Experiences with a Non-invasive Capacitive Sensor for On-line Partial Discharge Detection in Power Transformers

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Abstract

Most power transformers are equipped with special capacitive connections in the lower part of the bushing (bushing tap). By means of these connections partial discharge could be detected and measured in high frequency ranges but the poor earthing of these connections in PD measuring device may suffer the voltage distribution along the bushing. Additionally some of the old transformers haven’t this facility and because of the ageing, on-line PD measurements are also necessary for these devices. This contribution suggests an appropriate method to equip the transformers with a non-invasive capacitive PD sensor. This sensor particularly is suitable for on-line PD measurement and can be adapted to existing transformers. The optimisation method for this type of sensor is suggested and the experiments in the laboratory and also on-site are reported. The effect of various parameters on the performance of the sensor is described and the optimisation method for this type of sensor is suggested as well. The use of this sensor allows the partial discharge detection and localisation within a transformer and contributes therefore to a better monitoring and diagnostic of power transformers.

1 Introduction

An efficient tool for diagnostics and condition monitoring of the power transformers is measuring of partial discharge (PD). There are numerous devices available in the market for measuring PD in transformers but they have not been practically or economically applicable for a wide range of ratings of transformers as an on-line measuring and monitoring system. The reason is therefore that the equipment needed are quite expensive and processing of PD data is complex and requires experts to evaluate. To minimise costs and complexity of on-line PD measurement systems the required components have to be simplified and integrated without loosing the performance.

PD sensors play an important role in PD measurement systems. It is known that PD’s are very short duration current pulses and cause electromagnetic radiation. The base of all electrical PD detection systems is to detect the electromagnetic waves radiated by PD pulse so the capacitive and inductive sensors has been developed to pick up the energy of electric as well as magnetic waves caused by PD.

Our previous works for developing an on-line PD monitoring system [1] revealed that capacitive decoupling of PD on the surface of bushing at the bottom near the ground potential can be used efficiently. This kind of sensor also has been applied in order to localise PD origin in dry type transformers by Schering institute in Germany as well [2]. This work is an attempt to evaluate the performance of this type of sensors and try to optimise it for applying in a real PD monitoring system for oil immersed power transformers.

According to the kind of field which is used for PD detection, there are various sensor systems. Among them the capacitive and inductive sensors which use the energy of electric and magnetic field respectively are more common and therefore are more important. Due to the weak signal to noise ratio of inductive sensors their application for on-line PD measuring is confined.

2 Capacitive PD sensors

The capacitance between high voltage conductor and the electrode which is used for picking up the PD pulses as a capacitive sensor acts as a high pass filter for PD signals.
The proposed capacitive sensor is a thin layer of conductor which is installed on the porcelain surface of the bushing near the ground potential.

**Fig. 1** presents two versions of this sensor which were used in our investigation. Figure 1a shows a copper strap sticking up on the porcelain surface whereas figure 1b shows a conducting material coated on the porcelain by means of thermal process and a thin wire has been connected to this conducting surface.

![Fig. 1](image1.png)  
**Fig. 1**: Two capacitive sensors  
a. copper strap  
b. coated conduction material

### 3 Calculation of sensor capacitance

The capacitance of the sensor could be calculated using the relation for the cylindrical capacitors. **Fig. 2** shows the cylindrical capacitor while the outer conducting surface with the width of \( l \) covers all around the cylinder.

![Fig. 2](image2.png)  
**Fig. 2**: Cross section of a cylindrical capacitor

The capacitance is calculated with:

\[
C = \frac{2\pi \epsilon l}{\ln \frac{R}{r}}
\]  
(1)

\( \epsilon \) is the permittivity of the insulation between the two electrodes, \( l \) denotes the width of the conducting strap and \( R \) and \( r \) are the outer and the inner radius respectively.

**Fig. 3** Coaxial capacitor bushing with field stress control

In some bushings the outer conducting layer which is located just under the proposed sensor and behind the porcelain surface is grounded therefore the calculation of sensor capacitance is very cumbersome. A complicated model has to be considered for such a capacitive sensor for instance the one presented in **Fig. 4**. The C’s show the capacitance between conducting layers through paper and oil insulation which are in series with the sensor. C1c’s are the capacitance between the additional length of each cylindrical layer and the ground and the C2c’s are the stray capacitance
between sensor and various conducting layers. The resistors model the volume and surface resistance of the insulation. To investigate the influence of various parameters on the output of the sensor, a pulse voltage is injected to the inner conductor of the bushing while the output of sensor is connected to a detection impedance as the same as the impedance which is used for PD measuring devices.

Fig. 4  A detail model for the capacitive sensor and the bushing

4  Experimental results

4.1  Comparison of cupper strap and the coated conducting material

To study the effect of air gap between the porcelain surface and the conductor of capacitive sensor two configurations are used. As is shown in figure 1 the first sensor is a cupper strap sticking up on the porcelain surface of the bushing so there exist a small gap between the conductor and the porcelain. The second sensor is a conducting material coated at the surface of the porcelain with the thermal process; therefore in this case there is no gap between surfaces using this type of sensor. The size of conducting surfaces is the same in the two types of sensors.

A short duration square pulse was applied to the high voltage conductor and the outputs were measured at the sensor electrode while it grounded through PD detection impedance. The outputs showed no significant difference as is shown in Fig. 5. The cupper type sensor even indicates a better result therefore the cupper strap is more suitable to be used as the PD capacitive sensor because of the simple installation and no need to thermal processing of coating.

4.2  The effect of sensor dimensions

To investigate the effect of the width and the length on the performance of the cupper type sensor some measurements were carried out. While a square pulse shape signal was injected to the high voltage conductor with reference to ground, the sensor output which is grounded through RLC detection impedance was measured by means of a high frequency digital recorder. The voltage amplitude of the sensor is increased by increasing the width as well as the length of the cupper strap but the output changes are not completely linear. The results in time and frequency domain are shown in Fig. 6.

Fig. 5  The outputs of the cupper strap type and the coated conducting material type sensors

Fig. 6  The effect of cupper strap dimensions (width and length) on the sensor output in time and frequency domain

Another experiment was carried out to study the effect of horizontal and vertical installation of a single cupper strap with different length and width dimension. The results shown the vertical installation has a better output. The reason therefore may be that the inner
conductor in the bushing is vertical and more effective capacitance is attained if the strap be installed vertically.

4.3 Effect of grounded sheath

It is shown in figure 3 that there are various cylindrical conducting sheaths in bushing in order to equilibrate the potential from the inner high voltage conductor to the ground potential of the transformer tank. In some bushings the outer sheath just behind the porcelain surface is grounded and can be used as the bushing tap for some measurements.

![Diagram of bushing with grounded cylinder](image)

Fig. 7 Signal level of sensor output when the position of a grounded cylinder changes along the bushing

The results are shown in Fig. 7. With the grounded cylinder in the other positions the output is increased.

The connection between the sensor electrode and the detection impedance also plays an important role to the level of signal. If a coaxial connection is used the signal will attenuate considerably. By means of a connecting wire with a minimum inductance the output signal is quite good.

5 Conclusion

The outputs of the two sensors one made of conducting material coated on the surface of the porcelain and the other one made of cupper strap showed no significant difference therefore the cupper strap type sensor is more suitable for PD detection economically.

The voltage amplitude of the sensor is increased by increasing the width as well as the length of the cupper strap but the output changes are not completely linear so a cupper strap covering a small part of the bushing is enough in order to pick up the PD signals.

The signal picked up by the sensor attenuates if a grounded sheath exists behind the porcelain surface but even in this case the SNR is still enough for PD measurement.

6 Literature
