ASSESSING THE TYPE AND OPERATIONAL QUALITY OF SIR HV INSULATORS BY REMOTE LIBS ANALYSIS

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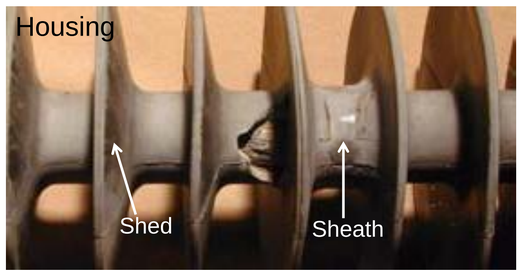
Abstract

Silicone rubber (SIR) high voltage (HV) composite outdoor insulators have been widely used in overhead transmission lines of most electric power distribution stations due to their unique properties such as low weight, high heat resistance, chemical stability and long-term hydrophobicity[1]. Compared to conventional insulators, made of glass or porcelain, polymer-based ones are suitable in areas with pollution and are less demanding on inspection requirements due to their reduced installation and maintenance costs. However, they are more easily subject to ageing and/or degradation processes, which may be caused by long-lasting exposure to unfavorable environmental conditions and/or electrical discharges. Therefore, it is important for technology today to develop suitable non-destructive diagnostic techniques[2], which would enable the remote and real time evaluation of the insulators performance.

To this end, data from tests with various spectroscopic techniques (FT-IR, Raman, LIF spectroscopies and LIBS) are shown and results are correlated to the physical and chemical properties of HV outdoor SIR insulators[3], that have been operational in the power distribution network of Crete for over ten years. Among the techniques tested, laser-induced breakdown spectroscopy (LIBS) is found to be quite an efficient and reliable one for assessing the state of HV outdoor insulators in service. Diagnosis is achieved by measuring specific spectral indicators, which reflect the extent of chemical modifications induced to the insulators surface as a result of their longtime presence in the field. Standard and remote LIBS measurements have been performed successfully both in the laboratory and on site, respectively, thus indicating that LIBS can indeed be used in the field for real-time diagnostic purposes.

Outdoor HV Composite Insulators



Polymer-based insulators are composed of a load bearing glass-fiber-reinforced epoxy rod, covered with an elastomeric housing.

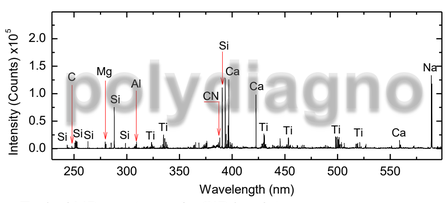
Such insulators have been selected and detached from the power distribution network of Crete, depending on their operation time in the field and their degree of degradation due to pollution and other environmental factors. Stock insulators, with no operation time in the field, are also examined for reference.

Shed samples are cut (from the housing of the insulators) and examined in the laboratory. For on-site measurements the insulators are examined as a whole, without any sample removal or preparation.

LIBS analysis of HV polymeric insulators

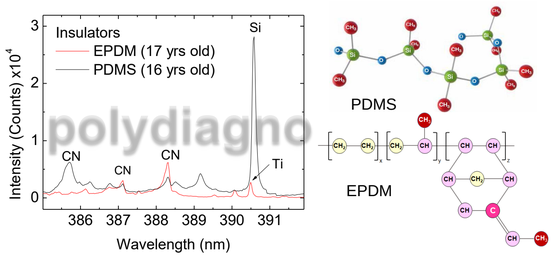
Multi-elemental analysis of the insulators for:

- fast identification of the housing material
- fast sorting of the different types of polymer-based insulators



Typical LIB spectrum of a SIR insulator.

C, Si, CN originate from the polymer and Mg, Al, Ti, Ca originate from fillers (e.g. MgO, $Al_2O_3 3H_2O$, TiO_2, $CaCO_3$), used in order to reinforce the insulator mechanical properties (Nd: YAG laser; λ=1064 nm)



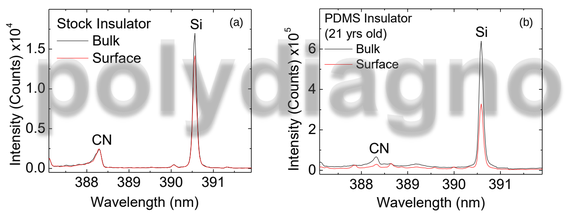
LIB spectra of two of the most common types of polymer-based (SIR or PDMS and EPDM) insulators (Nd: YAG laser; λ=1064 nm).

LIB Spectral Indicator

Integrated intensity ratio :

$$R = I_{CN388} / I_{Si390}$$

- Almost constant for the stock SIR insulators (R_{Ref} = 0.20 ± 0.02)
- Lower on the surface (R_{Surf}) in comparison to the bulk (R_{Bulk}) in the case of the field SIR insulators.



LIB spectra corresponding to the bulk and the surface of samples obtained from (a) a stock insulator and (b) insulator with 21 years operation time in the power distribution network of Crete (each spectrum is acquired by accumulation of 10 single-shot spectra; Excimer laser; λ= 248 nm).

This ratio can be used as a LIB spectral indicator of:

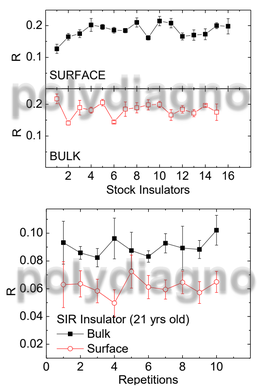
- **the type of insulator**

  If it is a SIR insulator then R is comparable to R_{Ref}.
  If the polymer does not contain Si (e.g. EPDM) then R is almost 10 to 20 times higher than R_{Ref}.

- **the operational condition of SIR insulators**

  R reflects the degree of the chemical modifications (e.g. loss of CH_3 groups from the surface) induced to the insulators as a result of their long-term operation in the field.

Spectral Indicator Reproducibility



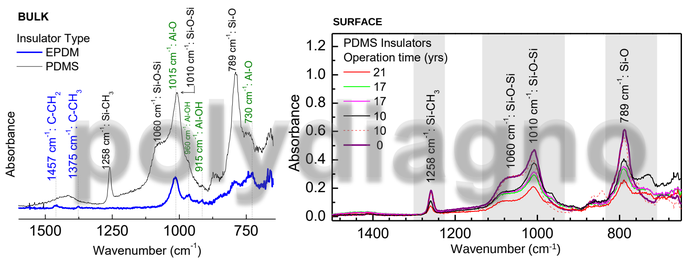
SIR Insulators Evaluation Criteria

$$\Delta R = 100\ (R_{Surf} - R_{Bulk})/R_{Bulk}$$

- When ΔR = 0-20%, the insulators are in a good operational condition, similar to the new insulators condition.
- When ΔR > 30%, the insulators performance is limited due to significant degradation.

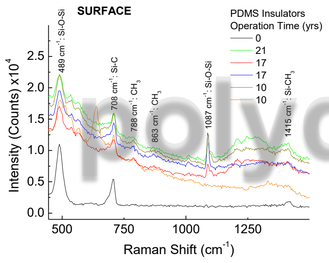
Other Diagnostic Techniques

FTIR - Attenuated Total Reflection (FTIR-ATR)

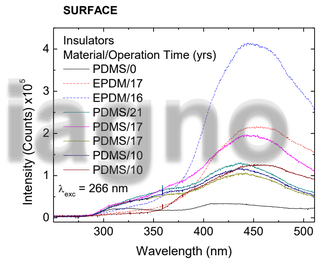


- PDMS and EPDM polymers are identified.
- For PDMS insulators the absorbance (at 1060 and 1258 cm^{-1}) decreases with operation time, indicating the loss of CH_3 groups and degradation of the Si-O-Si polymer chain.
- The absorbance at 1010 cm^{-1} is shifted towards lower frequencies when measured on the surface in comparison to the bulk of the samples. This frequency shift increases with operation time.

Raman Spectroscopy



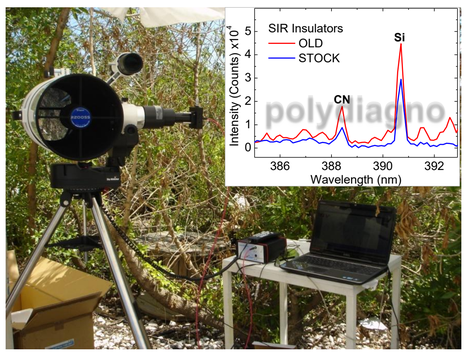
Laser - Induced Fluorescence



Insulator #	Polymer Chain Type	Operation Time (yrs)	UV – LIBS ΔR_{UV} (%)	IR - LIBS ΔR_{IR} (%)	Operational Quality (based on the suggested criteria)
8	PDMS	0	10 ± 11	-5 ± 12	High
12	EPDM	17	-26 ± 8	-16 ± 18	Criteria Not Applicable
13	EPDM	16	4 ± 19	-15 ± 10	Criteria Not Applicable
14	PDMS	21	- 64 ± 24	-33 ± 6	Low
15	PDMS	17	- 55 ± 16	-59 ± 9	Low
16	PDMS	17	-24 ± 16	-32 ± 18	High
17	PDMS	10	-38 ± 7	-38 ± 16	High
18	PDMS	10	8 ± 8	-20 ± 14	High

Remote (on-site) LIBS of SIR insulators

The suggested SIR insulators evaluation criteria, via standard LIBS, are also valid upon remote LIBS in the laboratory. However, this is not the case for on-site, real time measurements since it is not feasible to perform LIBS in the bulk of the insulators. Therefore, new criteria are required.



Remote LIBS at the HEDNO High Voltage Tests experimental facility at Linoperamata (Heraklion, Crete)

(a) The insulator is removed from the electricity distribution network (almost 20 meters above the ground) and (b) is placed on a special support, designed to ensure nearly normal incidence of the laser beam on the insulator surface (c) The Nd:YAG laser (λ= 1064 nm) beam spot on the insulator's shed surface.

Plasma radiation is collected by a telescope, which is placed at a distance of almost 7 m away from the target. An optical fiber is aligned at the focus of the telescope and transmits the plasma light into the spectrometer.

SIR INSULATORS

SURFACE Spectral Indicators

R_{OLD} = 0.34 ± 0.03

R_{STOCK} = 0.25 ± 0.01

Percentage Difference

$DR = (R_{OLD} - R_{STOCK})/ R_{STOCK}$

DR = (26 ± 13) %

⇒The old insulator tested is of high operational quality, since the measured spectral indicator does not differ much from the value corresponding to an insulator with no operation time in the field.

Conclusions

LIBS sensitivity on the detection of minor changes in the chemical composition of materials is exploited in the analysis of outdoor composite HV insulators. LIBS is proven to be a fast, efficient and reliable diagnostic method for assessing the type and performance of polymeric insulators. In contrast to other diagnostic techniques, LIBS is implemented remotely and on-site, therefore, it is most attractive for applications in the field. Chemical modifications induced by ageing and/or degradation of the insulators can be effectively probed by calculating suitable spectral indicators, the value of which is found to differ systematically on the insulators surface compared to the bulk. This result leads to the formulation of evaluation criteria, which have been validated both via standard and remote LIBS measurements in the laboratory.

References

1. H. Hillborg, U. W. Gedde, IEEE Trans. Dielectr. Electr. Insul. 6 (1999) 703-717.
2. S. M. Gubanski, A. Dernfalk, J. Andersoon, H. Hillborg, IEEE Trans. Dielectr. Electr. Ins. 14 (2007) 1065-1080..
3. D. Pylarinos, K. Siderakis, E. Thalassinakis, IEEE Electr. Insul. Mag. 31 (2015) 23-29.

Acknowledgements

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