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Online Condition monitoring technique for high voltage insulators using NL acoustic camera

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Summary:

Insulator has vital role in electrical insulation and mechanical connection in transmission and distribution lines. Insulators are used to isolate high voltage conductors from earth and to provide mechanical support to conductor. Moisture, pollutants and contaminants, creates a considerable reduction in surface resistivity which leads to insulator surface degradation, decrease dielectric strength and leads to surface flashover. In the modern world, various online tools are available which can early detect the surface discharge before flashover. Partial discharges (PD) generate electromagnetic waves, acoustic waves and optical waves which can be detected by various diagnostic methods using appropriate sensing elements. For early detection fault apart from conventionally used Infra-red thermal vision camera, new emerging acoustic signal using noiseless acoustic camera (NL camera) used for the detection of partial discharge. This online condition monitoring tool are high sensitivity to environmental weather, such as dust and rain. Partial discharges emit broadband sounds that can be both audible and inaudible. The NL camera combines both sonic and ultrasonic frequencies to detect partial discharges with higher accuracy which are often completely inaudible to the human ear. The NL Camera can find partial discharges missed by UV and IR cameras that do not have direct line-of-sight. Noiseless acoustic camera is a measurement instrument comprising many microphones for locating sound sources & optical sensor to co-relate the image. This simple, low cost and hand held NL camera is very much useful to monitor the condition of overhead line insulators in real time with visual identification and quantification of sound for any voltage level without disturbing the power supply. Presently research is going on for early detection fault before failure of insulator due to contamination near to highly polluted area and insulator present near the coastal area. However such methods are limited in use. In this research paper, comparative study of both conventional electrical measurement (as per IEC 60270) and noiseless acoustic camera has been done on HV insulators of various voltage rating in the laboratory. Measurement was conducted at different test voltage before and after contamination with salt solution in control environment. The effect of contamination on HV insulator has been studied at different test voltage level. From the experimental results it is observed that, at higher test voltage level surface discharge activity was drastically increased due contamination with salt solution. Apart from the detection, NL camera also visualize the location where the fault is occurring. Measurement of HV insulators at site has also been conducted using NL acoustic camera to monitor its condition. Experimental details, obtained results, findings and useful ness of this technique for online condition monitoring of high voltage insulators are discussed in this paper.

Keywords: NL Camera, Condition monitoring, Corona, Pollution, Partial Discharge, Flash over

1. Introduction

High voltage insulator is a material that impedes the flow of electric current. Its primary function is to resist or block the movement of electric charges, preventing the unintentional transfer of electricity between conductive materials. This property is crucial in various electrical systems and devices to ensure safety, reliability, and efficiency. Insulators are essential in overhead power lines, electrical transformers, circuit breakers, and other electrical devices where maintaining a clear separation of conductive elements is critical. In addition to preventing electric shock hazards, insulators also play a crucial role in minimizing power losses by reducing leakage currents and ensuring the proper functioning of electrical systems. Transmission line insulators are susceptible to contamination flashover, and thus are a source of power system failure [1]. The energy transferred through the transmission line is usually at its highest level to avoid losses since it is transferred over a long distance. Thus, insulators used on transmission lines need to have adequate insulation for the particular voltage level they are operating. Although they have been designed for that voltage level, environmental factors need to be considered as they affect the insulators' performance. The environment is one of the main causes of insulator flashover and breakdown in power systems. Aerosols and pollutants deposited on the surface of the insulators cause reduction in insulator surface resistance, thereby leading to the flow of leakage current [2,3]. This subsequently leads to the formation of surface discharges on the surface of the insulators. Since the environment in which the insulators operate cannot be controlled, electricity supply companies carryout maintenance services to prevent or reduce surface discharges from developing into a flashover. Nowadays researchers are studying and developing methods to predict the insulators' surface conditions during their operation to prevent flashover occurrences [4,5]. In such cases, the surface discharges that develop on the surface of insulators which are precursors to flashover incidences can be monitored. In this present work, comparative study of both conventional electrical measurement and noiseless acoustic camera were conducted HV insulators of various voltage rating in the laboratory. It is found that due to presence of pollutant results in surface discharge which due to formation of thin conductive layer over the surface of the insulator. The outcome of this work suggests that HV insulators which are more prone to pollution should be monitored by NL camera acoustic method which has the potential to identify fault location with visual identification, thereby resulting earlier diagnosis of insulator condition.

2. Experimental Detail

2.1 Sample preparation of HV insulator

Porcelain insulators of 33 kV class and 66 kV class were taken for the study as shown in Figure 1 & Figure 2 respectively. Before the measurement, these samples were thoroughly cleaned. After proper drying initial measurements were carried out on these samples before conditioning. Then these samples were conditioned in salt/fog chamber (Figure 3) with 5% NaCl salt solution [6] for 07 days for salt contamination. Measurements were conducted on these contaminated samples.

Figure 1: 33 kV Insulator Sample

Figure 2: 66 kV Insulator Sample

2.2 Measurement setup for Porcelain Insulator Sample

Measurements were conducted at partial discharge laboratory and Figure 4 shows the experimental setup. Resonating transformer of 900 kV rating was used as voltage source. For 33 kV support insulator, measurement were taken at voltage range from 10 kV to 25 kV. For 66 kV porcelain housing insulator, measurement were taken at voltage range from 30 kV to 60 kV. Measurement were carried out on 33 kV support insulator and 66 kV porcelain housing insulator before and after contamination for 07 days by both electrical and Noiseless acoustic camera (NL Camera) method simultaneously.

3. **Results and Discussion**

3.1 Measurement on 33 kV support insulator

3.1.1 Test on 33 kV Sample before conditioning

PD measurement was carried out on 33 kV support insulator by both conventional electrical method and NL acoustic camera method before conditioning. Figure 5 shows the 33 kV support insulator sample under test by NL Camera method in Partial Discharge laboratory.

Figure 3: Salt/Fog chamber

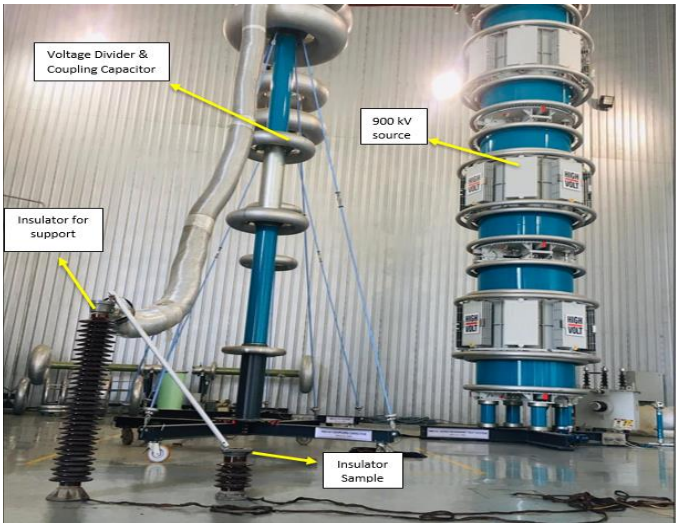

Figure 4: Experimental set up PD measurement

Partial discharge measurement was carried out up to 25 kV test voltage. PD inception was observed after 10 kV by both electrical PD and NL acoustic camera measurement.

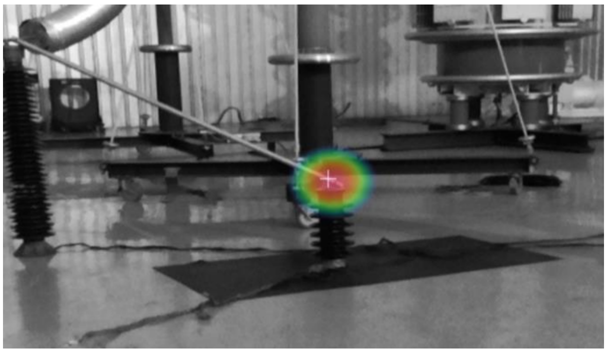

Figure 5: 33 kV support insulator under PD measurement

Figure 6 shows the phase resolved partial discharge (PRPD) patterns observed by the conventional electrical method. At 10 kV test voltage PRPD patterns which is typically corona type of discharge of magnitude 97.13 pC was observed. Voltage was further increased to 15 kV, PRPD pattern shows initiation of surface discharge and PD magnitude of 491.9 pC was observed. For the test voltage of 20 kV, PRPD pattern shows further increase in PD pulse with PD magnitude of 1.471 nC was observed. PD Measurement at test voltage of 25 kV the PRPD pattern shows PD magnitude of 1.966 nC. Figure 7 shows PD pulse of observed by the NL Camera acoustic method. At 10 kV test voltage maximum PD pulse of magnitude of 5.8 dB was observed. At test voltage of 15 kV maximum PD pulse PD pulse of magnitude of 18.9 dB was observed. As test voltage was further increased maximum PD pulse of magnitude 24 dB and 26.2 dB was observed at voltage of 20 kV and 25 kV respectively. Figure 8 shows type of discharge analyzed by NL camera acoustic method software.

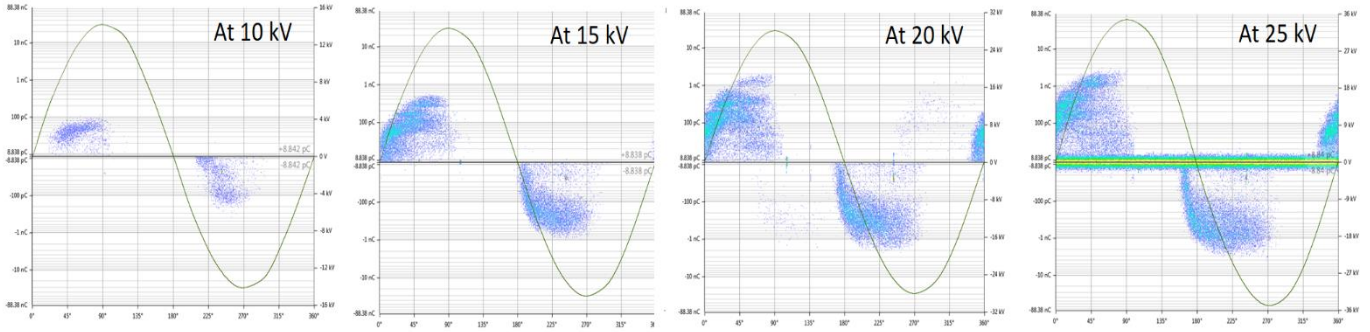

Figure 6: PRPD by electrical method at different test voltage

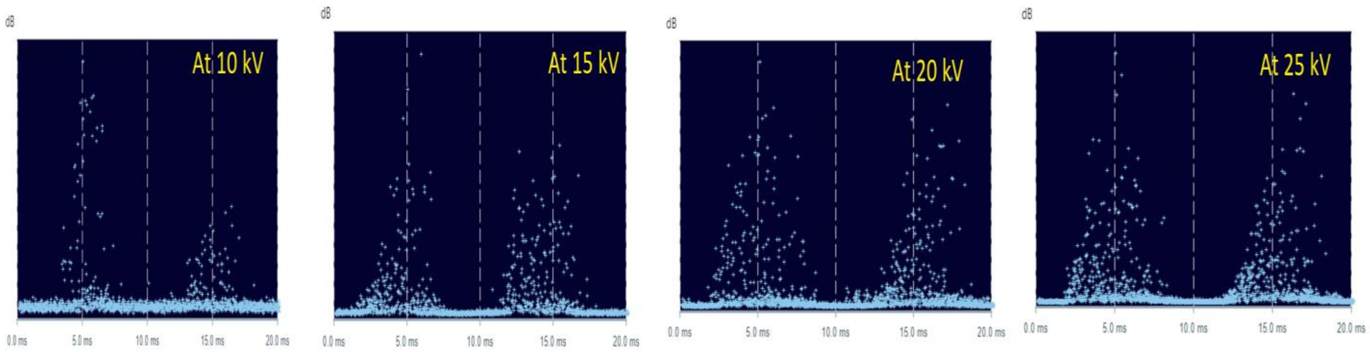

Figure 7: PD pulse observed by NL Camera

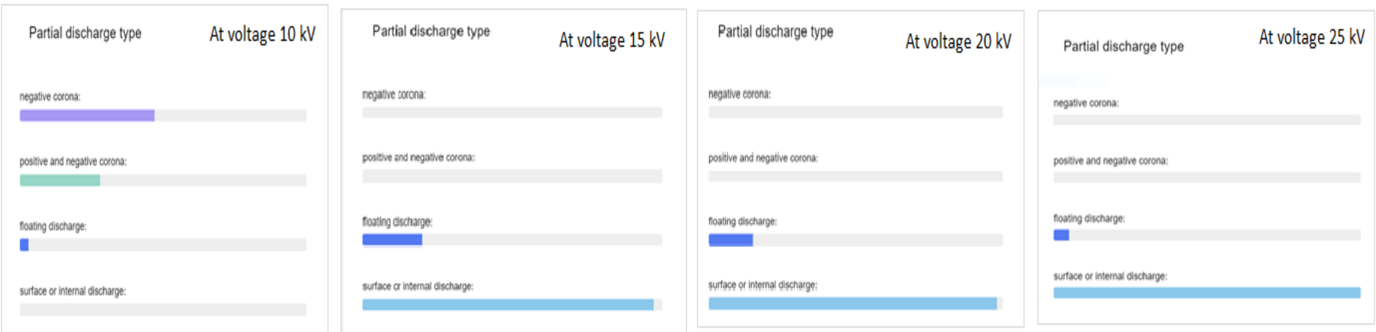

Figure 8: Type of discharge analyzed by NL acoustic camera software

For the 33 kV support insulator sample test voltage was limited to 25 kV. From the above measurement is observed as the test voltage increases more number of partial discharge activity have been observed and which was clearly observed by both the methods. NL camera analysis software also predicts the type of discharge mainly as surface discharge of lower magnitude before contamination. From the above measurement on 33 kV support insulator sample before contamination shows good correlation of between conventional electrical method and NL camera acoustic method.

3.1.2 Test on 33 kV Insulator Sample after conditioning

After conditioning in salt/fog chamber for 07 days, PD measurement was carried out on the support insulator. Figure 9 shows the PRPD pattern by electrical method at different test voltage. At test voltage of 10 kV and 15 kV PRPD patterns shows partial discharge of magnitude 1.817 nC and 5.485 nC respectively. As the test voltage further increased PRPD patterns at test voltage of 20 kV and 25 kV shows PD of magnitude 17.33 nC and 20.18 nC respectively. Similarly Figure 10 shows PD pulse by NL camera acoustic method at different test voltage. At test voltage of 10 kV and 15 kV NL camera acoustic method shows maximum PD pulse of magnitude 32.4 dB and 40.3 dB respectively. As the test voltage further increased to 20 kV and 25 kV, NL camera acoustic method shows maximum PD pulse of magnitude shows PD of magnitude 44.9 dB and 48.5 dB respectively. From both the PD measurement method, it is observed that the PD magnitude as well as intensity has been increased drastically after the salt contamination, which may be due to increase in surface leakage current. This leads to increase in surface PD due to contamination. Figure 11 shows type of discharge analyzed by NL camera acoustic method.

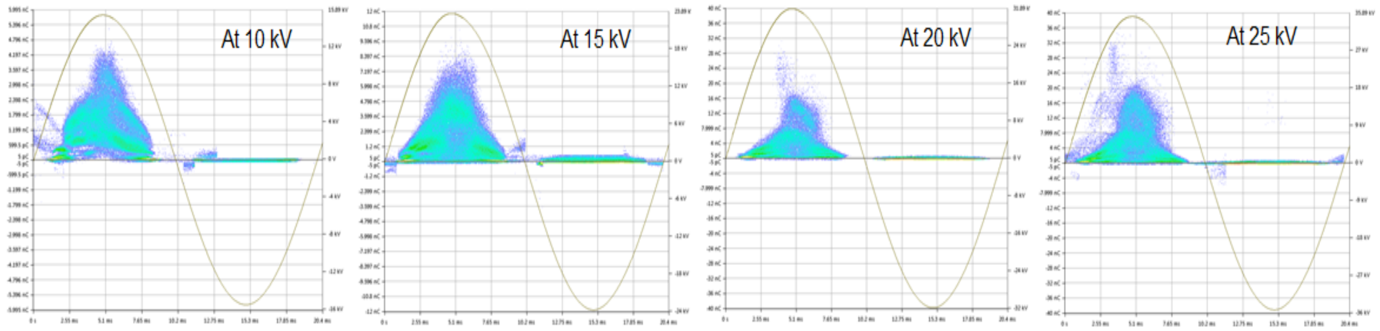

Figure 9: PRPD by electrical method

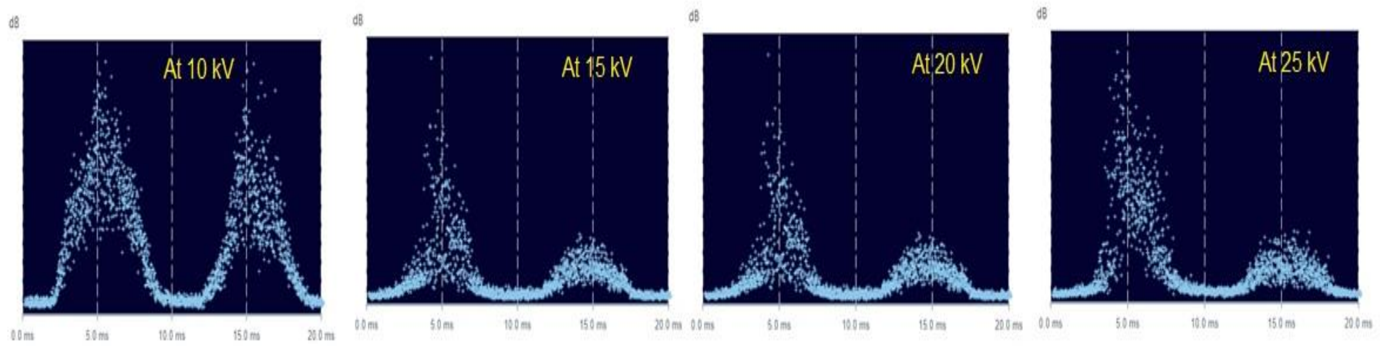

Figure 10: PD Pulse by NL acoustic

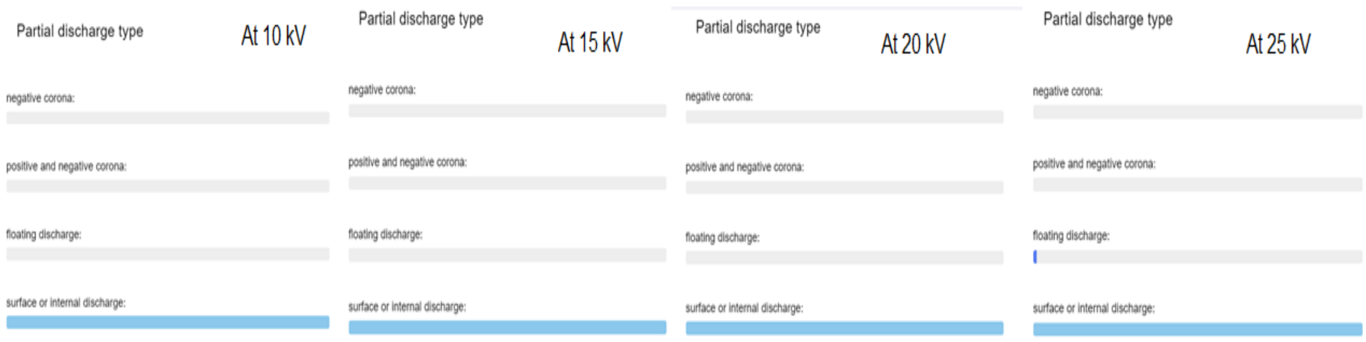

Figure 11: Type of discharge analyzed by NL acoustic

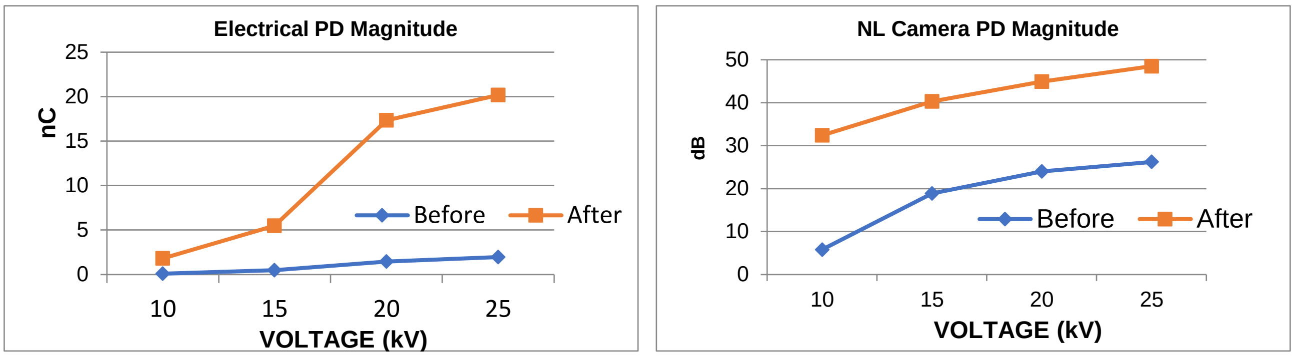

Figure 12: Comparison of PD magnitude by electrical and acoustic method

Figure 12 shows the comparison of PD magnitude by conventional electrical method and NL camera acoustic method before and after salt contamination. From the comparison it is observed that due to contamination, PD magnitude increases with applied voltage. As contamination leads to increase in surface current thus increase in surface discharge. Also this lab experiment gives good correlation between NL camera acoustic method and conventional electrical method.

3.2 Measurement on 66 kV porcelain housing insulator

Partial Discharge measurement was carried out on 66 kV porcelain housing insulator by both conventional electrical method and NL acoustic camera method before and after conditioning. Figure 13 shows the insulator sample setup in PD laboratory. Partial discharge measurement was carried out by slowly increasing the voltage up to 55 kV test voltage to find out the inception of PD. PD inception was observed after 30 kV test voltage by both conventional electrical method and NL camera acoustic method.

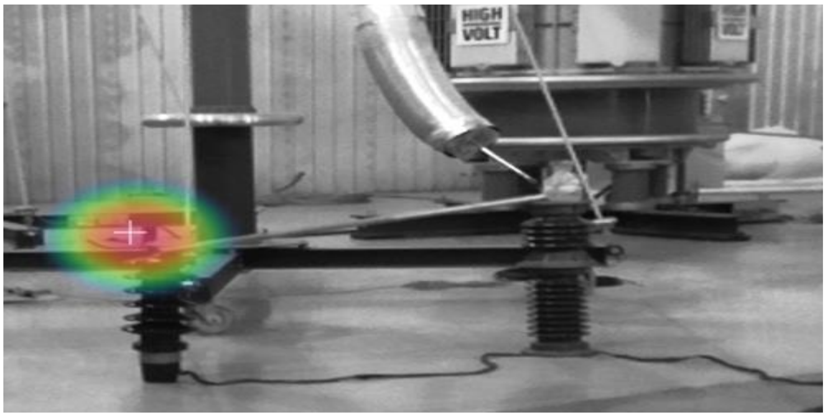

Figure 13: Measurement Set up of 66 kV porcelain housing insulator for PD measurement

3.2.1 Test on 66 kV Sample before conditioning

Figure 14 shows PRPD pattern observed by the electrical method at different test voltage. At 30 kV test voltage PD magnitude of 25.46 pC was observed and at this voltage no PD was detected by NL camera acoustic method. At test voltage of 40 kV and 50 kV PRPD patterns shows partial discharge of magnitude 183.4 pC and 1155 pC respectively. At test voltage of 60 kV PRPD patterns shows partial discharge of magnitude 3206 pC. Similarly Figure 15 shows PD pulse by NL camera acoustic method at different test voltage. At test voltage of 40 kV and 50 kV NL camera acoustic method shows maximum PD pulse of magnitude 18.4 dB and 26.6 dB respectively. As the test voltage further increased to 60 kV, NL camera acoustic method shows maximum PD pulse of magnitude 32 dB. With increase in test voltage the partial discharge activity has been increased with increase in more number of partial discharge pulses as well as in magnitude in both the method. Figure 16 shows type of discharge analyzed by NL camera acoustic method.

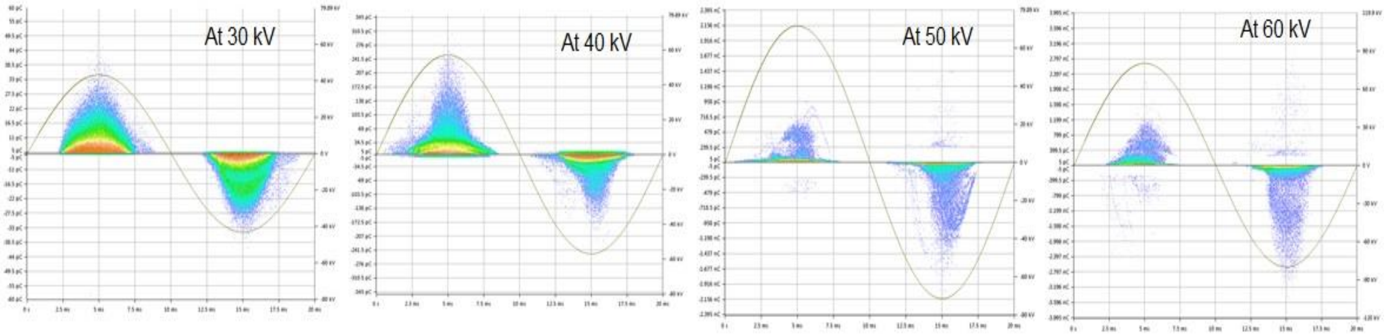

Figure 14: PRPD by electrical method

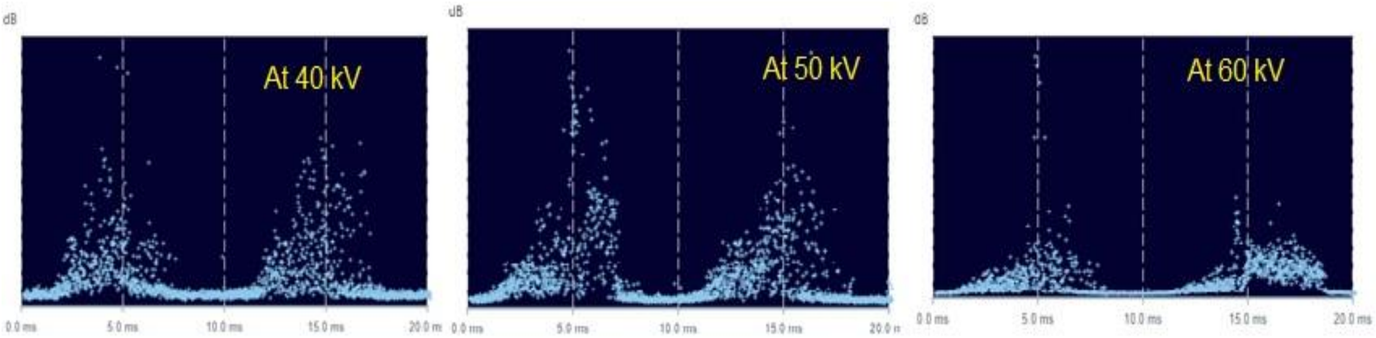

Figure 15: PD Pulse by NL acoustic

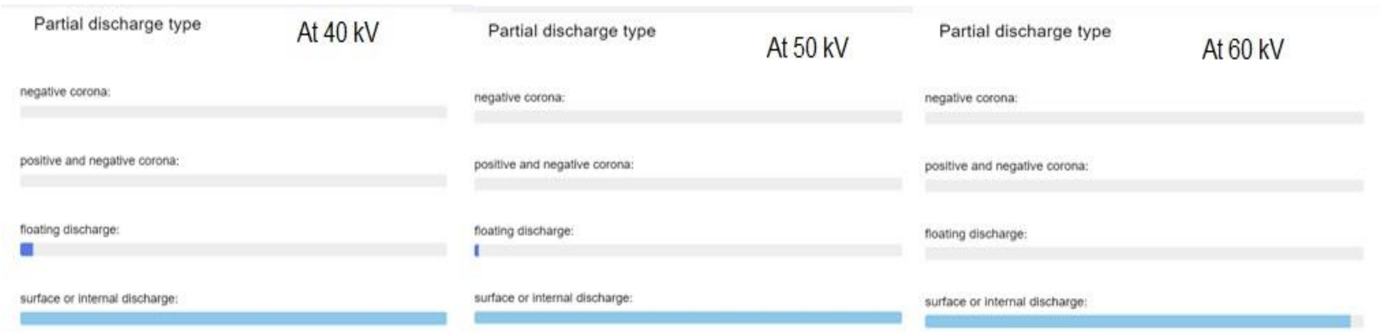

Figure 16: Type of discharge analyzed by NL acoustic

3.2.2 Test on 66 kV Sample after conditioning

Effect of contamination on partial discharge behavior were done by both conventional electrical method and NL camera acoustic method of partial discharge detection on 66 kV insulator. Figure 17 shows PRPD pattern observed by the electrical method at different test voltage. At 30 kV and 40 kV test voltage PD magnitude of 1.62 nC and 3.377 nC was observed respectively. At test voltage of 50 kV and 60 kV PRPD patterns shows partial discharge of magnitude 6.969 nC and 12.19 nC respectively. Similarly Figure 18 shows PD pulse by NL camera acoustic method at different test voltage. At test voltage of 30 kV and 40 kV NL camera acoustic method shows maximum PD pulse of magnitude 12.6 dB and 20.3 dB respectively. As the test voltage further increased at test voltage 50 kV and 60 kV, NL camera acoustic method shows maximum PD pulse of magnitude 37.8 dB and 41.3 dB respectively. Due to contamination, with increase in test voltage surface discharge activity become more prominent thus results in more number of partial discharge pulses as well as in magnitude in both the method. Figure 19 shows type of discharge analyzed by NL camera acoustic method at the test voltage level.

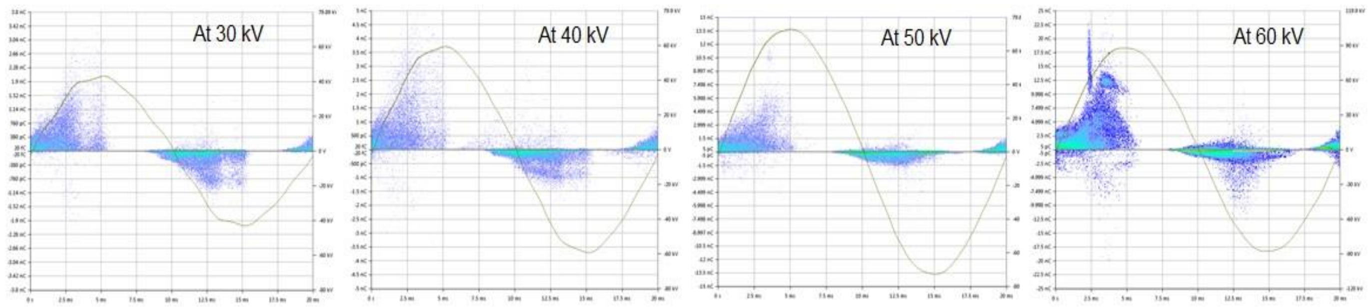

Figure 16: PRPD by electrical method

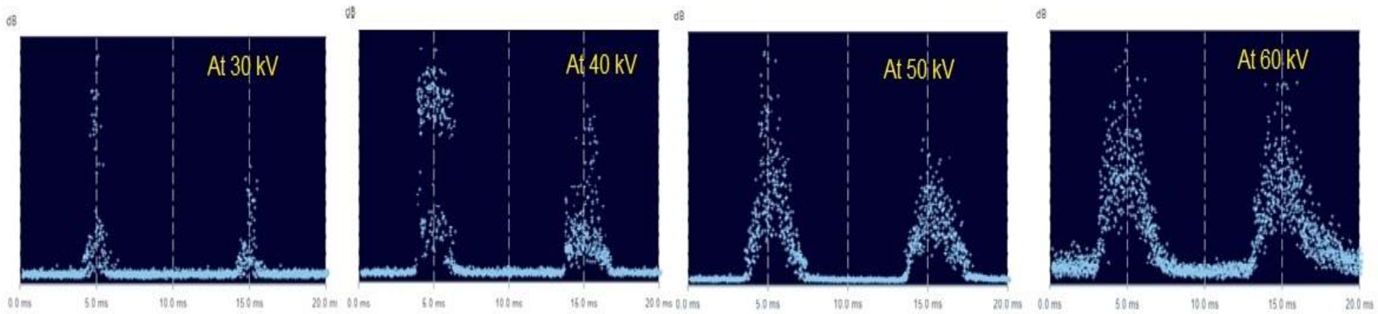

Figure 17: PD Pulse by NL acoustic

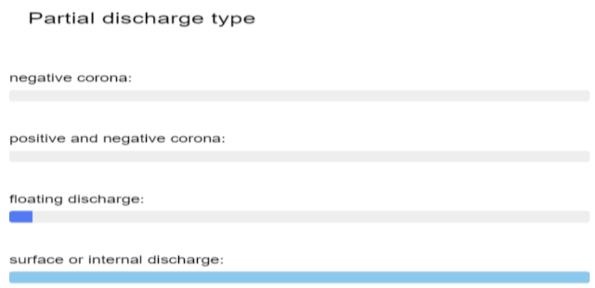

Figure 19: Type of discharge analyzed by NL acoustic at 30, 40, 50 and 60 kV

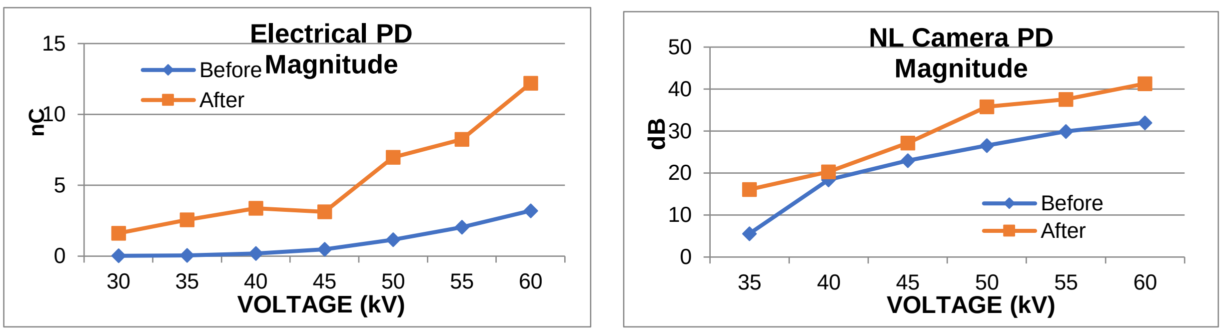

Figure 20: Comparison of PD magnitude before and after contamination

Figure 20 shows the comparison of PD magnitude by conventional electrical method and NL camera acoustic method before and after salt contamination. From the comparison it is observed that due to contamination, PD magnitude increases with applied voltage. As contamination leads to increase in surface current thus increase in surface discharge. Hence from the above experiment we confirm that failure of insulator due to contamination and pollution can be early detected using NL camera acoustic.

4. Conclusions

High voltage insulator plays the vital role in electrical power network. For the power system reliability, condition of the HV insulator should be well maintained to avoid flashover. In presence of moisture, pollutants and other contaminant HV insulator are more vulnerable to flashover. From this work, it is found that after salt contamination surface discharge activity are drastically increasing due to formation of thin layer of conductive path along surface of the insulator. This surface discharge are clearly observed by both conventional electrical method and NL acoustic camera method. Also the NL camera acoustic perfectly predicting the type of discharge occurring at the HV insulator along with magnitude which can be used for finding the severity of the discharge activity. With increase in applied voltage and contamination leads to increase in PD magnitude. As contamination leads to increase in surface current thus leads to surface discharge at higher voltage. Hence the failure of insulator due to contamination and pollution can be early detected using NL camera acoustic.

Field measurement of HV insulator by using NL camera acoustic shows the condition of the insulators in real time with visual location. Hence condition monitoring of insulator by NL camera acoustic measurements utmost necessary for the insulator which are more prone to pollution and contamination i.e. insulator present near the coastal line and most polluted environment in coal and cement industries.

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