ON LINE DETECTION OF PARTIAL DISCHARGE IN HIGH VOLTAGE EQUIPMENT USING ACOUSTIC EMISSION TECHNIQUE

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Abstract: Throughout the decade, generation of the high voltage (HV) electrical power gradually increases due to increase of demand in industrial growth as well as to meet the demand for modern civilization. Extensive electrical power networks installations have been built in industrialized countries and are being constructed in developing countries at a rapid increasing rate. The major function of such power systems is to generate, transport and distribute electrical energy over large geographical areas in an economical manner while ensuring a high degree of reliability and quality of supply. Apart from these, high voltages are also widely used in many industrial as well as engineering applications. In all such applications, the high cost and comparatively long life span of HV power equipments are need to be take care of continuously from its degradation. The degradation of insulation is responsible mainly for internal discharge i.e., Partial discharge (PD). High voltage insulation condition monitoring is one of the major important diagnostic tools for servicing the better quality of power. Therefore, on-line detection of PD in high voltage power equipment is getting more importance in the field of insulation diagnosis for early detection of incipient fault. In this work, detection of PD in the oil-paper insulation model has been carried out in high voltage laboratory using Acoustic Emission Technique. The observed PD signal is also analysis with the Fast Fourier Transform (FFT) and the Short Time Fourier Transform (SFFT) algorithm which is having the potential to find out the frequency component of PD signal with respect to time. This study intends to process the UHF signals obtained from indigenous developed experimental setup. The technique is having great potential to detect the PD activity inside the high voltage power equipment at any time without any power failure.

1 INTRODUCTION

Energy supply companies, national and regional power generation and transmission authorities spend large sum of money per year to maintain high reliability of electricity supply to consumers. Therefore, the reliability of the huge system is a function of the reliability of the many individual components such as transformers, circuit breakers, current transformer, potential transformers, motors, generators etc. Major attention has been paid to electrical insulation especially in high voltage transformers as it is consider one of the most important components of the power system network. Deterioration of such transformer insulations is one of the cause is Partial Discharge (PD) [1]. Physical and statistical models are required to understand the process leading to insulation degradation. Partial discharge occurs when this breakdown is confined within a small defect in transformer [2- 4]. This PD energy slowly creates a breakdown path which is seen as Electric Treeing in solid cavities.

The diagnosis and early detection of internal faults of high voltage equipment has become a prime interest to acquire failure tolerance, reliability, safety and the energy efficiency of all complex engineering system. Nowadays, online monitoring of high voltage power equipment and the early detection of potential failures are given great importance as these equipments of the power system play a crucial role for operation of the power system network [5-6]. The early detection of internal failure of high voltage equipment has done with several methods such as Dissolve Gas Analysis (DGA), Fiber Optic Sensor (FOS), Ultra High Frequency sensor (UHF sensor) etc. [7-14].

Acoustic emission (AE) inspection has been widely employed as a powerful aid for material testing and the study of deformation and fracture [12, 13]. Since, it is produces due to time varying rarefactions of the medium through which it passes; it is very specific to the defect type. The AE based frequency for oil gap was found to be over 200 kHz [4]. The on line PD detection was attempted by Black Burn [7]. AE techniques have been employed as testing tool for oil filled equipment such as reactors and transformers of voltage rating above 400 kV [8-10]. Apart from acoustic techniques, electrical detection and chemical detection methods have been used which rely on capturing electrical impulse generated by current streamers and change in chemical composition (in the form of by-products) using either Dissolved Gas analysis or High performance Liquid Chromatography, respectively.

In this work, on line detection of partial discharge in the oil-paper insulation model has been introduced in high voltage laboratory using acoustic emission technique. The observed PD signal is also analysis with the Fast Fourier Transform (FFT) and the Short Time Fourier Transform (SFFT) algorithm which is having the potential to find out the frequency component of PD signal with respect to time. This study intends to process the UHF signals obtained from indigenous developed experimental setup. The technique is quite capable enough to detect the PD activity inside the high voltage equipment.

2 EXPERIMENTAL SETUP FOR ONLINE DETECTION OF PARTIAL DISCHARGE

A transformer of 100 kV, 15 kVA rating is used as a high voltage supply in this experimental setup. A glass made chamber of dimension 457.2 mm × 304.8 mm × 304.8 mm is used as a dielectric test cell. A needle-plate electrode is placed horizontally in the dielectric test cell. The spacing between the needle electrode configurations is maintained at 40 mm with a circular disc of radius 30 mm and thickness of the plate electrode as 3 mm shown in Fig.1. The test cell is filled up with transformer oil with 90% of its volume. The needle is subjected to high voltage and the circular disc is grounded. An acoustic sensor is placed outside the test cell to collect the PD signal generated inside the electrode. The voltage is stepped up gradually till the inception voltage of magnitude 20 kV is reached. PD phenomenon occurs and it is measured by using the AE sensor. The acoustic signal has several advantages compared to direct measurement of electric signals as it is immune to Electromagnetic Interference (EMI). The acoustic sensor with a preamplifier is connected to a Digital Storage Oscilloscope (DSO) through a filter circuit for acquiring, recording and displaying the PD signal. The laptop computer is used for online monitoring of PD activities.

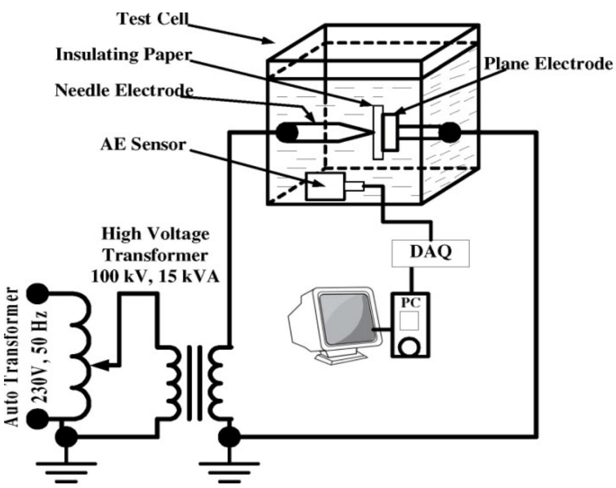

Figure 1: Schematic Diagram of Experimental Setup.

3 ACOUSTIC EMISSION SENSOR FOR PARTIAL DISCHARGE DETECTION

In this work, AE sensor PK15I is used with the narrow frequency bandwidth of 100 kHz-450 kHz and resonant frequency of 150 kHz were used to detect the acoustic signal generated by PD inside the dielectric test cell. A single coaxial cable is used for transmitting to power and receive the raw signal from the AE sensor. As the magnitude of the received the acoustic signal is too low which is further required to amplify with a preamplifier and band filter to eliminate the noise from the acquired signal. A small amount of silicon grease is used to increase the quality of transferred acoustic signal between the ceramic surfaces of AE sensor to metallic surface. The PK15I sensor is a medium frequency, resonant, acoustic emission sensor with an integral, ultra low noise, low power, filtered, 26dB preamplifier, which can drive up to 200 meters of cable. This new sensor represents an improvement in both noise and low power consumption performance, with noise level below 3 µV and power consumption of 25 mW. In order to provide excellent temperature stability over the range of -35º to 80º C the critical input stage of the preamplifier is thermally isolated. The PK15I features a strong stainless steel, integrated body structure and smaller in size. The integrated Auto Sensor Test (AST) capability allows these sensors to pulse as well as receive. This feature lets you verify the sensor coupling and performance at any time before, during or after the test.

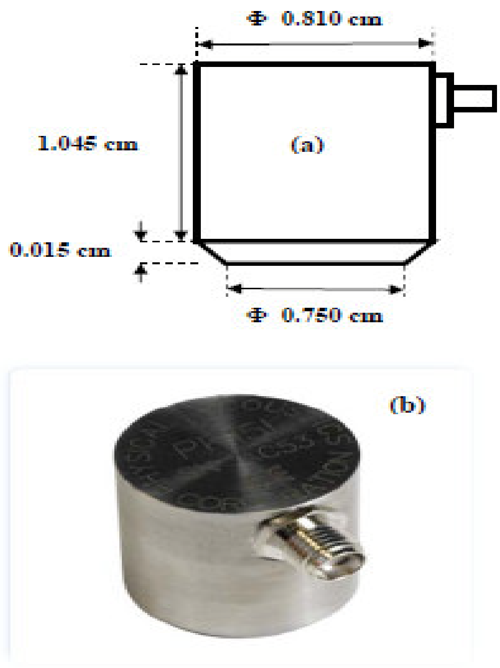

Figure 2: Acoustic Emission Sensor (a) dimensions of sensor used for PD detection (b) Acoustic emission Sensor for PD detection

This sensor is used for PD detection in the experimental setup. The front part of this made with Ceramic material and the case is made with stainless steel. Other physical, electrical, dynamic and environmental detail is given in the Table 1. In Fig. 2 (a) the dimension of the sensor is given, in that height, radius and other things are given.

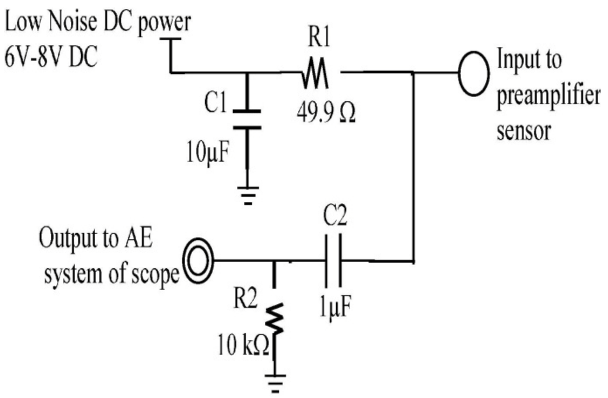

Figure 3: Power or signal connection diagram of sensor

Figure 3 shows the power/signal connection diagram. This diagram shows how the sensor is work and which electrical component is there. In this circuit diagram two resistors and two capacitors are connected as shown. The frequency response of used AE sensor is shown in Figure 4.

In The present study, the single channel ‘USB AE Node’ system is used. The AE system works on the principle of ‘hit, which can be expressed as detection and measurement of an acoustic emission signal on a channel. In Fig. 5, the peak amplitude refers to the maximum of AE signal while the energy is defined as the integral of the rectified voltage signal over the duration of the AE hit. The amplitude, energy and counts of the signals were measured to identify and characterized the partial discharge activity in the HV power equipment using integrated AE win software with the system. The duration in the graph is the amount of time from the first threshold crossing to the end of the last threshold crossing. Counts are equivalent to the number of AE signals that exceed threshold while the count rate gives the number of counts per unit time. The rise time is the time from the first threshold crossing to the maximum amplitude and the average frequency is the AE counts upon the entire duration as shown in Fig. 5.

The five most widely used signal measurement parameters are amplitude (A), counts (N), duration (D), rise time (R) and the measured area under the signal envelop (MARSE) shown in Fig. 6. The amplitude is the highest peak voltage attained by AE waveform. This is very important parameter because it directly determines the delectability of the AE event.

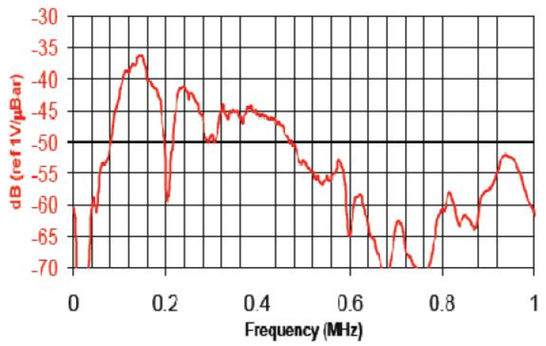

Figure 4: Frequency response of R15I sensor

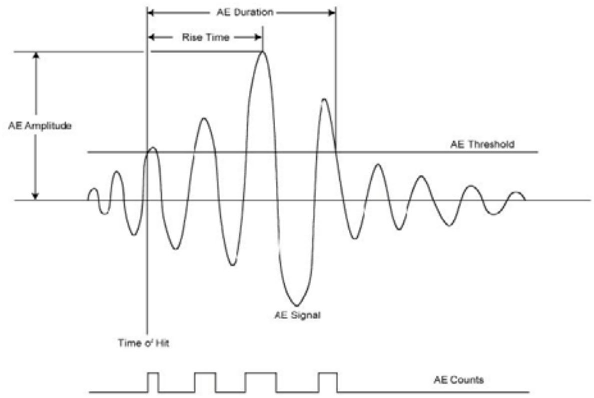

Figure 5: AE Hit features extraction of PD pulse

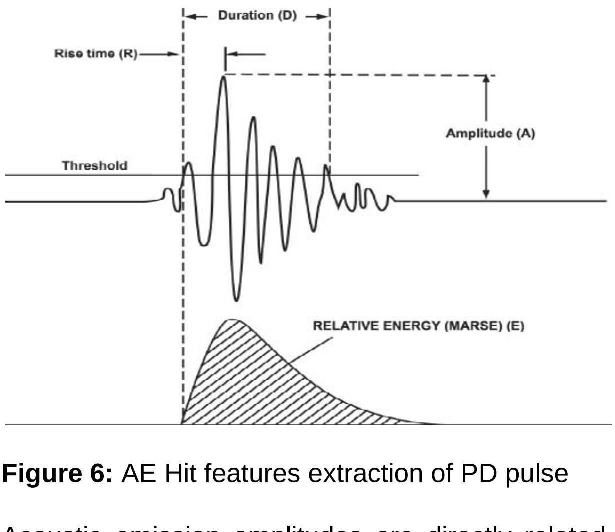

Figure 6: AE Hit features extraction of PD pulse

Acoustic emission amplitudes are directly related to the magnitude of the source event and they vary over an extremely wide range from microvolt to volts. Counts are the threshold crossing pulses and are one of the easiest ways of quantifying the AE signal. Counts depend on the magnitude of the source event, but they also depend strongly on the acoustic properties and reverberant nature of the specimen and the sensor. The duration is the elapsed time from the first threshold crossing to the last and directly measured in microseconds. The rise time is the elapsed time from the first threshold crossing to the signal peak. This parameter can be used for several types of signal qualification and noise rejection. MARSE is known as energy counts and is measured area under the rectified signal enveloped. As a measure of the AE signal magnitude, this quantity has gained acceptance and is replacing counts for many purpose even though the required circuitry is relatively complex.

TABLE 1 Operating specification of PD detection sensor

Dynamic	
Peak Sensitivity, Ref V/µbar	-36 dB
Operating Frequency Range	100-450 kHz
Resonant Frequency, Ref V/µbar	150 dB Directionality ±1.5dB
Environmental	
Temperature Range	-35 to 80°C
Shock Limit	500 g
Physical	
Dimensions	0.81" dia x 1.06" h (20.6 x 27 mm)
Weight	51 grams
Case Material	Stainless Steel
Face Material	Ceramic
Connector	SMA
Locations Connector	Side
Electrical	
Gain	26 dB
Power Requirements	4-7 VDC @ 5 mA
Operating/Max Current	5/35 mA
Noise Level (RMS RTI)	< 3 µV

4 SHORT TIME FOURIERR TRANSFORM (STFT) FOR PD SIGNAL ANALYSIIS

Fourier analysis of a periodic function refers to the extraction of the series of sine waves and cosine waves which when superimposed will reproduce the original pulse. This analysis can be expressed as a Fourier series. The fast Fourier transform is a mathematical tool for obtaining the frequency domain components using the Discrete Fourier Transform (DFT). Basically, the computational problem for the DFT is to compute the sequence {*X* (*k*)} of *N* complex-valued numbers given another sequence of data {*x* (*n*)} of length *N*, (n being the instantaneous time points)) according to the formula,

$$X(k) = \sum_{k=0}^{N-1} x(n) W_N^{kn} \ , \ \ 0 \le \mathrm{k} \le (\mathrm{N}-1) \qquad (1)$$

$$W_N = e^{\frac{-j2\pi}{N}}$$

Where, *WN* is the twiddle factor. The number of computations are drastically reduced from N^2 to N log (N), where 'N' is the number of discrete input points. Although among all the transforms, Fourier Transform is most popular method of thee transforms for finding out the frequency components along with its magnitudes from stationary signals but it does not informs the time instance when the frequency components exist. Short Term Fourier Transform ((STFT) solves the time localization of the frequency components in Fourier transform by applying the windows transforming the input signal. For non stationary signals like PD signal STFT is the perfect tool for analysis of PD signal which is enable to give the variation of all frequency information over total time duration. Short term Fourier transform is actually provides the frequency distribution throughout the whole period of acquired signal with a number of small windows [15]. Therefore, STFT is called the windowed Fourier Transform or the sliding Fourier Transform. However, longer window will result in correlation of signal with the window that has more 7. Spread of energy along time axis while shorter windows correlate the signal with window that is more elongated along frequency axis. The expression for STFT is given by

$$S(n,m) = \sum_{k=0}^{N-1} x(k) w\,(n-k) e^{-\frac{j2\pi km}{N}} \qquad (2)$$

k=0, 1, 2,..........,(N-1) which is discrete Fourier transform of x(k)*w*(n-k), Where fn [m] = x(k) *w*(n-k) is the short time section of given signal *x*(k) at time n, N is the frequency sampling factor and 2π/N is frequency sampling interval. Here *w* (n) represents the finite-length window. In this study, to find out the frequency component of PD signal in different time instant STFT has been introduced which is discussed in the next 'result and discussion' section.

5 RESULTS AND DISCUSSIONS

To generate the PD signal, a needle-flat electrode is horizontally place inside the dielectric test cell. Test cell is filled up with new transformer oil. The electrode is separated with small spice of press board of 5 mm thickness and immersed in the transformer oil. With the application of high voltage of 20 kV, the PD signal is generated and is being detected through AE sensor which is kept outside wall of the test cell. At deferent time instances the PD pulse detected by AE sensor which is shown in Fig.7 (a). From the Fig. 7 (a) it is observed that, the PD is started at the time of 92 second and stops at the time of 290 seconds. In between the 92-290 seconds i.e., within 198 seconds the PD signal amplitude is random in nature. Fig. 7 (b) shows the variation of the number of PD pulses at different time instances. It is observed that the number of PD pulse increases with the increase of time.

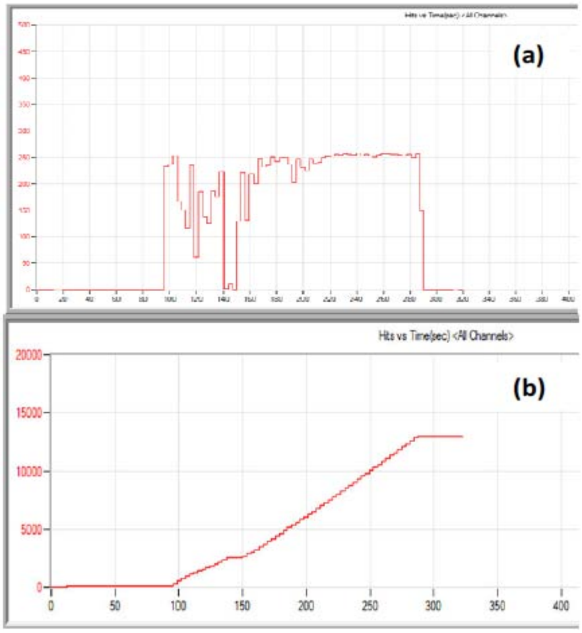

Figure 7: snapshot of online detection of partial discharge signal using AE sensor (a) Amplitude of PD signal along with the time (b) variation of number of PD pulses along with the different time instances.

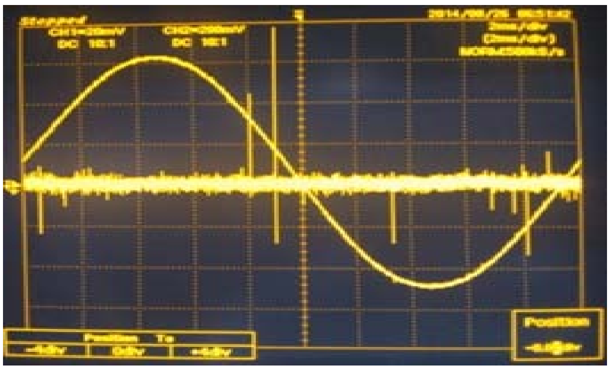

Figure 8: Photograph of PD signal with applied high voltage of 20 kV.

Further the PD signal is recorded when applied voltage is given 20 kV which is shown in Fig. 8. The detected PD signal in term of 'hit' and the frequency response of the recoded PD signal which is inset in Fig. 9. It is found that the frequency of the collected PD signal is varies in the range of 20 kHz to 500 kHz.

The detected PD signals are also collected in other time instance is shown in Fig.10. From the Figure 10 (a) it is clear that the PD signal is random in nature which sticks on the inside wall of the test cell randomly. It is also observed that the duration of the PD pulse is in the range of 'nano-second'. The generated PD signal is oscillatory in nature. It is found that two PD signal is appeared during the 80μs span in this figure which is denoted as first hit (Hit 1) and second hit (Hit 2).

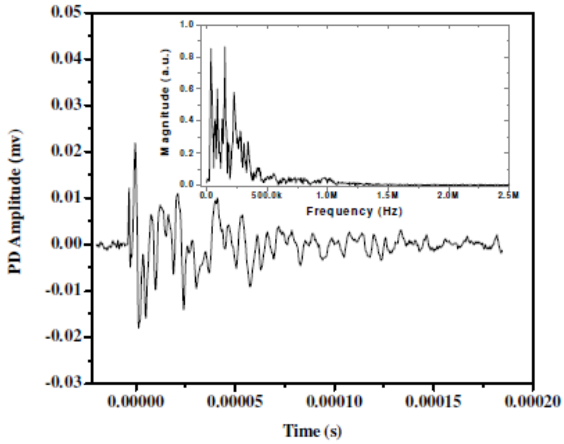

Figure 9: Single 'Hit' partial discharge signal along with its frequency response

Figure 10 (b) shows the frequency spectrum of the recorded PD signal. The frequency contain of the same recorded PD signal is varies within the range of 20 kHz to 1 MHz. However, in most of the time during the experiment the PD signal frequency varies within the range of 80 kHz to 600 kHz.

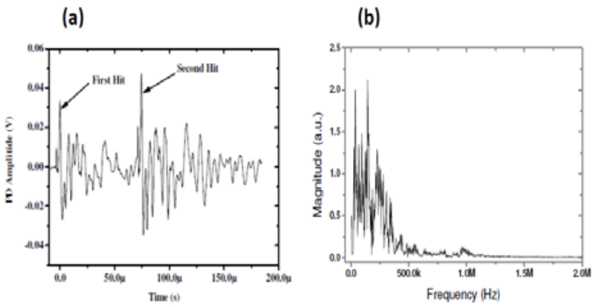

Figure 10: Recoded PD signal from test cell using AE Sensor (a) Double hit PD signal (b) Frequency response of recoded double hit PD signal

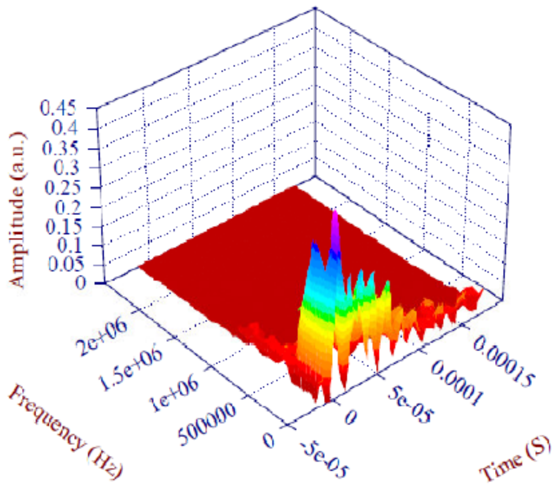

Figure 11: Short term Fourier transform of recorded PD signal

In addition, to know the frequency content of the observed PD signal is passed through the Short Time Fourier Transform (SFFT) algorithm. Figure 11 shows the time-frequency plot of the observed PD signal with the application of 20 kV. The spectrum of the observed PD signal is generated with STFT algorithm shows that frequency components are varies around the 0.5-1.1 MHz. It is observed that the maximum amplitude of the PD is appeared near 0.48 MHz and 0.51 MHz region.

5 CONCLUSSIONS

In this work, the partial discharge (PD) activity inside the dielectric test cell has been studied. The acoustic wave induced by PD is measured and used for online diagnostic monitoring of potential failure in power equipment. AE sensor is found suitable for diagnosis and detect the PD signal with the narrow frequency bandwidth of 20 kHz-1 MHz. The frequency spectrum of the acoustic signal based on presence of detected due to PD is also been studied. The acoustic emission technique has immense potential to diagnosis any high voltage power equipment for detection and measurement of partial discharges inside the equipment. Further, it is also possible to pin point the PD source location inside the oil-immersed power equipment by using multiple AE sensor.

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