Effect of Corona on Nonceramic Insulator Housing Materials

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Abstract: This paper presents results and analysis of corona studies performed on NCI removed from service as well as on new materials in the laboratory. It has been shown that it is possible to quantify the corona degradation and this could be used to answer important questions like remaining life. The approach can also be used to develop a rapid screening method for evaluating the corona resistance of materials used for NCI housings.

Introduction: Corona discharges can be a significant threat to the integrity of nonceramic insulators (NCI) due to the organic nature of the housing material [1]. For transmission class insulators (69 kV and above), corona can be problem not only in contaminated but in clean environments as well. From worldwide experience it has been identified that a majority of NCI applications are under relatively clean or lig htly contaminated conditions. On NCI, corona can be present locally for long periods of time due to inadequate hardware design, damaged hardware, and deficient interfaces due to improper design and/or manufacturing. Field inspections on 230 kV and 500 kV insulators confirm the existence of corona even under relatively dry and clean conditions [2]. In practical high-voltage systems it is difficult to avoid corona in the field, especially under wet and contaminated conditions [3, 4]. Hence, knowledge of the corona discharge magnitude and damage threshold of the housing material is essential. Corona is responsible for multiple effects such as mechanical, due to the impingement of charged particles, ultraviolet (UV) radiation, and liberation of ozone. Highly oxidizing and hydrated species of nitrogen oxides are generated which on dissolving in moisture leads to the formation of acids [5, 6]. Any cracks in the housing can expose the fiberglass core to moisture. The exposed rod can fail by tracking, erosion or brittle fracture [7, 8, 9], leading to premature failure. Hence, there is a necessity to periodically inspect NCI and replace degraded insulators in a timely manner.

Characterization of Degraded Polymers :

(i) Fourier Transform Infrared (FTIR) Spectroscopy

FTIR is a powerful tool for identifying different types of chemical bonds in organic materials [10]. Molecular bonds vibrate at various frequencies depending on the elements and the type of bonds. For a given bond, there are several specific frequencies at which it can vibrate. The wavelength of the light absorbed by the material is characteristic to the chemical bond and the strength of absorption is proportional to the concentration of the bonds [11].

(ii) Laser Treatment

The current interest in the use of lasers both for scientific investigations and for industrial applications is directly linked to the unique properties of laser light. The high spatial coherence achieved with lasers permits extreme focusing and directional irradiation at high energy densities. The monochromaticity of the laser light, together with its tenability, opens up the possibility of highly selective narrow-band excitation [12].

The interaction mechanisms between laser light and matter depend on the parameters of the laser beam and the physical and chemical properties of the material. Laser parameters are the wavelength, intensity, spatial and temporal coherence, polarization and the angle of incidence. The material is characterized by its chemical composition and microstructure which determine the type of elementary excitations and the interactions between them. Conventional laser processing is mainly performed with IR laser light. This can excite the free electrons within the metal or vibrations within the insulator. In general the excitation energy is dissipated in the form of heat within a time which is short in comparison to any other time involved in the process. As a consequence with low and medium intensities, the laser beam can just be considered as a heat source which induces a temperature rise on the surface and the bulk of the material [13, 14, 15]. This is schematically shown in Fig. 1.

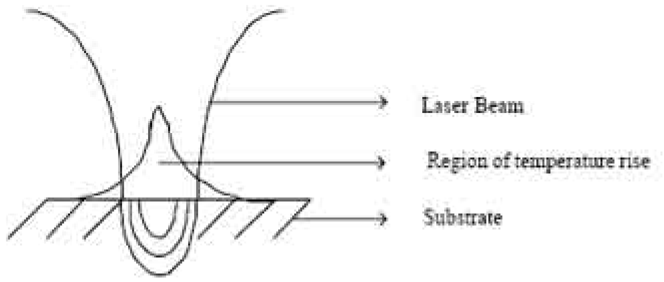


Fig 1: Heat treatment with laser

The temperature distribution is determined by the thermal and optical properties of the material. When the laser intensity (I) reaches a critical value (Iv) beyond which there is a significant material vaporization, a vapor plume is formed as shown in Fig. 2.

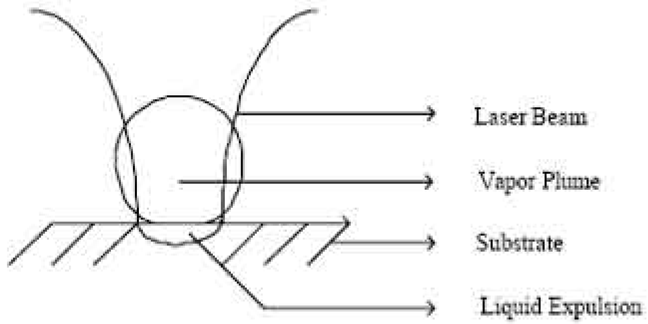


Fig 2: Heat treatment of the material with laser (I > Iv)

With further increase in intensity, the number of species within the plume increases and interactions between the laser and the vapor becomes very important. These result in the ionization of the species. The vapor can also be appropriately denoted as plasma [16, 17, 18].

Results and Analysis

(i) Silicone Rubber

A silicone rubber sample was subjected to corona exposure for 500 hours. A brass rod with a point tip (approximately 0.02 cm) energized by an ac voltage served as the corona source (point-plane electrode configuration). The electrode arrangement was enclosed in an acrylic chamber with dimensions 45cm x 45cm x 120cm. Corona activity was monitored by using an oscilloscope (Tektronix model 540C) and a corona camera. Corona induced degradation was quantified by visual changes on the material surface, optical microscopy, FTIR spectroscopy and laser treatment techniques. The FTIR spectroscopic analysis was performed with a Nicolet Magna-IR 560 spectrometer equipped with an ATR device (spectra-tech model PN-0048). The corona test setup is shown in Fig. 3.

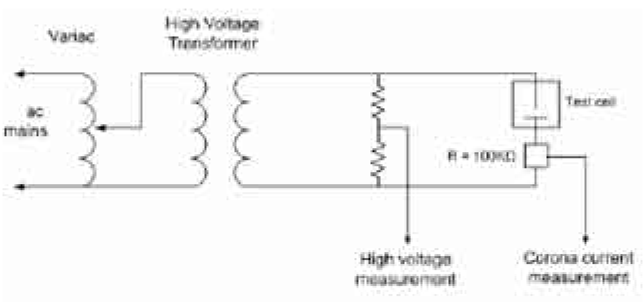


fig 3 a

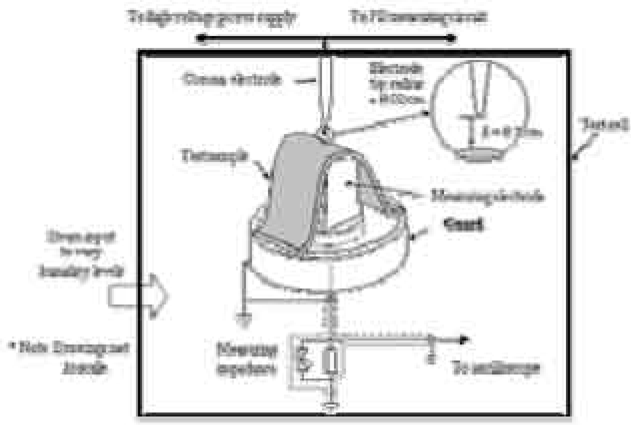


fig 3 b

Figure 3. Experimental setup to access corona performance

The sample was removed at periodic intervals to visually monitor changes on the material surface. Additionally, leakage current measurements were taken to access the corona performance of the silicone rubber sample. To determine changes at the microscopic level, if any, FTIR analysis was performed on the corona exposed region and compared with that of the virgin material. To reduce any variation in the data collected, the average of a number of spectrums (five in this study) was used. The variability reduces by a factor of $\sqrt{n}$, where n is the number of spectrums selected [19]. The FTIR spectrums are shown in Fig. 4.

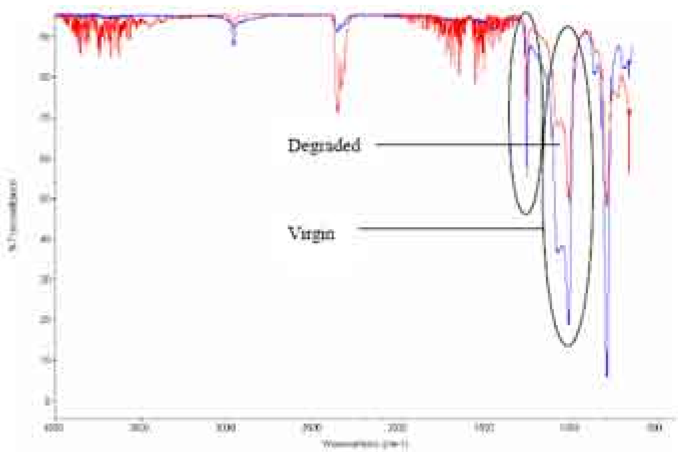


Figure 4. FTIR s pectrum of the sample before/after corona exposure

The absorption peaks corresponding to wave-numbers 1010 cm-1 [Si-O-Si] and 1376 cm-1 [-CH3] are used as indicators for degradation. It is clear from Fig. 4 that the corona exposed region has deteriorated significantly.

The FTIR spectroscopy is a surface analysis technique. The depth/region of analysis is limited to a few microns below the sample surface. The silicone rubber material is known to regenerate /recover with time by diffusion of low molecular weight polymer chains to the surface. The technique is hence unsuitable for quantifying changes in the bulk of the material. The recovery effect in silicone rubber is shown in Fig. 5. The absorption peaks corresponding to Si-O-Si and –CH3 are identical unlike the earlier case shown in Fig. 4.

Figure 5. FTIR spectrum of the sample before/after corona exposure and recovery

The corona exposed region and the virgin sample were treated with a 1.75 watts 532 nm double YAG laser radiation for a constant time (120 seconds). The experimental setup for laser treatment is shown in Fig. 6.

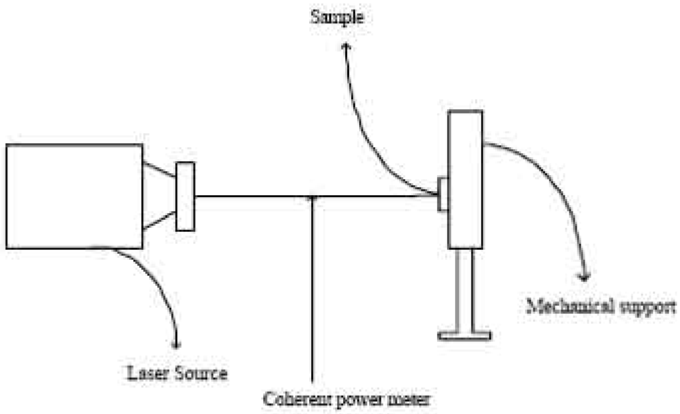


Figure 6. Experimental setup for laser experiments to characterize degradation

The laser power is measured by using a coherent power meter. The coherent meter is based on the principle of photodiodes. Each photon within the wavelength range of the device creates an electron hole pair. When reverse biased, the electron-hole pair generated results in a current flow that is proportional to the light flux. To obtain the best results the meter should be held perpendicular to the path of the laser beam. To enable measurements over a broad range of wavelengths, power levels, pulse energies and repetition rates multiple sensors can be used.

The response of the polymer sample can be categorized into, ? Initial stage (Dormant period or when there is no indication of a visual change on the surface),

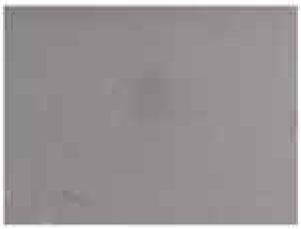
• Transition stage (when the material starts vaporizing),

• Degradation stage (when a ditch is formed on the material surface).

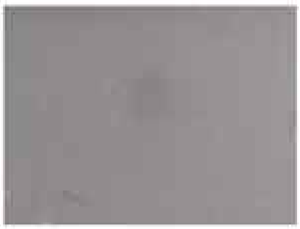
The area of the sample that was subjected to the incident laser radiation was in the order of 200 microns and the power of the beam was in the order of 8-9 mW. Though the power density was very high any degradation that occurred in the material was not perceived by naked eye. With exposure to laser radiation there were indications of color change in the material, however, the changes were subjective. The above problem can be eliminated by using a Raman spectrometer or by increasing the area exposed to the radiation so that any deterioration in the material can be observed visually. It must be noted that the power of the laser beam cannot be increased infinitely due to practical limitations and hence any increase in the area beyond a point results in an effective decrease in the power density. The time taken to visually observe changes in the material is selected as the parameter to quantify degradation. Depth of penetration and width of the ditch produced by the beam can also be used as indicators of degradation.

Literature search shows that the depth of penetration in the material is a function of bond strength and concentration. The results reported in Table. 2 and Fig. 7 are in agreement with the theoretical conclusions. FTIR results in Fig. 4 clearly indicated a lower bond concentration and laser treatment results show a greater depth of penetration in the corona exposed region

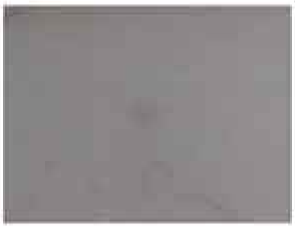
SN	Sample	Depth of Penetration (inch)
1	Virgin silicone rubber 1 (SR1)	Negligible
2	Virgin silicone rubber 2 (SR2)	Negligible
3	Corona treated SR 1	0.065
4	Corona treated SR 2	0.049



Virgin SR1 after laser exposure



Corona treated region after laser exposure



Virgin SR2 after laser exposure

Corona treated region after laser exposure

Fig 7: Depth of penetration as a function of degradation

Similar results (insignificant depth of penetration in the virgin material and the formation of a ditch in the corona exposed region) were obtained for the silicone rubber samples after recovery indicating that the laser technique could be a suitable method to characterize changes in the bulk of the material. The method can also be used to determine the energy required to cause various degrees of degradation in the material since the laser power and the time to laser exposure can be controlled.

(ii) Ethylene Propylene Diamene Monomer (EPDM)

A series of field inspections were conducted in the Phoenix metropolitan area to inspect corona occurrence on in-service insulators. An insulator (20 years field service) subjected to considerable discharge activity while in service was removed for research/experimental purposes. Corona cuts were observed on the underside of the first shed as shown in Fig. 8.

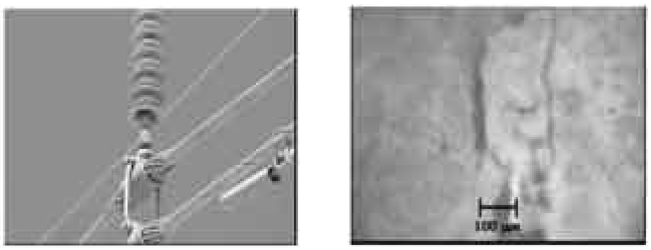


Figure 8. Corona induced degradation on a NCI (20 years field service)

A sample was cut from the shed closest to the high voltage end and FTIR analysis was performed. The region closest to the corona cut showed the maximum degradation and a decreasing trend was observed with increasing distance from the corona cut region as shown in Fig. 9.

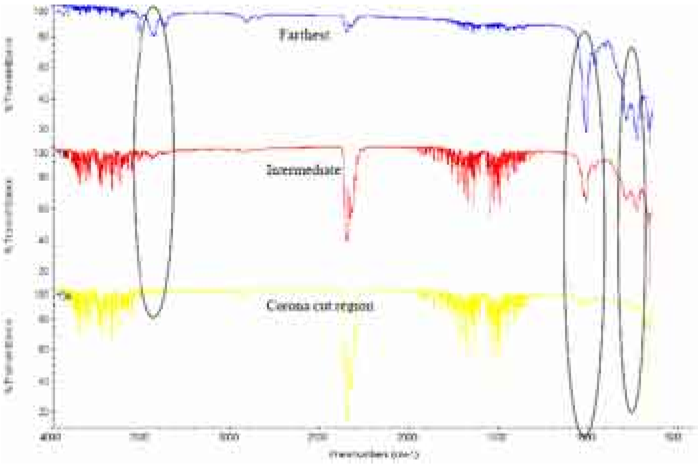


Fig 9: FTIR spectrum as a function of distance from the corona cut region

Samples from different sheds (1, 2, 3, 5, and 17) were treated with the 532 nm double YAG laser beam at 1 watt power level. The time of laser exposure was held constant (60 seconds). Samples from second shed and beyond showed little (in the form of discoloration) to no difference after laser treatment. However changes were observed along the first shed as a function of distance from the degraded region. The laser induced visual changes on the first shed is shown in Fig. 10.

Fig 10: Laser induced changes along the first shed indicated by the circles numbered 1-6

A second set of laser experiments were performed, where, time to cause a visual change was used as an indicator to degradation. The results are shown in Table. 3

S.N	Sample	Time (Sec)
1	Shed1	
	(III) In the region of corona cut	10
	(II) Intermediate region	30
	(I) Farthest from corona cut	60
2	Shed 2	63
3	Shed 3	65
4	Shed 5	64
5	Shed 17	67
6	New	120

Table 3 indicates that corona degradation in the housing material is prominent near the high voltage end and insignificant beyond the second shed. The table further indicates sheds 2 and beyond having identical but consistently lower time to deteriorate on laser treatment when compared to the new sample (due to natural aging process).

Conclusions:

>The preliminary results from the laser experiments have been interesting. It has been shown that the time for degradation due to a constant energy laser source is a function of the corona exposure. Sheds closest to the HV end or the energized electrode tend to degrade sooner than locations further away from these regions. More research is needed to improve on the available results and to probe into the unknowns of insulator science in further detail.

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