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Practical application of on-line partial discharge monitoring techniques on 500kV shunt reactors

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Abstract: Considering the damage mechanism caused by partial discharge in oil-impregnated paper insulation, a concept of "destructive partial discharge" is introduced in this paper. Its intensity is regarded as several thousands pico-coulomb (pC) and may cause the insulation a fatal damage. However, an oil-paper insulation is usually able to withstand this type of damage for a period of time before the breakdown occurs. This provides engineers a window to detect it thus any further disastrous power failure may be avoided. This paper has briefed the design of an on-line partial discharge monitoring system for 500kV shunt reactors. Two years later after the installation, a pre-warning signal was received from one shunt reactor indicating the existence of an intermittent discharge. The acoustic emission system had located its position at the low end of the high voltage bushing in the oil. Dissolved gasses analysis (DGA) in the oil also suggested the presence of partial discharge, as acetylene (C_2H_2) was as high as 20ppm. This on-line detecting result was further confirmed by a physical examination on the reactor.

1. Introduction

Shunt reactor as a reactive component is widely used in long distance high voltage transmission grid for regulating purpose. Its reliable operation directly determines the safety of the whole transmission system. Like other high voltage apparatus, its reliability is mainly dependent on the performance of its insulation system and the test on the integrity of the insulation system after the manufacture is not able to avoid the faults caused by the insulation deterioration in the operation. For instance, an investigation carried out on power transformer rating 110kV and above by EPRI of China [1] showed that about 70% of failures were caused by the insulation degradation during the operation. For a long time past, most of these insulation defects could be discovered and prevented by routine test. The analysis of the dissolved gases (DGA) and the decomposed byproducts of the cellulose insulating paper in the oil impregnated insulation apparatus are the most effective and widely used technique to detect gradually developed latent faults [2-4]. However, it may not succeed to find a quickly developing fault between two samplings. There are a few such examples in which insulation breakdown occurred without any warning signs in advance, although the critical partial discharge test has been carried out in the manufacture and on site after the installation. A further examination into these faults found that some partial discharges initiated at the certain weak points of the insulation were responsible for the final breakdown.

The initiation and development of partial discharge in the oil-impregnated insulation may vary in a great extent depending upon the structure of the insulation and electric stress. Most dangerous discharges are those develop very quickly and lead to an insulation breakdown in a short period of time. Up till now, there is no diagnostic method available to predict this kind of fault happening. Detailed investigation both in the laboratory and the fault cases [5] revealed that most of the partial discharges in the oil-impregnated insulation had a relatively long developing time prior to the electrical breakdown. They are simply classified as the treeing-type discharge along the surface or through the bulk of the pressboard and the discharge in the void (or air bubble) present in the oil or pressboard and floating element discharge. If these partial discharges could be found timely, the cost of the tremendous apparatus damage and the unplanned downtime lost of the power system would be reduced. Therefore, the aim of an on-line partial discharge detecting scheme is to find the partial discharge being of this level which could bring crucial damage to the insulation system and to give a pre-warning by "watching" the apparatus continuously.

2. Partial discharges in oil-impregnated insulation

A shunt reactor connected to a grid will pick up different interference signals, which are, in many cases, much bigger than the partial discharge occurred inside the apparatus. It is therefore difficult to discriminate the interested partial discharge signal from these noises. This means that an on-line PD detection will be difficult to achieve the same detecting sensitivity as the test carried out in a laboratory or under the condition of the apparatus being out the service [6].

It has been reported that the discharge in the air bubble in the insulating oil has a relatively low level which is usually not more than 2,000pC[5]. This type of discharge will only result in gradual deterioration of the insulating material and can be found after a certain period of operation. However, the partial discharge in the oil or paper insulation due to high electric stress will usually cause damage in a short period of time and leave carbonised tracks inside or on the surface of the pressboard. Its intensity is about several thousands pC or even more. The experimental results showed that different electrode and sample arrangements give different withstand times ranging from 2 to 15hours before the breakdown under such a discharge level.

The partial discharge being of this order of intensity in the oil-impregnated insulation is defined as “the destructive discharge”.

Both experimental results and the investigation on the real faults occurred in power transformers (insulation structure is similar to that in shunt reactor) indicated that even if this type discharge occurs, it normally takes some time to develop before the electrical breakdown occurs. These characteristics of large partial discharge have provided us a window to detect it before the disastrous electrical breakdown takes place.

3. Conceptual design of the on-line partial discharge detecting system

As the on-line detecting system has to perform in a very “noisy” atmosphere in which the real partial discharge from the insulation may be in the same order as the interferences from the overhead line corona, telecommunication and power electronic apparatus. The greatest challenge is to distinguish the partial discharge signal from these strong interferences.

Due to the single phase design of 500kV shunt reactor, the techniques of differential pulse current detection and pulse current polarity discrimination were adopted with the supplementary of an acoustic emission detection system to suppress the disturbance from the outside. The whole system is schematically illustrated in figure 1.

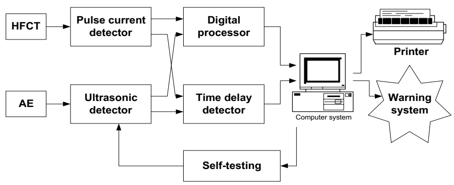

Figure 1. Block diagram of the on-line detecting system

3.1 Pulse current detector

The corona discharge from the overhead lines is always the difficulty for partial discharge detection as both of them have the similar frequency domain and amplitude. However, the opposite direction of the external corona and the internal discharge at the measuring point may be used to make a distinction between them by adopting a differential balance detecting circuit as shown in Figure 2.

The method was initially suggested and used by Malewski *et al* [7] in a single-phase power transformer. The partial discharge in the transformer will produce a current pulse which circulates between the neutral terminal and the oil tank earthing wire in opposite direction. On the other hand, the current due to corona from the overhead lines will have the same flowing direction in the neutral point and the tank grounding wire. By making a comparison between these two signals in a carefully chosen detecting frequency band, the corona disturbance can be suppressed to a sufficiently low level.

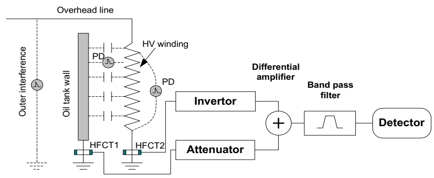

Figure 2. Schematic diagram of the differential detector

On the basis of this principle, an improved differential detecting system was designed for using on single-phase shunt reactor. The noise rejection ability is as high as 40 dB. Two pulse current signals are picked up at a high voltage bushing tap and tank grounding through high frequency current transformers (HFCT, frequency ranging from 50 to 300kHz) and amplified through the differential system.

3.2 Pulse polarity discrimination method

The basic principle of the pulse polarity discrimination method is simply described in figure 3. The external interference currents i_1 and i_2 from the high voltage side are detected through the detecting units $HFCT_1$ and $HFCT_2$. The electronic switch is locked up when the same signal polarities are identified. There will be no signal getting through the gate and the outer interference is rejected. Once partial discharge happens in the specimen, C_1, the pulse current circulating in $HFCT_1$ and $HFCT_2$ are in opposite direction and the electronic switch is turned on to let the interested signal flow into the detecting system.

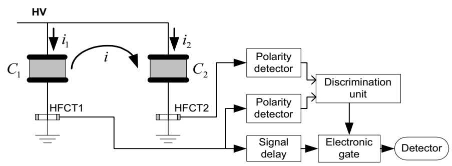

Figure 3. Pulse current polarity discrimination detector

This method was initially developed for using in a laboratory environment with a wide frequency band. As not only present corona but also some radio interferences periodically in the transmission grid, the electronic switch could be trigged continuously or locked all the time in an extreme situation. This problem may lead to the loss of the partial discharge signal in practical applications. For this reason, the method is barely used on site to measure partial discharge. A new pulse polarity discrimination system was designed in which a narrow measuring band frequency of 10kHz is employed with central frequency being variable from 50 to 200kHz. The new system is also able to adjust the detecting threshold to reject the noise with high magnitude or those signals are obviously distinguished as interferences from the outside. The detector with differential amplifier and discriminator in combination has given a sufficient elimination to the noise in the on-line monitoring system.

In order to suppress the interference impulse from the earthing grid (such as that generated by Silicon-Controlled Rectifier-SCR), an electronic windowing circuit has also been attached to the monitoring system, which locks the electronic switch as soon as the impulse signal arrives.

All the techniques listed above were employed in this on-line detecting system and a satisfactory noise elimination capability was obtained.

3.3 Acoustic emission detector

The system is also equipped with four ultrasonic detecting channels which has the overwhelming advantages in electrical interference elimination. The ultrasonic detector is briefly explained in figure 4. This also supplies an approach for locating partial discharge spot. In the case of partial discharge occurring, the current signal is detected by the HFCT installed at the high voltage bushing tap, whilst the acoustic signal emitted from the partial discharge source propagates through the different media, such as the winding, paper and oil insulation and metal tank wall and is detected by acoustic probes attached at different positions on the wall of the oil tank. The arrival time difference between the electrical signal and the acoustic signal detected at different locations presents the distance from the partial discharge source to the corresponding probe. Theoretically, the partial discharge source can be located by three acoustic probes at different positions. However, in practical application the time delays between the electrical signal and the acoustic signal is more complex. It is necessary to use a statistic method to seek the correlation between two signals. This method was firstly introduced by Kawada [8].

Due to its low detecting sensitivity and uncertain media in acoustic wave propagation path, the AE method is difficult to be used as an independent measure for partial discharge detection, especially for the purpose of quantitative measurement.

4. Results assessment

The data processing is carried out by an industrial grade computer over the monitoring period.

The features of the pulse current signal are continuously analysed. As soon as some changes appear, the reactor may be considered to have some partial discharge defects. Further assessments must be conducted to see if there are some acoustic signal being detected and the time difference between the electrical signal and the acoustic signal is of a good repetition and in a reasonable range as well.

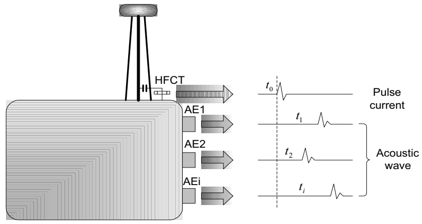

Figure 4. Schematic illustration of acoustic emission detection

There are two precaution criteria levels being set up in this on-line detecting system. Once the electrical pulse current is found abnormal, the first "pre-warning" system is trigged. If the acoustic system reports the same result, the second precaution signal is sent out indicating some partial discharge faults may exist. Further tests (e.g. DGA- dissolved gasses analysis) and measures are urgently needed to ensure the safety of the reactor.

The monitoring system is also capable of giving some useful parameter about the partial discharge, such as the average discharge current, n-q spectrum and rough location of the discharge source. These are essential for assessing the harmfulness of the partial discharge to the insulation.

It needs to be pointed out that the performance of an on-line detecting system completely depends on the ability of the system to obtain the correct signals. No matter how a complicate computer system or intelligent system is employed.

5. System installation

As the requirement of the safety regulation for the high voltage apparatus, any installation of auxiliary equipments like the on-line detecting system should not change the main electrical connection including the earthing system. The HFCT with an adequate large inner diameter can be easily installed to the oil tank grounding wire. For the HFCT installed to the high voltage-bushing tap, some modification was made on its grounding element as shown in figure 5.

The acoustic probes were firmly mounted on the oil tank surface and can also be removed easily around to precisely locate the partial discharge spot. As the pre-amplifier was adopted in the acoustic probe to improve the signal/noise ratio of the acoustic detecting system, the power for this amplifier is supplied through the single core coaxial cable whilst the signal is transmitted by carrier wave method.

All the necessary transducers, e.g. HFCTs and acoustic probes and connection cables were installed when the equipment was out of service.

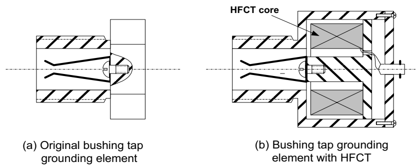

Figure 5. Grounding component of high voltage bushing tap

6. The performance of the on-line detecting system

Several years' continuous operation in field has proved the high reliable design of the system itself. The habitual self-diagnosis results indicate the systems are remaining in a normal detecting status. Pre-warning signal was received from one phase two years later after its installation. The reported results indicated the existence of an intermittent discharge and the acoustic system had located its position at the lower end of the high voltage bushing in the oil. Following suggested dissolved gasses test in the oil had also indicated the presence of partial discharge, as acetylene (C_2H_2) was as high as 20ppm. The reactor was then replaced by the standby set and the afterward investigation had proved the previous result.

Debugging test on the high voltage equipment either connected to or disconnected to the grid show that this on-line partial discharge detecting system has a high noise immunising ability. Partial discharge being of the order of 2,000pC could be detected for the shunt reactor in service.

7. Conclusion

Partial discharge detection in filed is often difficult to perform with the same sensitivity as that in the laboratory due to the electromagnetic interference from broadcasting, corona on the overhead line and power electronics. On-line partial discharge detecting is aiming at finding so called "destructive partial discharge" which has a fairly high intensity and may cause some unrecoverable damage to the oil impregnated paper insulation in a short period of time. Obviously, successful and right time detection of this defect in such expensive components in electrical infrastructures will provide utilities enough time to take proper measures.

The system presented in the paper adopted the techniques of pulse current detection, acoustic emission detection and computer assessment. All of these methods have given the system a high ability of external noise rejection.

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