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ONLINE MONITORING OF HEALTH CONDITION OF HIGH VOLTAGE APPARATUS

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Abstract

The high voltage apparatus quality/health assessment is an important aspect during manufacturing as well as operation of electrical motors. Today there are several offline insulation quality assessment techniques available such as surge test, DC high-pot test, Merger tests, step voltage test, continuous ramp test, partial discharge (PD) test, capacitance & dissipation factor test etc. However, there is only one online insulation quality test popularly available based on partial discharge analysis. This technique has a great potential to detect insulation degradation in high voltage equipment such as motors, generators, transformers, cables etc. Although partial discharge analysis has a potential detect degraded conditions of insulation in motors above 6.6kV such as tracking, cracking, porosity, delamination, contamination etc., it comes with a challenge to clearly discriminate between PD patterns generated by good and bad conditions of insulation and thus demands for extensive human interpretation. The other industry accepted standard test to assess health condition of ground-wall insulation of industrial motors is the capacitance and dissipation factor (C&DF) bridge test. This test is performed on the motors offline only. So far, it was not possible to conduct this test online on large motors due to the great difficulty in online measurement of very small motor insulation leakage currents (few mA) in the presence of large motor line currents (hundreds of amps). The line currents would produce enormous noise to mask the tiny magnetic field produced by the insulation leakage currents. HSCT also enabled to conduct the industry accepted capacitance and dissipation factor test on large industrial motors for the first time in the world. Such an online test adds a new 2 dimension to state-of-the-art online condition monitoring and greatly benefits the motor users to assess the insulation condition since no motor outage is required.

Keywords: Partial discharge (PD), High voltage equipment, Online monitoring, Offline testing, Capacitance and dissipation factor (C&DF), Wavelet transform, Condition-based maintenance (CBM), High frequency current transformer (HFCT), De-noising techniques, Smart grid, Insulation degradation, Acoustic detection, Electrical insulation diagnostics, Internet of Things (IoT), Big data analytics.

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I. INTRODUCTION

The new generation of power grid shows characteristics of large capacity, high voltage, intelligence, high reliability and sustainable development based on the new energy. The great improvement in operation voltage puts forward higher requirements to the insulation coordination of power equipment, and thus monitoring and evaluation of insulation condition become more essential. Intelligence of power grid is firstly based on the intelligence of power equipment, which is characterized by high efficiency and reliability. Therefore, to achieve higher intelligence of power equipment, they need to be accurately monitored and quickly diagnosed. Smart grid is highly intelligent and widely distributed network, which consists of advanced monitoring technologies, high performance electronic devices, more reliable information technologies and communication technologies. The introduction of variety of electronic devices (such as rectifier, variable-frequency drive, thyristor) into the power system can lead to the creation of more complicated harmonics, which is different from existing waveforms and consequently result in the acceleration of insulation aging, overheating power equipment, and shortened life of power equipment. For monitoring and evaluation of power equipment condition, on-line and off-line methods are commonly used. On-line monitoring methods have many advantages over off-line methods, especially for not outage of the operation of power equipment during the monitoring. In the past, the offline method was the main way used for condition monitoring and diagnosis. With the development of sensor technologies, on-line condition monitoring was gradually proposed and used in practical engineering. In recent years, the rapid development of sensor technologies, computer technologies, information technologies and other new technologies bring the new progresses in condition monitoring and fault diagnosis of power equipment. This report discusses the present techniques used to determine the partial discharge in the high voltage system and give a technical review on the how the online detection of partial discharge is helpful in monitoring and maintaining the high voltage systems. Also, a theoretical method is proposed to de-noise the signal to obtain the partial discharge pulse. The technique will be mainly focusing on how to remove the white noise from the signal. And also, few ideas on how to receive the analyzed data are discussed.

II. LITERATURE REVIEW

Fig. 1. Procedures where offline & Online monitoring comes into function

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The high voltage apparatus quality/health assessment is an important aspect during manufacturing as well as operation of electrical motors. To achieve higher intelligence of power equipment, they need to be accurately monitored and quickly diagnosed. There are several offline assessment techniques available such as surge test, DC high-pot test, Megger tests, step voltage test, continuous ramp test, capacitance & dissipation factor test etc. The major concerns of offline health condition monitoring is the cost of test equipment is excessively high, time consuming and skills required to run the tests are high.

The differences between the offline and the online monitoring techniques are shown below:

A. Offline Monitoring

- The offline health monitoring technique is a proven technique with better sensitivity.
- The major drawback of this technology is, the circuit is not loaded during testing and system outage is required.
- This technique is an expensive and time consuming.

B. Online Monitoring

- The major advantage of this technique is there is no need for system outage and no need for circuit isolation.
- This technique is less costly when compared to offline monitoring.
- Even this system has drawbacks such as it requires earthing pre requisites.

III. PARTIAL DISCHARGE

Partial discharge activity has been one of the most important and traditional indications of insulation degradation. Also, it is easier to detect in high voltage systems. Partial discharges are in general, a consequence of local electrical stress concentration in the insulation or on the surface of the insulation. There is a need for online monitoring of PD activities of power equipment such as, transformer, rotating machines, circuit breakers, current and potential transformers. Partial discharge (PD) diagnosis is of great importance to the power supply industry as it provides a suitable warning time of insulation problems, thus allowing power supply companies to plan the maintenance of their network equipment or plant items at convenient times. OLPD testing refers to the testing of in-service high voltage (HV) cables and plant (including both static and rotating plant). The OLPD technique detects, locates and monitors partial discharge activity within the HV plant insulation, without the need to de-energize the plant. The assessment of the health of HV network can thus be made with minimal disruption to operations and cost. OLPD diagnostics are an essential tool for the effective implementation of condition-based maintenance (CBM) techniques within HV power networks. The choice of PD sensor depends on rating of the machine, size of the cable box, whether it is bus-fed (HVCC) or cable fed (HFCT). Partial discharge breakdown of insulation produces light, heat, smell, sound and electromagnetic waves. There are different ways of diagnosing the PD sources according to the varied types of signals generated by partial discharge. The mostly used techniques are:

- Electrical detection
- Acoustic detection
- Optical detection

Sensor	PD Sensor Options	
	Picture	Coupling Method
High Voltage Coupling Capacitor		Capacitive
Ferrite-cored High Frequency Current Transformer		Inductive
Transient Earth Voltage		Capacitive

Fig. 2. Various Partial Discharge Sensors

IV. DETECTION METHOD

A. Electric Detection

Pulse-current method is a conventional partial discharge measurement. When there is partial discharge in the transformers, the change of transient voltage would be detected. This method has high sensitivity and is easy to quantify the change. However, the current detected by pulse-current method is not actual PD. Capacitive component is another method to detect PD. The sensitivity of this method decreases when the sample capacitance increases. The partial discharge measurement set-ups often have subtle limitations of distinguishing the electrical noise and partial discharge. In this occasion, ultra-high frequency (UHF) sensors were developed to detect the electromagnetic wave generated by partial discharge at the frequency range of 300 MHz–3 GHz. UHF sensors are able to locate PD source with low noise levels and resist local disturbance with the UHF sensor connected to power transformer with a non-electrical unit. However, this method cannot give a reliable indication of residual life.

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B. Acoustic Detection

The acoustic methods locate the position of partial discharge by detecting the amplitude attenuation or phase delay of the acoustic waves spreading from PD. In acoustic detection method, acoustic sensors are placed outside the HV equipment for detection of PD. The acoustic method endeavors to sense and record the acoustic signal created during a PD event instead of capturing an electrical signal. It is immune to electromagnetic interference (EMI) noise. The primary problem with acoustic detection is the complex in nature of the acoustic wave propagation. Moreover, HV equipment's are not homogeneous device; the wave does not travel in perfect spherical wave fronts.

C. Optical Detection

This method has low signal attenuation, good sensitivity and compact in size for the PD detection. It can also locate the PD sources in the equipment, and it is immune to electromagnetic interference which is a unique feature of this PD detection technique.

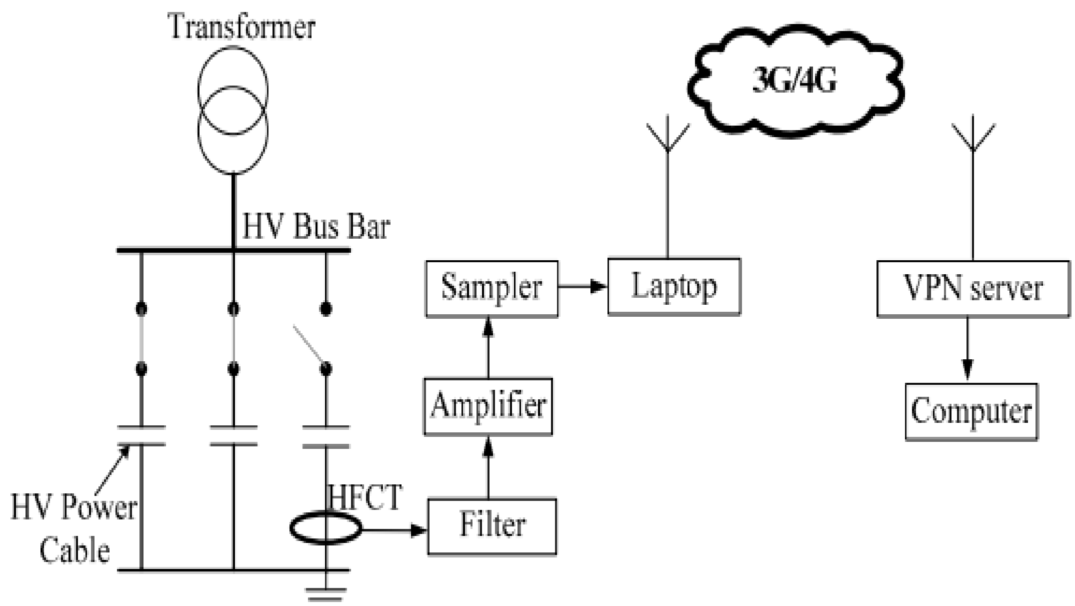

Fig. 3. Describes the online monitoring technique using high frequency current transformer sensors

V. PROPOSED METHOD

A. Wavelet transform of de-noising using interval based threshold technique

A theoretical approach for de-noising a signal to a better extent is discussed and proposed in this report so that identifying the partial discharge can be easier. The present most reliable technique used in industries to identify the partial discharge by de-noising technique is carried out by Fast Fourier Transform (FFT). This method is useful in identifying the partial discharge but when it comes to identifying the location of the partial discharge in a high voltage system it is not accurate. For the better de-noising and to obtain the accurate location of the partial discharge we can use the wavelet transform. The below HFCT sensor is developed to improve detecting the partial discharge in high voltage systems. The prototype HFCT sensor shown below in the figure is developed with a resistance of 75ohms which has a better sensitivity to that of sensors used now. NiZn Ferrite core is used as it easily available in the market for lower price. Theoretically, the frequency range of this sensor can be 100kHz-35Mhz.

Fig. 4. A Prototype of HFCT sensor developed

B. Wavelet Transform Method for de-noising an Electric Signal

A basic de-noising method for an electric signal is discussed and the results are obtained in the MATLAB to show how a noisy signal can be de-noised to obtain a signal like the original signal. The aim is to show that a high voltage electric signal involves many noises internal, external noise, white noise, non-white noise. We will discuss how to remove these noises so that is easier to detect the partial discharge.

We are not detecting the partial discharge, but a method is proposed how we can possibly detect it in a better way as the subject is vast and requires lot of time to research. Firstly, the signal is decomposed on a wavelet basis by correlating the various dilated and scaled versions of a wavelet with the original signal. Secondly, a threshold is applied to the resulting wavelet coefficients and finally the signal is reconstructed using the coefficients that survived the threshold process. The reconstructed signal is an estimation of the original without noise. The de-noising using wavelet transform is carried out on and two different threshold levels:

- Low threshold
- High threshold

The analysis is further carried out on how this method can be effectively improved and applied. The MATLAB implementation and the results are shown below.

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VI. MATLAB IMPLEMENTATION AND RESULTS

A. Wavelet Transform Technique using Threshold level is 5.5

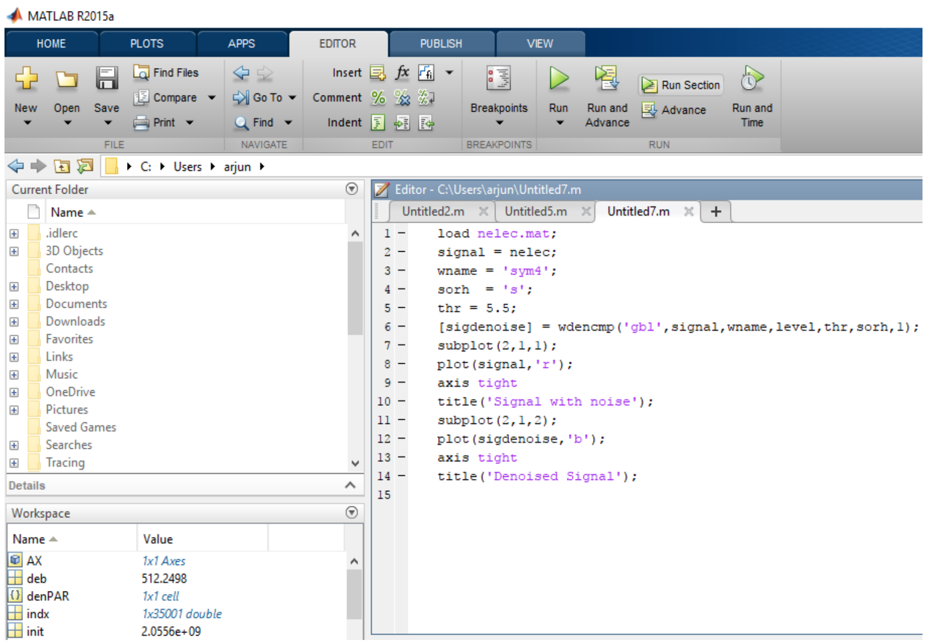

Fig. 5. Matlab code for 5.5 threshold value

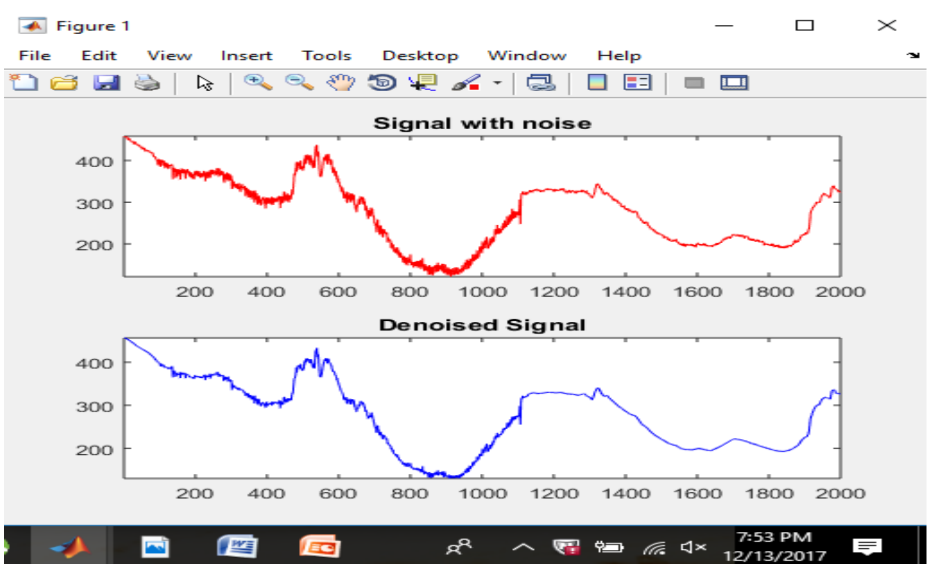

Fig. 6. Original and de-noised signals

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B. Wavelet Transform Technique using Threshold level is 11.5

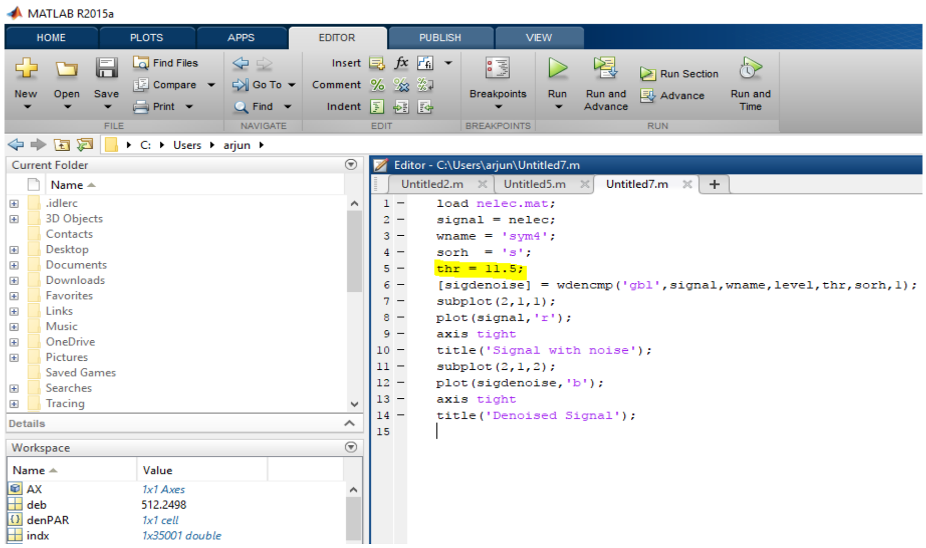

Fig. 7. Matlab code for 11.5 threshold value

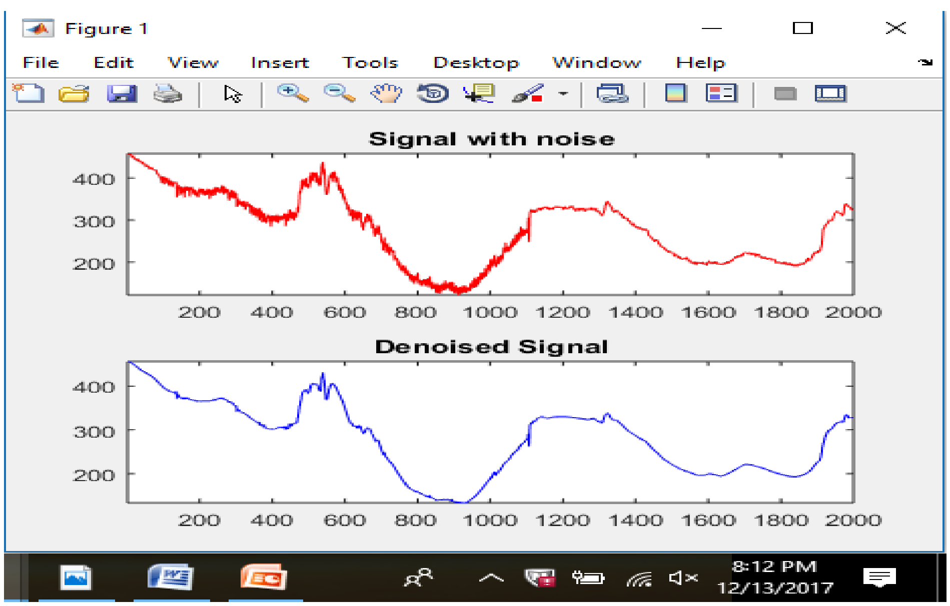

Fig. 8. Original and de-noised signals

From Fig 6 & 8 we can observe that using low level threshold there is little noise still visible in the graph. Whereas, when a high-level threshold is applied there is a loss in the signal (data

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loss) which is not recommended. We can use another technique which is interval-based threshold, unlike earlier where we applied a threshold value completely to a signal, we select the threshold values at certain intervals as per the signal and de-noise the signal. This is shown below.

C. Wavelet Transform using Interval based de-noising Technique

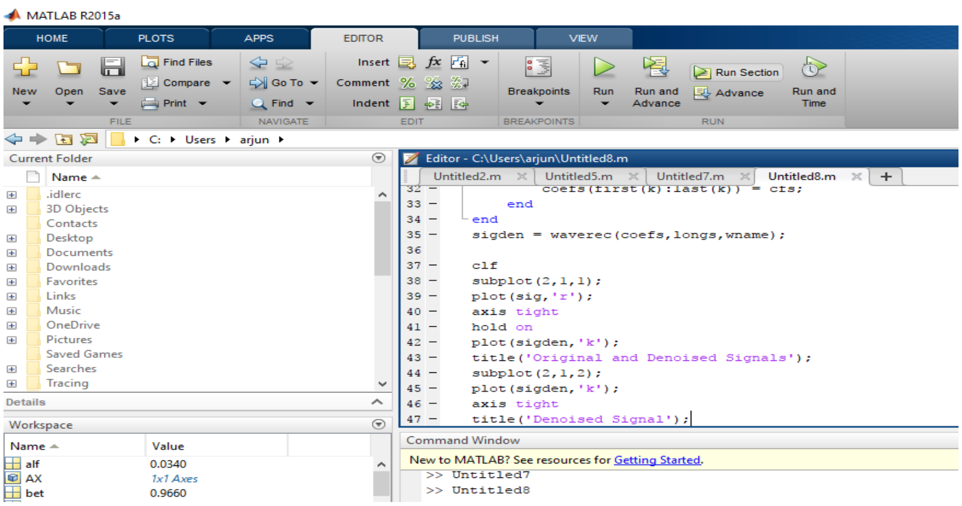

Fig. 9. Matlab code for interval based threshold

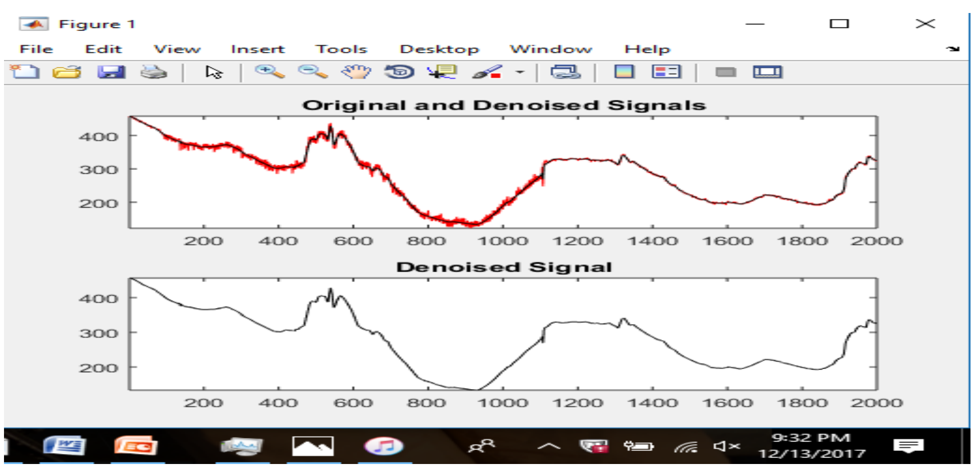

Fig. 10. Original and de-noised signals

In Fig 10 the first graph shows the original and de-noised signal using threshold de-noising technique and the second graph shows de-nosing using interval-based threshold. We can see that we can obtain the signal without loss of data and noise is eliminated to a better extent compared to previous techniques. This way we can de-noise the signal and identify the partial discharge in high voltage systems.

VII. FUTURE TECHNOLOGIES THAT CAN BE USED TO IMPLEMENT ONLINE MONITORING

Few ideas which I can think of online monitoring can be implemented to collect the data more effectively, the technologies, such as big data, IOT, cloud computing should be used for condition monitoring and diagnosis of power equipment. With these technologies not only, we can monitor the data timely but using the technology like IOT we can even make a possibility to control the affect and react.

A. Big Data

Big data is the data set characterized by large volume, variety, high data access velocity, which attracts much attention in current data processing. The new generation of power grid is now gradually evolving into a system that can gather huge data and a large amount of information. The real-time data collection, transmission, data access, and rapid analysis of huge amounts of multivariate data are becoming the basis for sustaining the reliable operation of power system. Therefore, big data technologies can be wildly used in the huge data collection and access, on-line analysis mining, and visualization fields.

B. Internet of Things

The IOT can realize the intelligent identification, localization, tracking, monitoring and management of things through connecting them with the internet for information exchange and communication. Through incorporation IOT into smart grid, an instrumented and real-time communication system is constructed, which can eliminate blind spots of information acquisition and get rid of the information isolated island, achieving the bidirectional interactive communication platform of smart grid.

C. Cloud Computing

Cloud computing can easily access the large scale of computing resources in the internet, thus offering a method to solve huge data processing and heavy computational work in power system. Through construction of 'cloud computing platform' based on condition monitoring and diagnosis of power equipment, huge condition data will be reliably stored and rapidly inquired, and thus the accuracy of condition evaluation and fault diagnosis can be greatly improved.

VIII. CONCLUSION

Online monitoring of partial discharge in HV power equipment is increasingly getting its importance in the field of maintenance as well as prediction of its health for the reliable operation of power system. A literature review on offline monitoring & online monitoring are carried out which shows how online monitoring is more effective than offline approach. Different types of sensors used to detect the partial discharge in a high voltage system are mentioned and what are the different detection techniques that can be carried out for PD detection are given. The wavelet transforms de-noising using interval-based threshold in an electric signal is shown with the MATLAB results. We can say that by using the wavelet transform we can obtain a de-noised electric signal which can give us better scope to detect partial discharge in the high voltage apparatus. While the wavelet based de-noising technique is effective, its shift variant characteristic makes it bit difficult to extract features for the classification of PD pulses. Also, technologies that can be used for online monitoring are discussed. IOT is one such technology which we can bet on to improve the online monitoring.

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