Locating the PD source in power transformer using cross-correlation

상호상관을 이용한 변압기내의 부분방전위치측정

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Abstract

According to the increasing capacity of power transformer, the effect of the transformer failure have increased. In this paper, using ultrasonic signal measurement technique, which is used to diagnosis of Partial Discharge(PD) in the power transformer, Locating the PD source using cross-correlation of the two ultrasonic signals are studied.

In order to improve the accuracy, it was suggested to use the cross correlation of the two ulrtasonic signals and the results both in the simulations and in the laboratary experiments showed that the suggested method is s good one to locate PD source accurately.

요 약

전력수요의 증가에 따라 전력계통의 대규모, 고전압화 되는 현실에서 변압기의 사고는 사회여러분야에 큰 영향을 주게 되었다. 이에 세계 여러 나라에서는 변압기 사고 예방진단시스템을 연구하고 있으며 일부는 실제 설치, 운영중에 있다.

본 논문에서는 변압기사고진단의 일환으로 변압기 사고의 원인이 되는 부분방전을 제거할때 방전점을 예측하여 비용과 시간을 줄이고자 하였다.

부분방전의 위치를 예측하는 방법으로 2개의 초음파 신호의 상호상관법을 이용하였으며 모의 변압기를 통한 실험에서 오차가 4%이하로 비교적 정확한 위치예측이 가능함을 보여주었다.

1. Introduction

Recently the importance of the diagnosis and monitoring techniques of power transformer is incresing as the effects of power tranformer failure is increasing. One of the diagnosis method is testing Partial Discharge(PD) level and locating its source.[1),2),5),6),10)]

PD activity within high voltage power transformer can result in serious insulation damage. This breakdown is usually detected by the measurement of the eletrical pulses generated by the discharge or the chemical degradation products dissolved in the insulating oil.[3),4),9)]

PD also generate ultrasonic pulses which are transmitted through the oil and can be detected on the surface of the transformer tank. The time delays resulting from the signal velocity may be used to locate the PD source.[6),7)]

Locating the PD source is very important to find PD itself and to reduce the time and cost of the repairing power transformer.

And for this locating the PD source, electrical

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접수일자 : 1993. 4. 27

pulse-acoustic method and acoustic-acousitc method were studied. They have some advantage and some disadvantage over each other, but we select the latter because it is low cost, high sensitive and high resistive to the external noise such as air corona. In the acoustic-acoustic method, two acoustic sensors are used and they detect ultrasonic signals generated by PD and from this signals, time delay between the two signals is analysed to locate the PD source.

In this paper, we use the cross-correlation of the two signals to measure the difference in the arrival time of signals (time delay). Through the laboratory experiments, we demonstrate that this method have accuracy enough to use in the locating problem of PD source.

Ⅱ. Locating the PD source

PD generates electrical pulses and acoustic ones in the power transformer. Electrical pulse could be detected by Rogowsky Coil(RC) mounted on the cable of the transformer tank or of the neutral winding.

Electrical pulses propagates in the light velocity and its propagation time could be neglected. Acoustic pulses could be detected by the acoustic sensor mounted on the surface of the transformer. About 1300[m/s] is the velocity of acoustic pulses in transformer oil and about 150 [KHz] is their frequency in the range of main power.

Ⅱ-1. Current-ultrasonic location method

Electrical pulse current detected by RC could be assumed that there are no time deley (practically there are time deley about 3.3×10^{-9} [sec/m] and this signal may be used as a reference time signal. But ultrasonic pulses propagate very slowly relative to current (about 1300m/s] v.s 3×10^{8}[m/s]), and the difference in arrival time (Δt) of the two signals could be used to locate the PD source: the distance from acoustic sensor to PD source is $\Delta t \times v$, where v is the ultrasonic velocity in transformer oil. Then the PD source will be located on the surface of sphere which has radius of that distance. The schematic diagram of this is shown in figure 1.

This method has merit that the distance from sensor to PD source could be easily caculated and the PD source can be locaed with another two distance measure without complex calculations.

But it has dismerit that it is sensitive to noise.

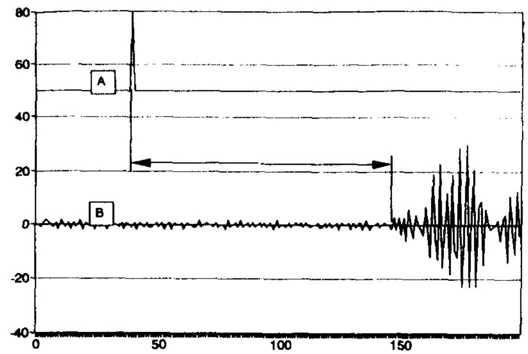


Fig 1. The current ultra sonic PD locating method

Ⅱ-2. Ultrasonic-ultrasonic locating method

Using two ultrasonic sensors, measurements are performed at the same time and the measured two acoustic signals are shown in figure 2. Some time delay to arrive the ultrasonic pulses to the sensors may be occured and this time delay may be assumed to stand the different distance d, that is

$$d = l_2 - l_1 \quad (t_2 - t_1) \times v \quad \cdots\cdots (1)$$

where v is the velocity of ultrasonis pulses in transformer oil, and t_1, t_2 are the time that the ultrasonic pulses propagate from PD source to the sensor A, B respectively.

The PD source locates on the paraboilc plane which has its focus at the sensors.

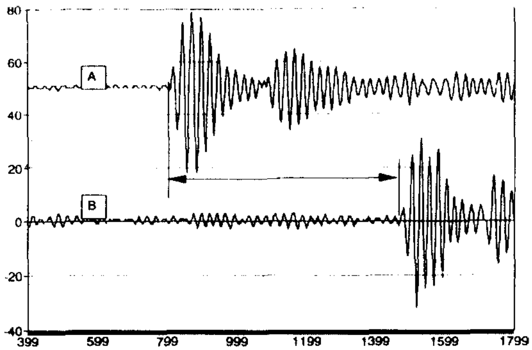


Fig 2. Ultrasonic ultrasonic PD locating method

If two pairs of sensors are used, two parabolic lines could be made. And with another one sensor pair, the PD source could be located at a point at which the parabolic line cross the another parabolic plane.

Ⅱ-3. The effects of noise in the signals

Two method described in the above may be used directly but in general, there are some difficulties to overcome. One of them is noise in the signal-electrical signals and /or ultrasonic signals. This noise cause of error to measure time t_1 and t_2, and so Δt. To overcome this, it is well known that averaging method and correlation method is effective one.(See figure 3).

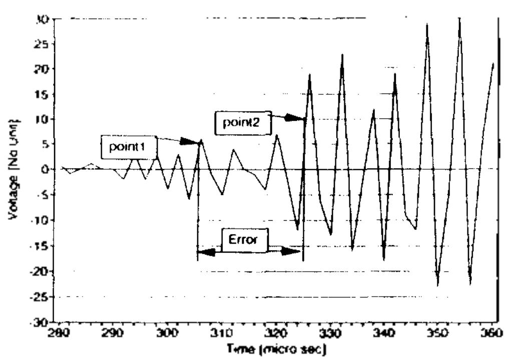


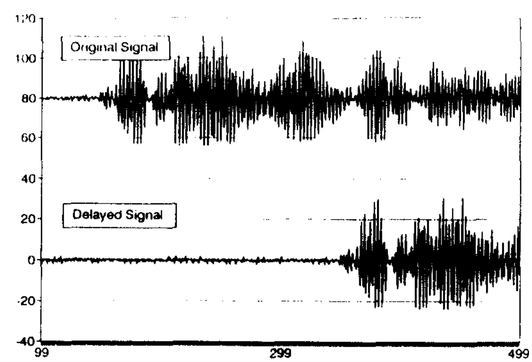
Fig 3. Error according to the threshold level in the noisy signal

To improve the signal to noise ratio (SNR), signal averaging is a well developed data processing technigue when the noise have random process property. This is essentially a digital processing where a signal is sampled. These are then summed algebraically and the average value obtained. In this way the random noise in the signal tend to be reduced to zero, while the truelt repetitive portion of signal remains essentially unaffected.[8,11]

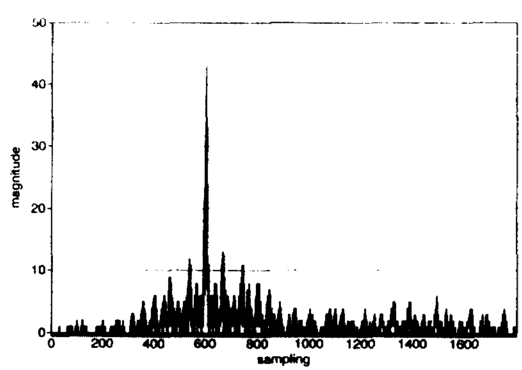
The time delay information is obtained using a cross-correlation function $r_{xy}(k)$, that is

$$r_{xy}(k)=\frac{1}{N}\sum_{n=0}^{N} x(n)\cdot y(n-k) \quad \cdots\cdots\cdots\cdots\cdots (2)$$

where N is the number of samples, $x(\cdot)$ and $y(\cdot)$ are acoustic signals detected.



(a) A original signal and a delayed one



(b) the result of cross-correlation

Fig 4. Cross correlation between a signal and its delayed one

In the figure 4, (a) is wave forms of a measured signal and its delayed one, and (b) is their cross-correlations.

Its showed that the peaks are well defined and from the difference of the time delay $\Delta t(=t_2-t_1)$ is also well difined.

Ⅲ. Experiment and the results

Ⅲ-1. Experimental apparatus

Experimental apparatus consist of steel tank filled with oil, electrode for PC generation, ultra sonic sensor with preamplifier, band pass filter, analog-digital converter with interfacing circuits, personal computer and timing circuits. Figure 5 shows this experimental set-up.

The dimension of the steel tank is 800×400×500mm and there are no coil or core but oil and insulation paper in the steel tank. PD signals generated at the gap between needle and plate electrode which is fixed at (300, 250, 400)mm (rectangular coordinate). On the outer surface of the tank, ultrasonic sensors (piezo-electric resonant transducer) is attached as shown in figure 6, and all of them have the same hight (400[mm]) which is also the same height with the PD source.

Because of this, PD locating problem reduces from three dimension to two dimension-plane problem.

The sampling rate of the ultrasonic signals is selected as 2[MHz] and sampled data are converted to 8 bits digital signals and stored in the buffertemporary memory on the interface circuit board.

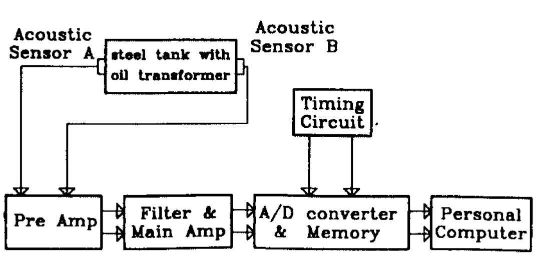


Fig 5. Schematic diagram of experimental set-up

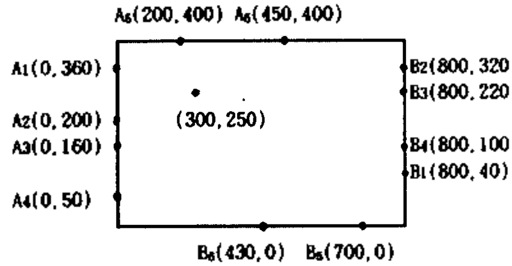


Fig 6. Allocation of the ultrasonic sensors

The data in the buffer could be transferred into personal computer.

Ⅲ-2. The results

Figure 7 is the examples of the cross-correlations of two ultrasonic signals.

Compair the two figures figure4(b) and figure7. In the figure 4(b), there are no boundary condition effects. But in the figure 7, there are included in the measured signals such that noise and mode version effects etc.. Some pseudo peaks are shown in the figure 7, but the true one could be selected easily.

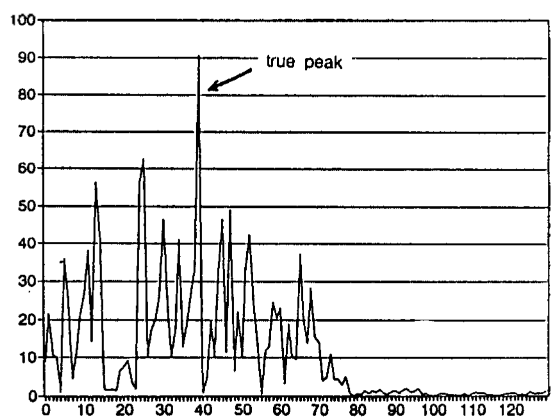


Fig 7. Cross-correlations of the measured data

(Sensors and PD source are the same points and the difference is read from these as 65 samples)

Sensor locations are shown in the figure 6, and sensor A_i with sonsor B_i is a sensor pair. The acoustic signals are detected at the same time from these sensor pairs and then data processing such as averaging and cross-correlation done.

The table 1 shows the distance difference $d_i(=|\overline{A_iP} - \overline{B_iP}|)$ and measurement one on the base of these data processing. From this table the distance difference d_i could be mesured with less than 4%.

Table 1. The results of distance measurements

di	True value(A) mm	Measured value(B) mm	Error[%] $\frac{A-B}{A} \times 100$
d1	222.78	214.11	3.89
d2	200.74	192.52	4.09
d3	187.69	185.43	1.20
d4	161.46	164.95	2.16
d5	291.42	302.87	3.93
d6	69.65	71.40	2.51

Since we selected positions of the sensors are selected as the same in height, the PD source may be located as the crossing point of the two parabolic lines which are given as following equation.

$$d = |l_2 - l_1| = |\overline{BP} - \overline{AP}|$$

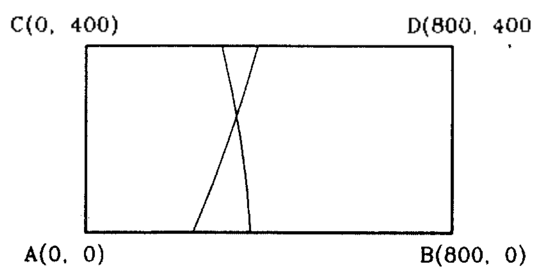
$$= |\sqrt{(b_1 - x)^2 + (b_2 - y)^2} - \sqrt{(a_1 - x)^2 + (a_2 - y)^2}| \quad \cdots\cdots (2)$$

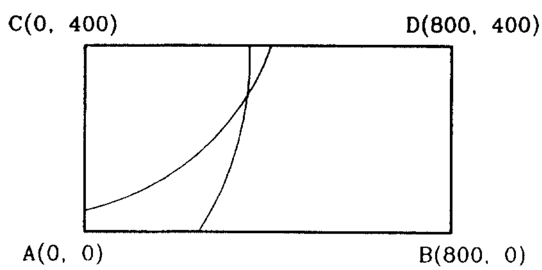
where (x, y) is the points where the PD source may be, and (a_1, a_2) and (b_1, b_2) are positions of sensor A and B respectively.

And then, if two difference of distance d are obtained, and PD location could be found. The table 2 is the results calcuated on the basis of the d's in table 1. Figure 8 shows the locating method using sensor pair S_1 and S_j.(sensor pair S_1 means sensors which is located at point A_1 and B_1) It could read in table 2 that the mean error of the PD source locating is about 3.4mm in radius, and maximum error of that is about 18.4mm in radius. This value is accurate enough to use in practice.

Table 2. The results of PD location(mm)

Sensor pairs	Measurement(x,y)	
S1 S2	(302, 254)	1.5
S1 S3	(301, 252)	2.3
S1 S4	(298, 248)	2.8
S1 S5	(307, 264)	18.4
S1 S6	(300, 251)	1.0
S2 S5	(301, 259)	9.1
S2 S6	(302, 250)	2.0
S3 S5	(300, 257)	7.0
S3 S6	(301, 251)	1.4
S4 S5	(298, 254)	4.5
S4 S6	(298, 251)	2.3
S5 S6	(295, 252)	5.3
Average	(300, 253)	3.4





(a) sensor s1－s3 pair are used

(b) sensor s1－s5 are used

Fig 8. Locus of two parabolic line (Sensor pair S_1 and S_j are used)

* remark : In table 1, there are six pair of sensors. Although 15 combinations of two sensor pairs from these six sensor pairs could be selected and there are not found three combinations such as $S_4 - S_3$, $S_2 - S_1$ and $S_3 - S_1$.

In these cases, two parabolic line is so near pararell that small error in d make big error in PD location and they are discarded as a bad data.

IV. Conclusion

PD locating techniques of the power transformers could be used to improve the reliability of the diagnosis by PD measurement and to reduce repair time and repair cost of fault transformer. In this paper, the cross-correlation method are studied to reduce the noise sensitivity and to improve measurement accuracy in the ultrasonic ultrasonic PD location method.

The loaborotary experiments showed that this method was good performance as we expected. The error in the difference measurement was less than 4% and mean of that in the PD location is 3.4mm in radius.

Although we used the steel tank filled with oil but without any coil or core and we experimented in the lab where there are relatively low external noise, it was verified that PD locating method base on the cross-correlation method is very accurate and useful.

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