A NEW APPROACH TO INTEGRITY ASSESSMENT OF ELECTRICAL COMPONENTS OF THE MEDIUM VOLTAGE DISTRIBUTION NETWORK

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ABSTRACT

*The paper reports the experience of CESI RICERCA on the use of innovative diagnostics systems for the monitoring of **M**edium **V**oltage (MV) components. The activity is aimed at the assessment of the applicability of optical based sensors having the advantages to be non invasive, not affected by unwanted electrical disturbances, and also quite cheap. The paper reports the results achieved in the first part of the research program mainly devoted to medium voltage switchboard.*

INTRODUCTION

In the framework of the liberalisation of the electrical market, deregulation and increasing competition force the Utilities to optimise the management of their network. In particular the MV network plays a strategic role from a technical and economical point of view.
Reference [1] reports that 80% of outages is due to electrical failure on components and that the switchgear are the second cause of failure in a MV network after overhead line and before cable. The percentage of outages due to electrical failure on components is very dependent on the type of the network and consequently on the Country [2].
In the past years in Italy a very large campaign of diagnostic tests on MV power cable has been carried out using PD measuring systems based on off line technique [3]. The results have shown that the techniques is useful from a technical point of view but with the present regulation in Italy is very expensive to be applied systematically on the cable network.
The diagnostic on the MV switchboard is important either because a failure will cause higher outage time with respect to cable failure, at least for the present configuration of the Italian network, and for the very high number of components installed.
For example, in Italy there are more than 300000 MV/LV substations relevant only to the power cable lines, each cabin including at least two switchboards.
Bearing in mind the return of experience relevant to diagnostic on MV cable, the research was addressed to apply innovative sensors, to be used in MV switchboard both as permanent systems or to be removed and easily installed again in different places to have a statistic behavior on families of components. The paper reports the application of optical based sensors, to detect the induced effects of both corona and surface predischarge phenomena, such as light emission and generation of acoustic noise.
The results of measurements performed on artificial defects detected by a low cost, simple and reliable diagnostic system based on the combination of optical and acoustic sensors are discussed

EXPERIMENTAL DETAILS

A typical switchboard configuration was reproduced in laboratory using normalized components exploited in Italian distribution network (12/20 kV) where artificial defects were introduced to simulate Partial Discharge (PD) activity.

Simulated defects

Two different types of fixed defects were introduced with the aim to reproduce:

- corona effect: a wire with a 300 mm length and 1mm diameter was positioned on the three phases of the disconnector alternatively (see figure 1a).
- surface predischarge phenomena: a strip of electrical semiconductive tape with a length of 70 mm and 15 mm wide was attached to two phase cables termination alternatively (see figure 1b).

Tests were performed to verify that without artificial defects the switchboard was PD free up to an applied voltage of 2.5 U_0 and in case of presence of the artificial defects the repeatability of the phenomena in term of inception voltage and PD amplitude, measured according to IEC Standard 60270. Typical results are reported in Table 1 for the two artificial defects.

Table 1: Inception voltage and PD level

Defect type	*Inception PD voltage [kV]*	*PD value [pC]*
Thin Wire	8-10	<20
Strip	15	700-1700

Equipment

Optical sensors

Two different types of optical sensors have been introduced to detect light emission of both corona and surface discharges:

- a fluorescent fiber, of 2 mm diameter shaped as a coil of 500 mm diameter for a total length of 4 m, was attached to the switchboard wall, in front of the terminations, see figure 2. The corona UV emission, collected by the fiber coil, excited the fiber fluorescence in the 380÷400 nm band [4]. The signal was conveyed through the fiber itself toward the photoreceiver: a photomultiplier with selectable gain.

- A standard optical probe, with a photomultiplier detector, was mounted on an adjustable ball joint on the door of the compartment (see insert of figure 2). The PD light emission was detected through an optical lens (9 mm focal length, $f_{\#}=1$). An UV bandpass filter (centered at 364 nm, ±10 nm) was mounted behind the lens to avoid environmental light interference.

a) b)

Figure 1: Defects realised in the switchboard

Acoustic sensor

Commercially available sensors, operating in acoustic band were used to investigate the feasibility to detect corona and surface discharge audible emission, in agreement with reference [5]:

- A low cost omnidirectional back electret condenser Microphone (MC), internally preamplified (Frequency Bandwidth = 20÷12000 Hz ± 3 dB) was located, inside the compartment, approximately 300 mm from the nearest termination;
- a recent commercially available omnidirectional optical Microphone (Frequency Bandwidth 10-15000 Hz ± 3 dB), was inserted in the MV compartment. As described elsewhere [6,7], this optical Microphone (MO) detects the intensity modulation of the light back-reflected by a sound sensitive membrane.

Both these microphones were installed on the door of the compartment as shown in figure 2, nearby the optical probe.

Signal Processing

The signal outputs were recorded with an A/D acquisition board. The standard acquisition was 1 sec long with a sample rate of 50kSample/s, synchronised with the supply voltage reference.

For the MC and MO the time domain signals were filtered and Fourier Transformed into the frequency domain and averaged over 20 acquisitions.

Preliminary tests

Preliminary characterization of corona acoustic emission was performed with the microphones faced to the "corona" defect. A calibrated Bruel & Kjaer mod. 4165 Microphone, (Bandwidth 20-20000 Hz) ,was used as a reference. Typical spectral pattern of the corona discharge is shown in figure 3.

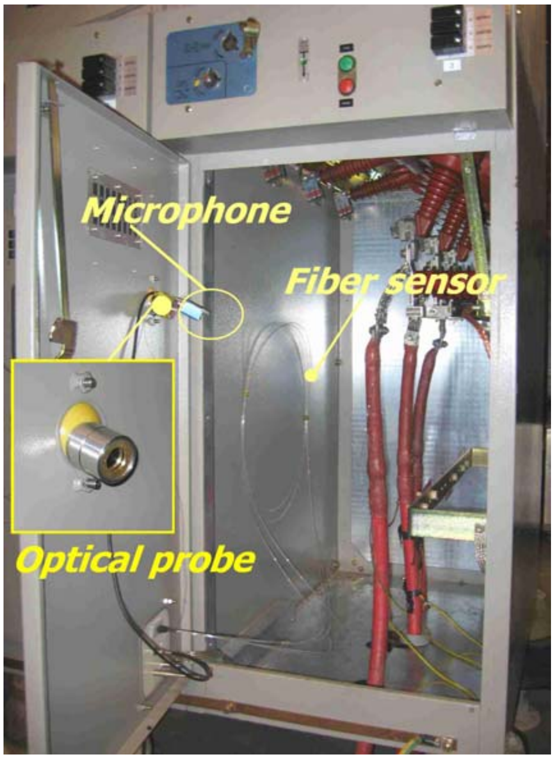

Figure 2: Experimental layout

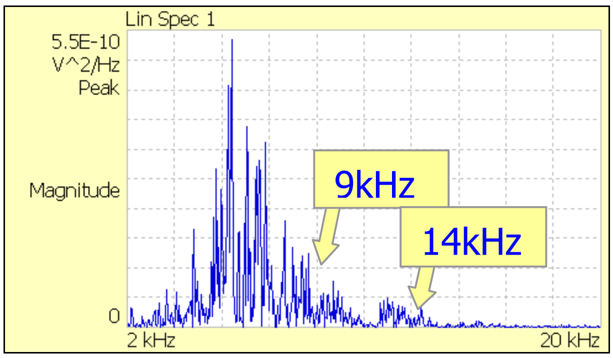

Figure 3 Typical spectral response of corona discharge in the range up to 20 kHz measured by the reference Microphone.

Figure 3 highlights that the "corona" fingerprint shows, in the range up to 20kHz, two resonances at frequencies of 9 kHz and 14 kHz. This suggests the possibility to suitably filter MC and MO output signals to get rid of environmental noise and have still a good sensitivity. Spectral bands of 9kHz and at 14kHz respectively for the MC and MO Microphones, were selected for the tests. Figures 4a and 4b, show two examples of recorded signals.

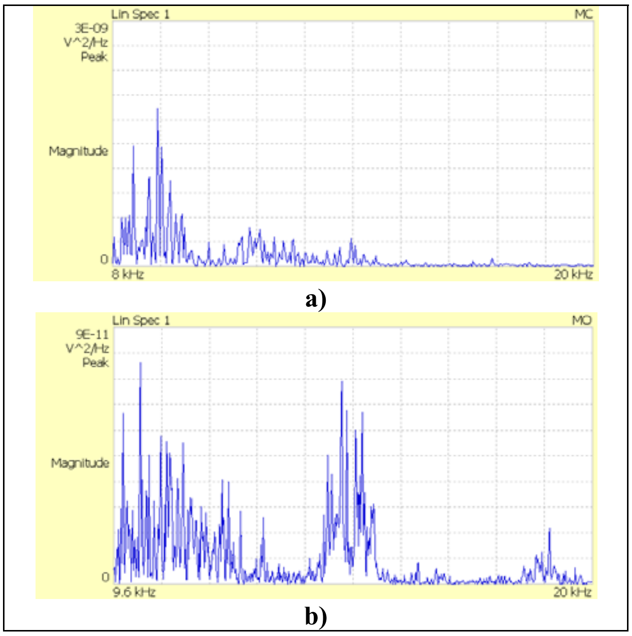

Figure 4. Typical spectral response to corona discharge of: a) MC and b) MO.

EXPERIMENTAL TESTS AND RESULTS

The tests in the MV switchboard were performed with the sensors layout shown in figure 2. The defects were introduced once at a time and located in different positions within the switchboard.

For each type of defect, a series of tests were carried out increasing the applied voltage step by step, from the inception levels, up to 2.5 U_0. For each step, 1 minute duration, several acquisitions of both optical and acoustic signals were recorded.

For both defects, the output signals of both optical sensors was analysed to check the time behavior and its correlation with applied voltage, see figure 5.

At inception voltage, the optical signals appeared in correspondence with the negative crests of the applied voltage, for all the analyzed defects; at higher voltage levels the corona activity was observed on both polarity in good agreement with PD Resolved Pattern (PDRP). No emission on the positive polarity was evidenced, instead, with the semiconductive tape.

Figure 6 reports for the two simulated defects the optical power measured by the fiber optic sensor as a function of the applied voltage normalised on U_i. One can notice that optical signals recorded by fiber optic sensor depend on defect position: in fact, for the defects located in hidden part, the minimum applied voltage necessary to

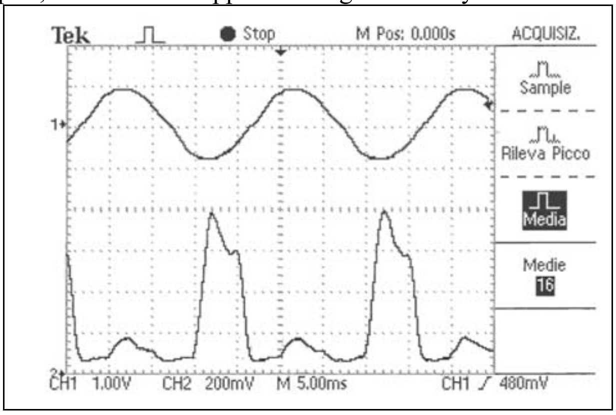

Figure 5. Reference 50Hz applied voltage (upper trace) and time behavior of the optical signal (bottom trace) in presence of a Corona discharge.

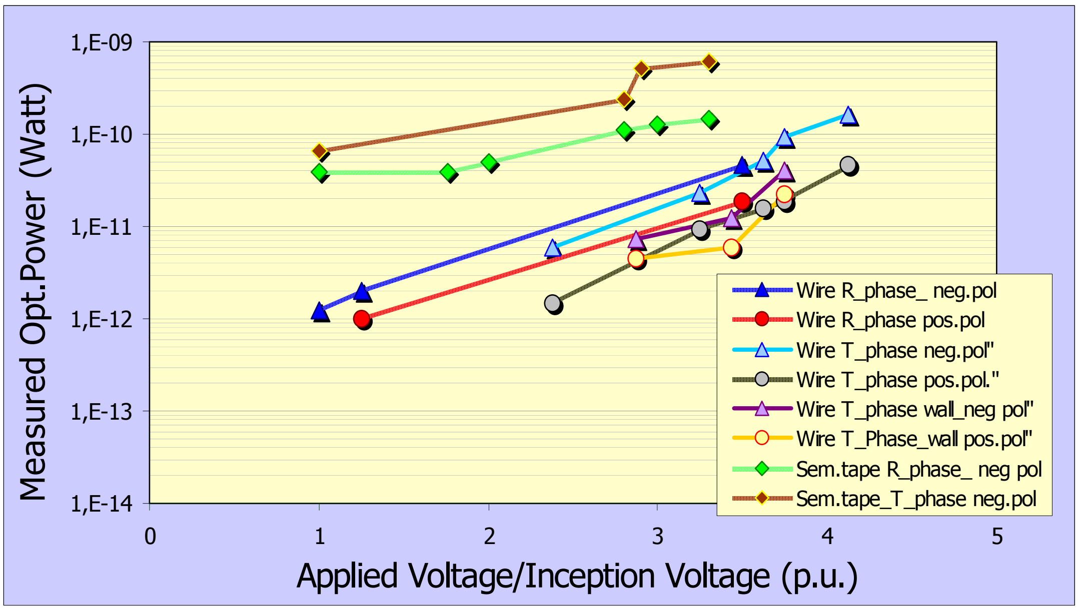

Figure 6. Output power measured by the Fiber optic sensor vs. the Normalized Applied Voltage (p.u.), for the wire and the semiconductive tape defects.

record optical activity, was about $3U_i$. On the contrary, no evidence of such dependence was observed for the semiconductive tape; probably due to the high pC levels related to the inception of the surface Partial Discharge. It has to be underlined that comparable optical power levels were obtained for the two optical sensors and for both corona and surface discharges, when the defects are positioned on the terminations nearest to the sensor (phase R), in that condition an equivalent sensitivity of 2 pC was assessed.

Same measurements performed with both the Microphones showed that the minimum detectable threshold of the acoustic pattern was 2.5 U_i for the semiconductive tape, as shown in figure 7 and higher (3-3.5 U_i) for the wire. A corresponding resolution of 450 pC was estimated.
No appreciable difference in the frequency patterns of the two type of defects was evidenced in the analyzed spectral bandwidth, as expected since the characteristic emission of air/surface discharge should be similar.

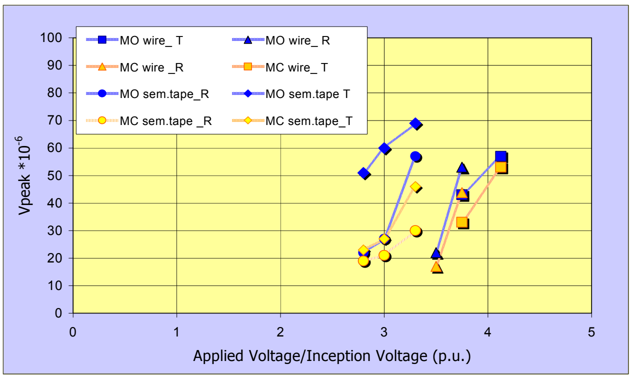

Figure 7. Amplitudes of the power spectral bandwidth (Vpeak) of the acoustic patterns acquired with the MO (blue lines) and the MC (orange lines) Microphones, for the two defect types.

A higher signal to noise ratio was obtained for the MO with respect to the MC one, both for the intrinsic transducer characteristics and higher frequency bandwidth operation. For both these devices it is possible to increase the performances by upgrading the sensor configuration and by means of an optimized signal processing.

SUMMARY AND CONCLUSION

This paper was aimed at giving a contribution to the studies finalised to develop a low-cost combined diagnostic system with high sensitivity to corona and surface PD phenomena arising in MV compartment, under real operating condition. Preliminary tests performed with two types of representative defects demonstrated the reliability of the optical sensors.
Optical signals with high S/N ratio were obtained also at the inception levels detected by the PD standard measuring system; this opens wide margin to further reduce the cost of the optical sensor by the introduction of standard UV enhanced photodiodes. The fiber optic configuration allows, with respect to the standard optical probe, further improvements of the hidden signal detection by the use of an optimized layout of the sensing fiber along the wall of the compartment.
Acoustic PD detection, with the use of commercially available optical microphone, was confirmed for minimum detectable levels lower than 500pC. Compared with the conventional acoustic sensors, this sensor has the advantages of being non-electrically conductive, to be immune to the electro-magnetic interference and to be chemically inert and of a very small size.
The research will continue to verify the feasibility of application of a whole-optical detection unit, realized with standard components, on in service switchboard. Moreover the two aspects relevant to MV/LV transformers diagnostic and the smart management of the acquired data will be taken into account.

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