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Application of Acoustic Sensing and Signal Processing for PD Detection in GIS

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Abstract

The presence of free moving metallic particles and discharges deteriorates the insulation strength of a compressed SF_6 (Sulpher-hexa fluoride) Gas Insulated Switchgear (GIS) and causes serious limitation in its practical application. Free moving metallic particles and other defects inside GIS cause partial discharge (PD) which can degrade insulating properties of insulant gas SF_6 to such an extent that breakdown may occur in GIS system. So, it is necessary to detect partial discharge in GIS at an early stage before the system failure and extensive damage to the equipment and the rest of the power system. Partial discharge emits acoustic signals which can be detected by applying an acoustic emission sensor (AE sensor) outside the GIS chamber. This paper initially describe some fundamental aspects as related to PD detection. Finally development of acoustic PD detection system and some experimental investigation have also presented.

Keywords: Acoustic emission sensor, PD detection, Signal Processing, GIS.

1. Introduction

GIS are now widely used in the electricity supply system throughout the world including Malaysia because of its superior performance. The SF_6 is an excellent dielectric for high voltage application and it is used as an insulant in GIS. However, the excellent insulating properties of SF_6 are adversely affected by conducting metallic particle and partial discharge. Although the GIS is highly reliable, any internal breakdown due to metallic particle or partial discharge may cause serious damage to the operating equipment and financial penalties due to service interruption and maintenance would be very high. A system is, therefore, required to monitor the condition of GIS apparatus to prevent system failure. Among the various detection means available, the partial discharge testing using acoustic technique is one of the most effective diagnostic tools for the detection of defects in GIS. The acoustic method is the promising one because of its high sensitivity to most common defects and immunity to electromagnetic interference (EMI).

The characteristics of acoustic signal from defects in GIS are the basis for the choice of test procedure and instrumentation. The test instrument should be simple, portable and easy to use. Also it should not pose any hazard to the operating personnel and equipment. A portable PD detector has been developed that can detect acoustic signal from PD and metallic particle inside GIS.

The main objective of this paper is to provide a theoretical and practical basis for PD detection in GIS using acoustic technique.

2. Acoustic PD Detection

Acoustic PD detection is based on detection of acoustic signals emitted from partial discharges and free moving metallic particles bouncing on the GIS chamber floor. The acoustic signals inside GIS have broad bandwidth and travel from the source to the sensor by multiple paths. The acoustic signals generated by partial discharges or metallic particles inside the GIS can be picked up by using an AE sensor attached to the outside of the GIS chamber together with a portable PD detector. The output of the PD detector then can be analysed using a storage oscilloscope or a personal computer. By analysing the nature and shape of the acoustic signal it is possible to reveal the type of defects associated with the deterioration of the dielelectric properties of SF_6 before the system fails completely.

3. Fundamental Aspect

3.1 Acoustic wave Propagation in GIS

The Propagation of an acoustic wave takes place in elastic solids, viscous compressible fluids and perfect compressible fluids such as SF_6 gas in GIS [1].Unlike the electrical signals produced by PD the acoustic signals have many modes and paths of propagation. The propagation paths include entirely through gas, entirely through the casing and involving many combinations of the two. The acoustic signals from the particles propagate through metal to the sensor. On the other hand, acoustic signals due to partial discharge propagate through gas and metal before they reach the sensor as shown in Fig.1.

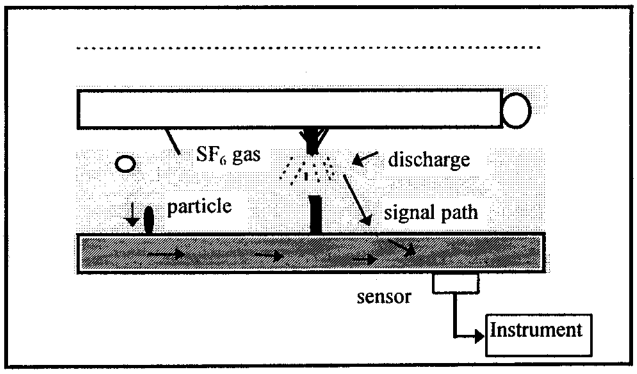

Fig. 1. Defects and Signal paths in GIS.

Acoustic wave propagation through different media depends on the matching of the acoustic impedance of the media involved. The ratio of acoustic pressure **p** in a medium to the associated particle speed **v** is the specific impedance [1],

$$z = p/v \tag{1}$$

For a plane wave the ratio is

$$z = \rho_0 c \tag{2}$$

where

ρ_0 constant equilibrium density.

c phase speed .

ρ_0 c is called the characteristic impedance of the medium For efficient transmission , the characteristic impedance should be matched.

Acoustic wave transmission and propagation in a solid is a very complex problem. Assuming an infinite medium, waves will then propagate in two modes: longitudinal (compression) and transversal (shear) wave. The two waves do not propagate with the same velocity. The transversal wave propagate at around 60 percent of the speed of the longitudinal wave. The sound velocity in SF_6 at atmospheric pressure is 156 m/s [5]. In the case of a pipe (like a GIS chamber), a cylindrical boundary is introduced and the two waves might then combine to form a Raleigh wave. The three waves propagate with different velocities. As the three waves are reflected, a very complex wave pattern will be introduced [4]. In a gas, acoustic waves are longitudinal waves, the molecules move back and forth in the direction of propagation of the wave, producing adjacent regions of compression and rarefaction similar to those produced by longitudinal waves in bar. The restoring force responsible for propagating a wave simply the pressure change that occurs when a fluid is compressed or expanded. This can be best explained from acoustic wave equation. For a time harmonic plane acoustic wave propagating in the x direction, the acoustic pressure (P) is given by [1, 2],

$$P(x,t) = A_0\{\sin(\omega t \pm \frac{\omega x}{c})\} \tag{3}$$

This equation indicates that pressure wave varies with time(t) and location with an angular frequency ω . The value of excess pressure repeats itself f times a seconds ($T=1/f$). At any given time, the pressure repeats itself with a space interval (along the direction of propagation) given by $\lambda=c/f$.

3.2 Signal Attenuation

When an acoustic wave propagate through GIS, the intensity and amplitude of the wave decreases as a function of distance from the source. The amplitude of an acoustic signal is proportional to the squire root of energy [2]. Attenuation is the loss of acoustic energy from a sound beam. The attenuation of the waves is frequency dependent. This is much more pronounced in non-metallic materials. In a GIS, The signal attenuation can be caused by:

- Transmission loss in propagation from one medium to another (SF_6 gas to GIS chamber)
- Scattering of acoustic energy in the medium
- Acoustic absorption in the medium.

3.3 Noise

During PD detection in GIS, the acoustic signals are influenced by various noises that may cause false indications during PD tests. The characteristics of noises and their sources should be known to separate them from PD signals.

Noise arises from variety of sources and the detection instrument should be shielded properly to minimise its effect. Electrical noise may be introduced due to thermal effect in the detection circuits. External noise is more severe than thermal noise in the detection instrument. The sources of external noise are:

- Corona discharges from power supply system that may introduce during PD test
- Mechanical vibration of the equipment under test
- Arc welding near the detection instrument
- Power line carrier communication
- Radiating Electromagnetic signal
- Radio transmissions
- Thyristor switching
- Switchihg transient noise.

4. Instrumentation and Signal Conditioning

The acoustic PD detection system shown in Fig.2 contains of the following units:

- PD Detector
- Fibre-optic system for signal transmission
- A/D Conversion
- Storage oscilloscope and Computer.

4.1 PD Detector

A new portable PD detector has been developed which can receive acoustic signal from sensor output. It consists of the following sections:

- Sensor.
- Pre-amplifier
- Amplifier.
- Band-pass Filters.

Sensor: The detection of partial discharge highly depends on sensor. Sensitivity and bandwidth is a primary consideration for the selection of sensor. Acoustic emission sensors are used for PD detection in GIS. AE sensors are ultrasonic resonant sensor of frequency response from 20 kHz to 1 MHz. They are made from piezoelectric crystal. These sensors produce an electric signal proportional to the received acoustic signal.

Pre-amplifier: Since the sensor output voltage is very low (in the μv range) the signal from the sensor is amplified first with a pre-amplifier. The pre-amplifier must have good frequency response, high stable gain, low noise, high slew rate and ability to operate with input voltage in the μv range. A pre-amplifier of 40 dB gain has been designed. The signal from pre-amplifier is filtered, amplified and filtered again in the PD detector.

Amplifier: An amplifier has been designed with variable gain from 20 dB to 60 dB with a step of 10 dB to match the acoustic signal level with measuring instrument. The amplifier uses distributed amplification to prevent noise from overloading the amplifiers and to reduce amplifier noise. For a distributed amplification it is possible to use op-amps of lower gain-bandwidth-product and thus reduce cost, noise and circuits complexity [4]. The noise contribution of op-amps with higher gain-band width-product is high and it is also expensive.

Band Pass Filter: The output signal of amplifier obviously contained a degree of noise from various sources. To reduce the effect of noise on the PD detection system performance, filters are designed to attenuate unwanted noise from the signals. Two types of variable band pass filters are designed: Multiple feedback band pass filter (narrow band) and Filter with low pass and High pass section has been used to create a band pass filter (wide band) using Sallen-key circuits.

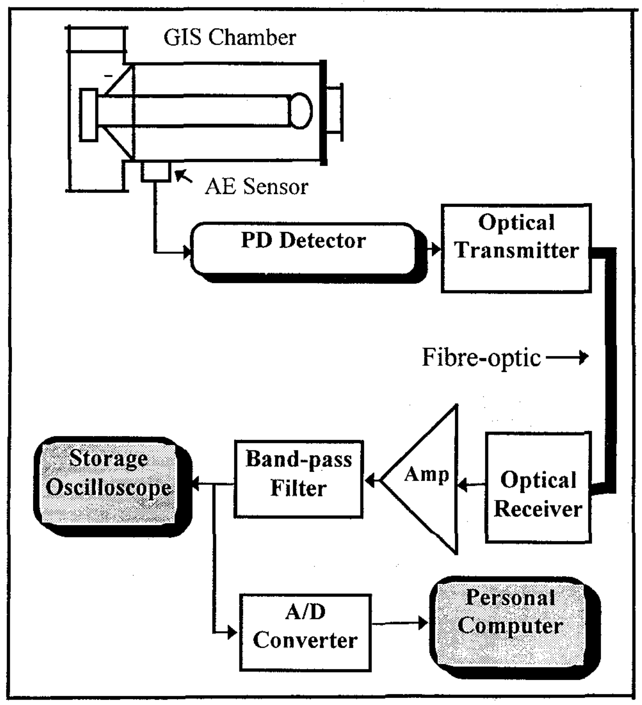

Fig. 2 : Acoustic PD Detection System.

4.2 Optical-Fibre System for data transmission

The signal from PD detector is to be transmitted to the computer-based PD measuring system installed far away from the GIS. The optical fibre system is used for data transmission to reduce the influence of interference of external noises [5]. In the transmitter, the signal is modulated by a voltage controlled oscillator (VCO), The signal then fed to a light emitting component which changes the electrical signal to light signal. The optical fibre system transmits the light signal to the receiver unit where the light receiving component (photo detector) receives the light signal and changes it to electrical signal and amplifies it. The receiver output signal is identical to the PD detector output signal. The receiver include a filter bank to separate the signal and carrier waves and after demodulation the original signal is recorded for processing and analysis.

4.3 A/D Conversion

To use computer for data acquisition, pattern display and signal analysis, the analog signal is to be converted to digital signal. The first stage for digital signal processing is the conversion of the analog input signal. This conversion requires a Sample & Hold circuit and A/D Converter. The accuracy depends on sampling rate and A/D Converter. The minimum sampling rate allowed to reconstruct a band limited (B Hz) wave form without error is $f_s = 2B$. For no aliasing f_s should be greater than 2B (Where 2B is the nyquist frequency.)

5. Experimental Investigation

Using the developed acoustic PD detection system the tests were performed in the laboratory. The performance of this system were satisfactory. The system can detect PD and metallic particles inside the GIS chamber.

Calibration of acoustic sensor is accomplished by generating a known acoustic signal. A metallic particle of 15 mm length (1 mm dia.) was dropped down on a steel pipe to simulate acoustic signal and sensor was calibrated using this signal as shown in Fig.3.

To simulate PD in GIS, the set up shown in Fig.4 has been developed. This consists of a coaxial cylindrical chamber and electrode system with variable spark gap. A high voltage generator was used for voltage supply. The simulation and system were used to simulate corona discharge, floating electrode discharge etc. Experiments were also performed on a real GIS chamber.

The nature and shape of the acoustic signal from various sources contain valuable information about their sources. It is possible to know the cause of partial discharge from the characteristics of detected acoustic signals. Free moving

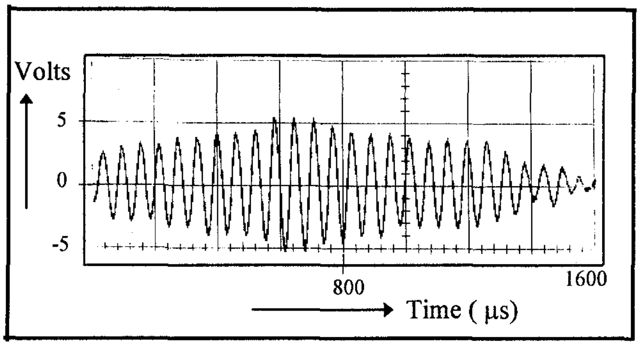

Fig. 3. Typical Acoustic signal used for sensor calibration.

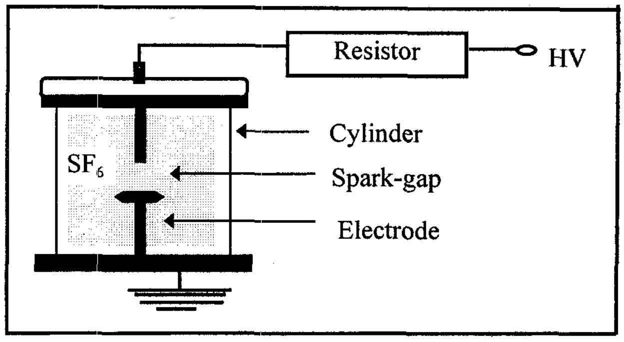

Fig.4. Simulation of GIS

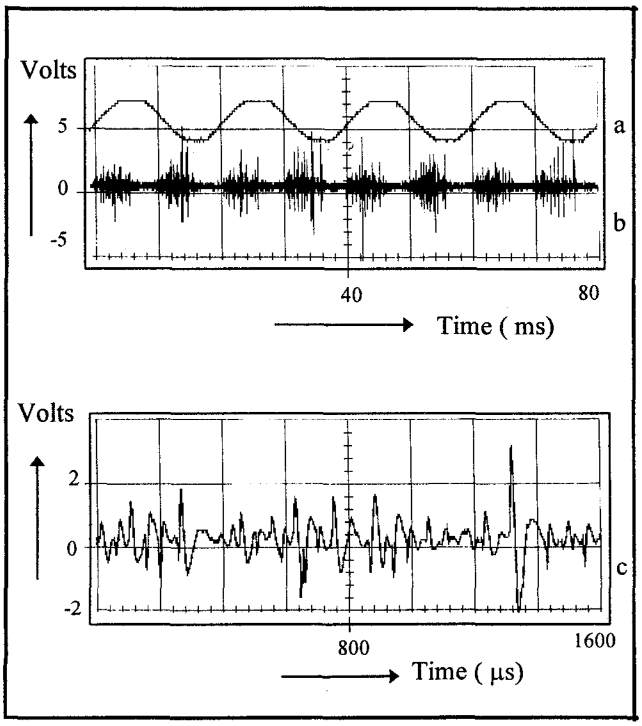

Fig. 5. Acoustic Signal from partial discharge (40 kHz sensor used).

a) Power cycle.

b) Acoustic signal.

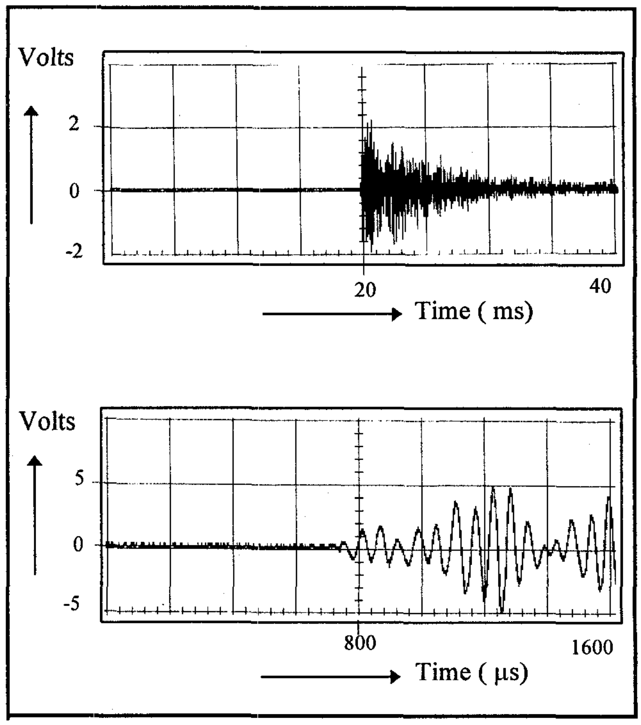

Fig.6. Acoustic signals due to particle impact (sensor placed 0.4 m from source).

metallic particles bounce in side the GIS chamber due to high electric field and acoustic signal due to their impact on the chamber can be distinguished easily from other signals. Metallic particles produce pulse type signals and the signals are not correlated with power cycle as shown in Fig.6. On the other hand, partial discharges generate continuous signal which appear randomly and correlated with power cycle as shown in Fig. 5. The sharpness of the acoustic signal depends on the distance between sensor and the source. The location of the source can be revealed from the sharpness of a signal. The easy method for source location is to apply two sensor and measure the difference in the arrival time of the signal. From this time lag the distance to the source can easily be determined.

6. Discussion

The acoustic PD detection system has been successfully applied to detect PD and metallic particles inside GIS. A frequency analysis shows that most of the energy emitted from PD is in the ultrasonic frequency, but SF_6 is a poor ultrasonic transmission medium. Acoustic signal travelling through SF_6 become heavily distorted because of large sound absorption in SF_6 gas.

some knowledge about frequency content of the acoustic signal and noises is necessary to select the appropriate sensor, preamplifier, amplifier and filters. For signal analysis time domain approach is more efficient than frequency domain approach.. The visual observation of time domain signal with respect to signal shape, duration, rise time, correlation with power frequency is sufficient to characterise a defects in GIS.

A computerised neural network approach is useful to improve signal interpretation, pattern recognition of PD and encourage the future development for automatic detection of defects in GIS

7. Conclusions

The concept of basic acoustic theory (wave propagation, attenuation, reflection etc.) is a prerequisite for correct interpretation of the detected signals. Also the characteristics of external noise and signal should be known.

The developed PD detection system was successfully used to detect the internal partial discharge and metallic particle inside GIS. The new PD detector has several advantages such as low cost, small size, outage independence, portability and accuracy . Also it has better immunity to noise.

The optical fibre system was used for signal transmission to reduce the influence of noise and to avoid risk of equipment fault.

An acoustic emission sensor working in ultrasonic range (20 KHz to 100 KHz) is suitable for PD detection in GIS.

From the nature and shape of the detected acoustic signal it is possible to reveal the type of defects in GIS.

Experimental investigation shows that the performance of the acoustic PD detection system was satisfactory.

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