

A MULTI SENSOR DEVICE FOR MONITORING PREDISCHARGES IN MEDIUM VOLTAGE EQUIPMENTS

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ABSTRACT

The paper analyses the feasibility of a fibre optic multi-sensor device for detecting in situ predischARGE phenomena on electrical components of Medium Voltage (MV) network. Preliminary tests have been carried out in a typical MV switchboard and a combined diagnostic parameter has been identified for evidencing critical predischARGE conditions.

INTRODUCTION

According to failure statistics, electrical equipments of Medium Voltage (MV) substations are one of the major causes of outages in a MV distribution network [1]. Diagnostic and monitoring techniques on MV switchboards can thus play an important role in reducing outage times given also the very large number of these components installed.

The presence of pre-discharges (corona and surface pre-discharges) in MV switchboards and their persistence for long time can induce a progressive degradation of insulating surfaces of the electrical equipment. On long term this process can evolve to flashover, leading to switchboard failure. Therefore a diagnostic tool should be able to detect both pre-discharge inception and its time evolution, by monitoring the trend of the physical parameters induced by pre-discharge phenomena such as light emission, generation of acoustic noise and ozone production [2]. The sensor system should be used inside MV switchboard either as permanent or temporary system, it should be easily removed and installed again in different places, to obtain statistic behaviour on families of components. Moreover sensor costs should be reasonably low, given the low costs in general of MV electrical components to be monitored.

At this aim authors, recently, proposed a potentially low cost multi-sensing approach for a promising tool to assess critical predischARGE evolution in MV switchboards [2]. A multisensor prototype was assembled and each sensor unit was individually tested in laboratory. This paper describes the multisensor device basic principle together with preliminary experimental results for assessing the system feasibility.

MULTISENSOR CONCEPT AND DEVICE

The developed fibre optic multi-sensor device is based on the integration of three different sensors: optical, acoustics and chemical. Each sensor detects an effect of corona and/or

surface pre-discharges: respectively, UV light and sound emission and ozone generation.

All these sensors are of optical type in order to be not invasive, immune from electrical disturbances and chemically inert. In details, an active probe based on fluorescent optical fibres (FO) is used to detect the ultraviolet UV predischARGE emission, as described in [2]. The produced visible light is detected by amplified photoreceivers on opposite sides of fibres ends. At predischARGE inception, an optical signal in relationship with the phase and polarity of the supply voltage (50Hz) is observed.

Optical microphones (OM) are used to detect sound emissions of pre-discharge, in the range up to 20 kHz. As reported in [3], the acoustic wave, generated by the predischARGE, is directly converted into an intensity modulation of light.

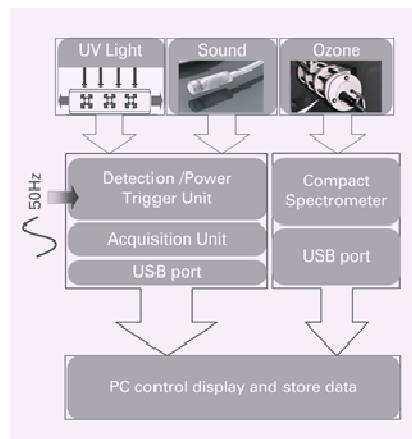


Figure 1. Scheme of the fibre optic multisensors device.

A fibre optic spectroscopic type sensor is used to detect increase in ozone concentrations in the MV switchboard. It exploits the differential spectral absorption of ozone in an absorbing UV band and in a non absorbing visible band respectively [4,5]. Changes in ozone concentration, induced by predischARGE inception, are evidenced as intensity changes of the UV radiation @254nm with respect to a reference value. Both UV and visible radiations

simultaneously propagate inside the optical probe as shown in Fig.1

These sensors are interfaced to a hybrid and modular unit, which performs complementary and simultaneous analyses of different types of acquired signals.

Optical and acoustic sensors are connected to the same electro-optic unit (Fig.1). This consists of a power supply, detectors with conditioning electronics and of a trigger circuit board; this last one generates a TTL pulse at the zero crossing on the positive edge of the supply voltage (50Hz) for the synchronism. Output signals are sent to a compact acquisition chassis, which is USB connected to a PC notebook. An Analog Input Module and a Dynamic Signal Analyser Module perform acquisition of optical and acoustic inputs respectively. A digital trigger module is used to synchronise acquired signals.

Ozone sensor is connected to a compact spectrometer directly interfaced to the PC, through USB connection.

A SW interface was developed to simultaneously control configuration settings of input channels, the display on the PC screen of acquired data and their storage. Different levels of priority are assigned to each operation to always guarantee efficient resources to data acquisition. Lower priority is assigned to the management of the configuration panel.

An example of the simultaneous acquisition of responses of three sensors in presence of predischage is reported in fig.2. The panel shows respectively acoustic and optical waveforms (left side) and time trace of ozone signal (right side on the bottom). Data storing is enabled by buttons on the right of the panel.

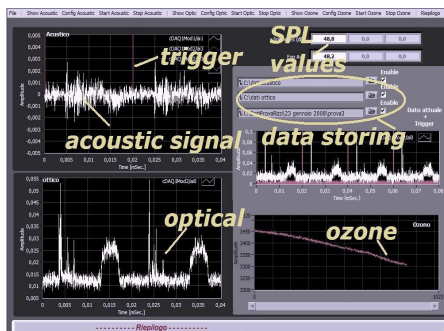


Figure 2. User interface: display panel showing simultaneous acquisition of optical (left side below), acoustic (left side up) and ozone (right side) time domain signals.

For each sensor several parameters can be simultaneously displayed and analysed, as listed below:

- optical fibre sensor: cumulative or averaged optical patterns (Fig.2 on left side), in phase with

50Hz trigger reference. Trends of maxima signal amplitudes is then monitored and saved together with optical waveforms for signal off-line processing;

- optical microphones (MO): Acoustic patterns in phase with 50Hz, spectral responses of microphones in a suitably selected frequency range and Sound Pressure Levels SPL (dB) can be simultaneously displayed on the acoustic control panel (Fig.3). SPL values can be saved together with acoustic waveforms;
- ozone: the acquired optical spectrum is displayed together with time traces of intensities at selected spectral (@254nm in Fig.4).

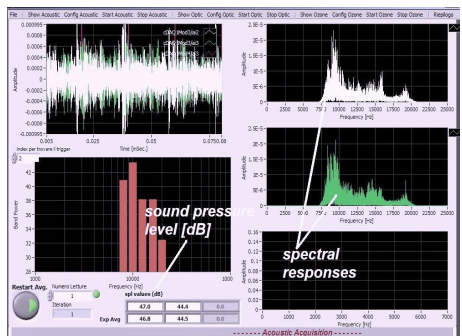


Figure 3. Control panel of Optical Microphones (OM) showing time domain signals (on the left) filtered and Fourier Transformed into the frequency domain (8 kHz-16kHz, on the right).

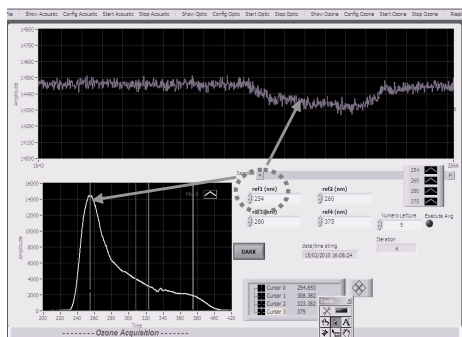


Figure 4. Control panel of the Ozone sensor showing the acquired optical spectrum (below) and monitored intensity changes of the absorbing band @254nm (up).

The simultaneous display and analysis of several parameters for each sensor give the possibility to evidence the most

suitable ones to detect predischage effects with high signal to noise rejection. Afterwards preliminary tests were performed in a MV switchboard to identify an effective combined diagnostic parameter.

TEST EQUIPMENT

A typical MV switchboard configuration was reproduced in laboratory using components of the national distribution network (12/20kV).

Fig.5 shows optical sensors installed inside the switchboard: fluorescent fibres were placed along the walls of the MV enclosure. On opposite fibres ends, two photoreceivers detect simultaneously optical signals with different intensities, in respect with the predischage location. Optical microphones were installed on opposite walls and the ozone probe was put on the bottom of the enclosure.

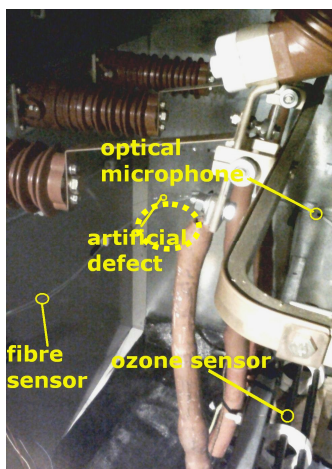


Figure 5. Sensors installed in the MV switchboard. In the inset is shown the artificial defect used to simulate the corona predischage.

An artificial defect, a wire (300mm length and 1mm diameter), was inserted to simulate corona predischage activity. It was introduced on the central phase of the disconnector as shown in fig.5. Due to its low inception voltage level a corona defect was preferred to evaluate sensitivity and response times of the multisensor prototype. An ICM electrical system for Partial Discharges diagnostic was used to correctly assess this phenomenon. It consists of a sensor (a current transformer operating in the high frequency band 40 kHz – 800 kHz) which was positioned inside the enclosure closed to the defect to increase its sensitivity.

EXPERIMENTAL TESTS AND RESULTS

Experimental tests were carried out by rising the supply voltage up to the corona inception and then by increasing it gradually to evaluate the multisensors performances. Data were recorded by the PD standard system and by the multi-sensor device.

Optical and acoustic acquisitions were one second long with a sampling rate of 50Ks/s. Ozone acquisitions were longer (>30s) and not synchronised with the 50Hz reference supply voltage, since these measurements are correlated to the natural diffusion time of the ozone inside the MV enclosure.

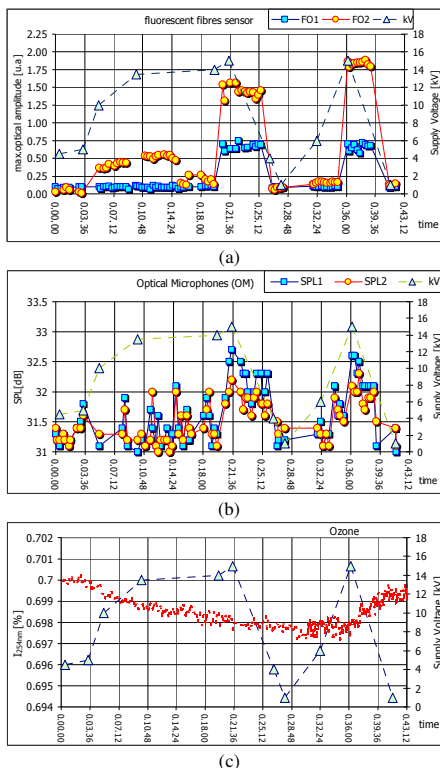


Figure 6. Time Responses of sensors: a) fluorescent fibres: maxima of optical amplitudes; b)OMs: SPL (dB); c) Ozone: intensity changes @254nm. On the secondary axis corresponding supply voltage levels.

Examples of typical and simultaneous response times of each sensor are reported in fig.6. It shows maxima of amplitudes of optical patterns measured by the two photoreceivers (fig.3a), SPL values for the two OMs

(fig.3b) and intensity changes measured at the ozone absorption band (fig.3c). These signals were recorded as a function of the time during which the supply voltage was increased step-by-step. On the secondary axis the supply voltage is reported. For inception level $U_i=4kV$ and at $U=3U_i$, corona entities measured by the ICM system were $\sim 50pC$ and $\sim 300pC$ respectively.

From fig.6a higher optical amplitudes were measured by fluorescent fibres positioned closest to the artificial defect. This suggests the possibility to identify the source of the corona predischARGE by comparing output signals of both photoreceivers.

In fig.6b some transients were evidenced on SPLs (dB) acquired by two optical microphones (OM) and close to the U_i level (range: 5-8kV). They are due to the step increase of the supply voltage affecting signal to noise ratios.

At higher voltages OMs behaviours are similar independently from location inside the MV switchboard, probably due to their omni directional features

Several positions of the artificial defect analysed as summarized in fig.7. This figure shows a comparison among sensitivities of the different sensors as a function of defect direction in the MV switchboard. The sensitivity is expressed as measured inception voltage in percent unit (p.u.) of the values recorded by the standard PD system.

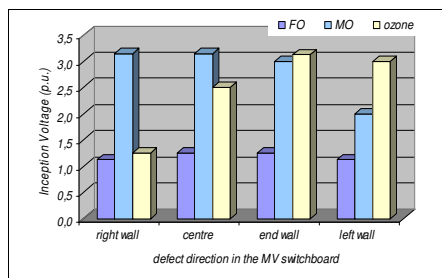


Figure 7. Sensitivities of optical sensors to “corona” defect direction. Measured inception voltages are in percent unit (p.u.) of the values recorded by the standard ICM system.

Highest sensitivities were obtained with the optical sensor: it showed lowest inception levels for all position of the defect. Ozone sensitivity strongly depends on the ozone diffusion inside the MV enclosure; so when the sensor is nearby the defect, its sensitivity is higher.

A joint predischARGE detection threshold for all optical sensors could be ~ 3 p.u., which corresponds to a $\sim 300pC$ predischARGE activity, measured by the ICM system.

SUMMARY AND CONCLUSION

This paper describes a predischARGE monitoring device for MV switchboard, which exploits a multisensor concept to reduce the occurrence of false alarm. These sensors are

based on optical fibres technology to survive in the switchboard functionality and without the need of periodic replacement of sensor probes.

For a preliminary assessment of the prototype feasibility, a hybrid electro-optic detection and acquisition unit was assembled; it includes a separate compact spectrometer for ozone detection PC interfaced trough USB connection, as for the acoustic and optical unit. The simultaneous analysis of three signals was managed through a polyfunctional user interface; this interface allows also the optimisation of parameter setting for each sensor individually.

Sensors were installed in a typical MV switchboard configuration; a comparative analysis with a PD standard device was executed as a function of different directions of an artificial corona defect inserted in the MV switchboard and for different supply voltage levels.

The correct operation of the multisensor device was confirmed on short period. An effective “predischARGE diagnostic parameter” seems to be as a joint analysis of amplitudes of optical fibres signals, sound pressure levels, (dB) for Optical Microphones, and time behaviours of the ozone absorbing band.

According to this result a simplified version of the user interface is under development; a further long duration experimental activity in a real operating MV switchboard is foreseen to consolidate obtained results.

ACKNOWLEDGMENTS

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE (formerly known as ERSE) and the Ministry of Economic Development – General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency stipulated on July 29, 2009 in compliance with the Decree of March 19, 2009.

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