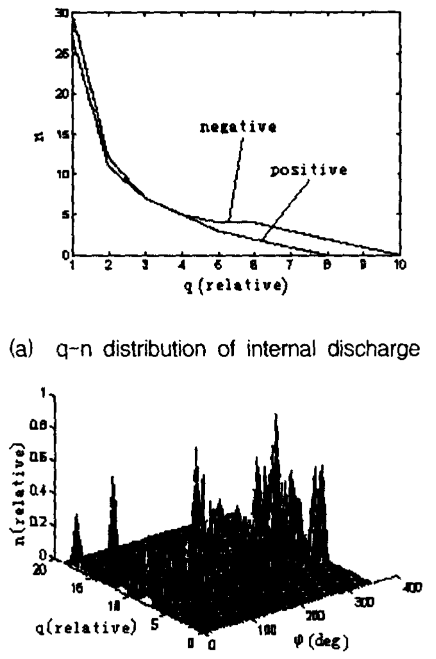
1--Conductor 2--Insulation layer 3--Varnish cloth tape
4--Stator winding 5--Void 6--Electric contact point

Fig. 5 Test sample of slot discharge

3.1.2 Results and Discussions

3.1.2.1 Internal discharge

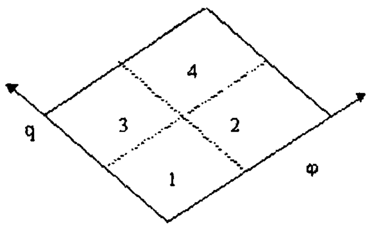
Test result for internal discharge is shown in Fig.6. By using digital signal processing technique, q-n distribution and the three dimension φ-q-n distribution can be obtained, which was shown in Fig.6(a) and Fig.6(b), respectively.



(a) q-n distribution of internal discharge

(b) φ-q-n distribution of internal discharge

Fig. 6 Internal discharge distributions



1--positive half cycle, low magnitude 2--negative half cycle, low magnitude
3--positive half cycle, high magnitude 4--negative half cycle, high magnitude

Fig. 7 Separation of φ-q coordinate plane

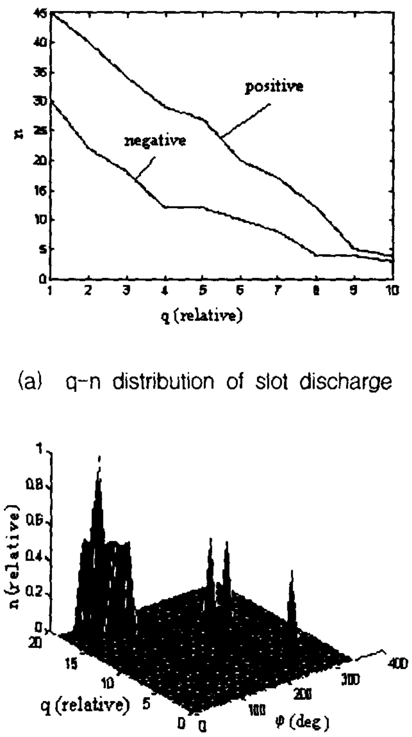
From Fig.6(a) we can conclude that positive q-n curve and negative q-n curve were almost overlapped each other. If we divide the φ-q plane to four parts as shown in Fig.7, we can conclude from Fig.6(b) that discharge summits in area 1 and 3 were almost symmetry to those in area 2 and 4. The heights of the summits were also similar. Therefore, positive discharge pulse counts were similar with negative discharge pulse counts. Their phase almost symmetry to phase of sinusoidal wave. Recurrence of internal discharge can be found elsewhere in [11].

3.1.2.2 Slot discharge

Fig.8 is the test result for slot discharge. Using digital signal processing technique, q-n distribution and the φ-q-n distribution can also be obtained, which was shown in Fig.8(a) and Fig.8(b).

From Fig.8(a) we can conclude that positive q-n curve is upper than negative q-n curve. In Fig.8(b), discharge summits in area 3 were much taller and more than those in area 1 and 2, which were much lower and fewer. This feature can help us to find out slot discharge in large generator easily.

Recurrence of slot discharge can be described as follows: In the positive cycle of applied voltage, the stator winding is negative. Therefore, the electron is easy to release from the winding which was considered as the electrode. Furthermore, positive ion can not accumulate



(a) q-n distribution of slot discharge

(b) φ-q-n distribution of slot discharge

Fig. 8 Slot discharge distributions

and not easy to hit the electrode. Thus, the discharge initial voltage was high. This resulted in the high magnitude of discharge. Discharge counts were much more as well. During the negative cycle of applied voltage, the winding is positive. Electrons are not easy to release. That makes the discharge counts few. Meanwhile, positive ions, which were produced by electron emission, would hit cathode and release one and more electrons. Therefore, initial discharge voltage is lower compare to the positive initial discharge. As a result, discharge was fewer and discharge magnitude was lower. Furthermore, voids which existed between stator winding and bar made the capacitance much larger because of the larger dimension. As a result, slot discharge is a kind of high-energy capacitance type of discharge. It is harmful and could destroy insulation quickly.

Therefore, different discharge sources have different characteristic spectrum. This can be applied in recognizing PD source and insulation diagnostics.

3.2 Field test

The PD on-line monitoring system was applied to a 200MW generating set in a power plant in order to obtain filed test result. PD monitoring results of time domain and frequency domain was shown in Fig.9a, Fig.9b, respectively. We can conclude from Fig.9b that the central frequency of the discharge signal is less than 1MHz. The above filter system, which contains both hardware and software filters, was applied to suppress the noises. PD signal, which was after filtering, is shown in Fig.9c and Fig.9d. From Fig.9d, we can conclude that each frequency component was similar with that of the whole frequency domain. Therefore, there was no hazard discharge sources existed.

From the above on-line monitoring test results, we can also conclude that rather large noise was existed in the generator. Magnitude of the noise sometimes a few hundreds of times than discharge signal.

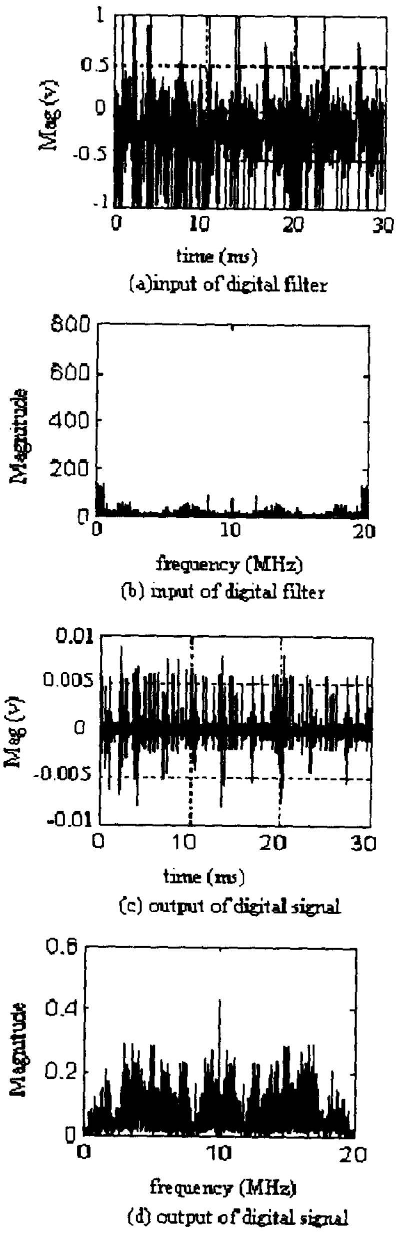


Fig. 9 Field test results

4. Conclusions

(1) A broadband PD on-line monitoring system was developed which can be applied for PD on-line monitoring test effectively and tracing insulation degrading procedure.

(2) Two typical discharge sources were simulated: Internal discharge in the stator bar; Slot discharge between insulation and stator core. Characteristic spectrum was obtained, which can be used as the basis of generator PD on-line monitoring and diagnostic technique.

(3) The filter system which was applied contained a programmable fabricate filter and an adaptive digital filter. The programmable filter consists of three bands, which is from 10kHz to 100kHz, from 10kHz to 2MHz, from 10kHz to 10MHz. The adaptive digital filter is a FIR structure, RLS algorithm digital filter. With the above filter system, the noise can be suppressed up to 40dB. Discharge signal can be extracted from rather large noise surroundings. Simulated test and field test results show that this filter system can be a great help to suppress noise in PD measurement especially for on-line monitoring system.

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