NON INTRUSIVE OPERATIONAL MV SWITCHGEAR CONDITION ASSESSMENT

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ABSTRACT

The electricity distribution scenario around the world is experiencing a number of often clashing drivers: regulating Authorities statutory objectives pressure to enhance distribution networks quality and performances, high level of competition in the energy supply and equipment manufacturer business, higher industrial and commercial end users consciousness to the electricity commodity continuity and availability issues and its economic value.
In this scenario we face, in particular in industrialized countries, an aging electrical infrastructure.
Condition assessment of MV substation equipment can play a significant role in supporting asset management decisions and drive maintenance, retrofit or refurbishment actions. On the long run it can help to limit loss of supply events due to equipment failures and relevant personnel safety concerns.
The paper describes an experimental campaign to assess the capability of commercial non-intrusive Partial Discharge (PD) equipment to detect different PD sources induced in a 17.5 kV metalclad/internal arc switchgear (SWG) assembly and to properly locate them, comparing the performances with a conventional electrical detection system.
The use of non-intrusive PD detectors is proposed in the scheme of routine controls to provide confidence in the safety and reliability of installed switchgear and as condition monitoring method to support maintenance policy, and investment decisions on plant replacement or refurbishment.

INTRODUCTION

The medium voltage switchgear is the core “component” of distribution networks and of industrial users power plants and in the rare but catastrophic occurrence of an internal failure may have a significant impact on power availability to supplied loads, in particular as restoration time can be long.

While mechanical issues of the switching equipment are often addressed by manufacturer prescribed maintenance and related condition is easier to check; insulating parts surface or internal degradation, especially if triggered from environmental or electrical stresses, may become critical in the equipment operating life when aging phenomena starts and standard maintenance procedure are not likely to prevent or detect them.

The majority of the degradation processes affecting insulting components as bushings, cable termination, current and voltage transformers, etc. are associated to Partial Discharge (PD) activity, that can be defined as “a localized electrical discharge in an insulation system that does not completely bridge the electrodes”.
PD activity associated to an insulation aging and degradation process typically increases with the defect evolution. Therefore PD activity measurement can be used as a diagnostic tool to assess equipment condition and to locate defect source, enabling selective intervention to remove aging component prior to complete failure.

PD PHENOMENA AND DETECTION METHODOS

The PD presence and activity amplitude can be important criterions to assess the insulation system condition, both in the production process and later on site during the electrical equipment service life.
When PD occurs, typically in some defective part of an insulation or in high electric field region on surfaces or in air, several detectable physical effects are associated, as dielectric losses and heat production, electromagnetic transients over a wide frequency spectrum, sound, light and chemical reactions.
Several of those effects can be measured and the information thus collected can be used to assess the affected insulation system condition.
Traditionally the most used detection method has been based on electrical measurement, in accordance to the IEC 60270 standard [1]. Widely used in laboratories for material characterization and as quality acceptance method on insulating components and new equipment in electromechanical manufacturing, the electrical PD measurement has increased in recognition capability by the introduction of digital instrumentation, enhancing sensitivity and noise rejection.
In field applications, it is mainly used while commissioning electrical systems but is less friendly when the task is to evaluate the insulation condition of an on-line system, as it has to be out of service, test conditions are different from operational ones and typically tests are then conducted in single phase configuration and with no load, therefore on cold equipment.
They enable high sensitivity measure of the PD activity apparent charge in picoCoulumb (pC) and definition of the inception voltage, i.e. the voltage above which a PD activity threshold is overcome. The inception voltage defines at which level an inherent defect becomes active and related to

the SWG operating voltage may help in assessing the defect severity.
Non-intrusive PD commercial equipment, better suited to operate on installed equipment in operation condition and respecting safety procedure on live equipment, are based on the detection of the PD effects, as sound and electromagnetic high frequency emission
Non-conventional PD detection methods are not yet supported from a suitable international standard (CIGRE WG D1.02 works to recommendations for non-conventional PD detection methods standardization [2]).
In particular the impossibility to use direct calibration procedures or to make measurements of the PD activity apparent charge (pC level) arise questions on how to compare measurements, sensitivity and fault location capability with respect to conventional PD detection methods and have to be verified case by case.

COMMERCIAL EQUIPMENT

The commercial equipment considered in this experimentation is based on different detection criteria (see table 1) and has been selected aiming to on-line condition assessment. The table shows the main features of the equipment used from two supplying companies involved, listing the different devices versus the detection criteria.
All equipment detects electromagnetic emission in the HF to VHF range but with different coupling systems.

Transient Earth Voltage (TEV)

TEV detection, available in all EA Technology family devices, enables a capacitive coupling to the SWG metal frame with handheld devices. In PDL1 device, as signal travels from PD source, enables location by triangulation with two probes with a 600mm minimum resolution.

Acoustic

Using acoustic method to detect and locate the PD source at about 40kHz aims to measure the airborne sound. Primarily used on outdoor equipment and overhead lines, application to AIS is possible when an air path is available, as through vents.

Antenna

It is fitted in the electric field between high voltage and earth forms a capacitive coupling electrode to the system under analysis. The need to be installed in high voltage "view" makes it the less flexible for on-line assessment.

Rogowski coil

Inductively coupled to the power system on cable terminals shields or accessible SWG earthing connections. It is the only system that enables an electrical calibration.
Of the considered equipment only UltraTEV, the most basic device from the reading point of view, combines detection of acoustic emission to electrical detection.

	UltraTEV	MiniTEV	PDL1	IDP16
Acoustic	x			
TEV	x	x	x	
Antenna				x
Rogowski				x

Table 1: Commercial equipment detection methods

TEST SWITCHGEAR SETUP

A 17.5 kV rated voltage metalclad/internal arc switchgear assembly of four units of ABB main product air insulated switchgear (AIS) has been assembled to assess in an experimental campaign the capability of commercial non-intrusive PD equipment to detect induced PD sources and to properly locate them, comparing the performances with a conventional electrical detection system.

Number and location of PD sources rules

Defect are installed only below the circuit breaker (CB) in the cable compartment so to isolate each defect/PD source by opening the CB and therefore to have the possibility to search a defect at the time.
For the same reason a maximum of one defect per phase and per panel is installed, so that by single-phase energization it will be possible to identify the each active source.
It is possible to obtain a PD free condition to evaluate background noise level energising the busbar system with all CBs open.

Induced defects

In figure 1 the different position and type of artificial defect is shown: post insulator - in "high" or "low" position - and bushing.
PD free post insulators have been modified to induce surface discharges by short-circuiting part of the original creeping distance.

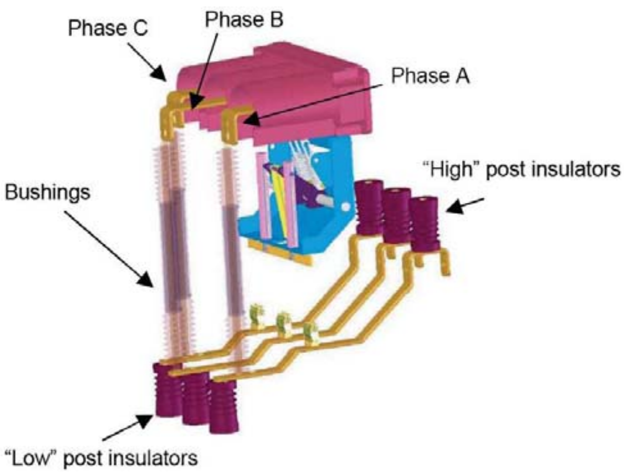

Fig1. Switchgear possible induced defect location

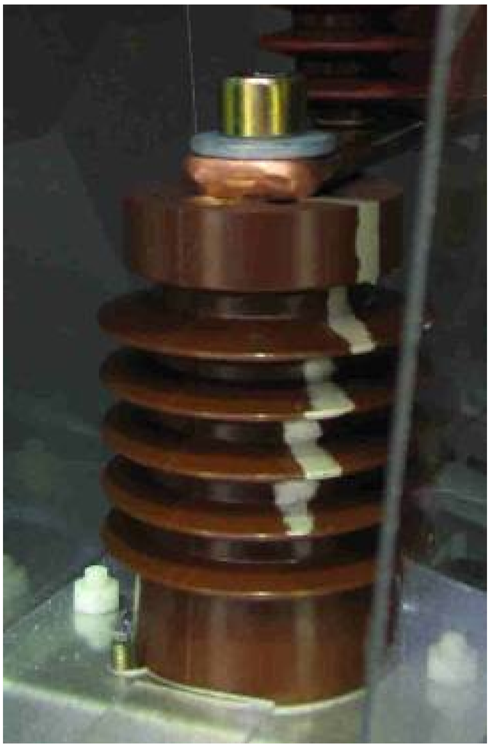

Fig 2. “Low” post insulator with conductive HV defect

Using different short-circuiting length, PD sources of different amplitude at the test voltage have been relized, either by laying a conductive paint band on the surface starting from one of the terminals (figure 2), or by connecting a copper wire to the HV terminal till one of the intermediate shreds.

In a preliminary assessment activity two MV industrial installations have been surveyed. One substation was experiencing supply interruption due to earth current leakage causing the Utility upstream protection intervention.
The faulty element was identified in casted CTs dated 1978 with high level of surface erosion due to tracking phenomena, related to high humidity operating conditions. The CTs have been removed and one was installed in the cable compartment in the test SWG as real defect (Fig. 3).

TEST PROCEDURE

Artificial defects were tested to measure PD amplitude and to define the location in the SWG in agreement to the PD source rules.

Energization rules

The validation tests on the AIS were performed according to two modes, as a PD free single phase HV supply was available:
- tests with all three phases connected to HV single-phase supply, for identification of highest-level source with heavy background noise by multiple sources. Opening of CBs and withdrawal procedure is permitted to identify source.

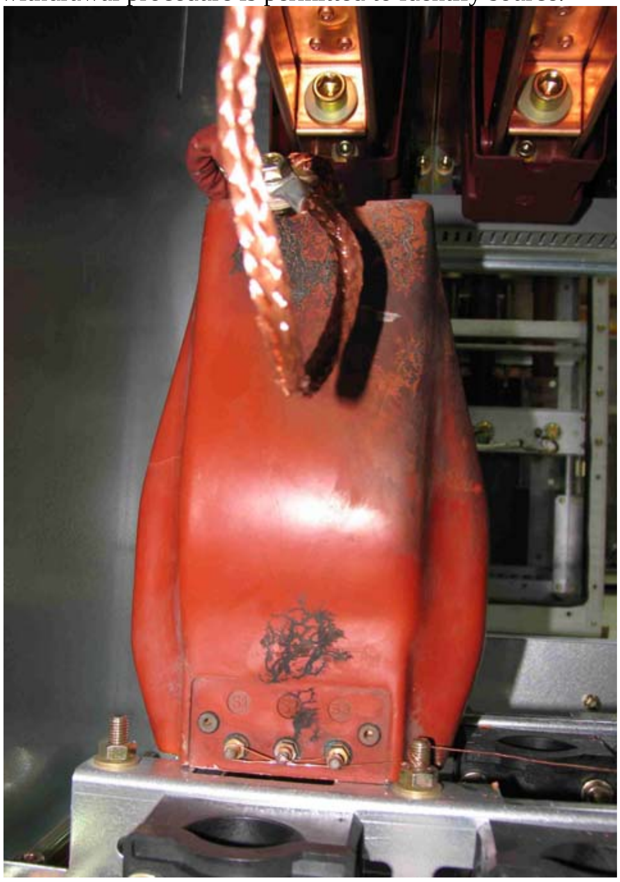

Fig 3. Real defect, treeing surface erosion on CT

- single phase tests: SWG is supplied phase by phase while the other two phase are grounded.
Test voltage and excitation voltages were selected based on AIS rated voltage Um=17.5kV:
Uexcitation= 1.5 Um / √3= 15.2 kV
Utest=1.05 Um / √3=10.6 kV

RESULTS HIGHLIGTHS

Commercial equipment tested, based on TEV and Ultrasonic methods, demonstrated the capability to clearly identify the presence of PD sources [3].
UltraTEV device is the most versatile instrument in terms of easiness to use and clear indication. The “traffic light” indication methods, while introducing insensibility due to discrete range for the three indication level, is straightforward in judgment and best suited for preliminary screening and routine surveys.
The combination with ultrasonic (U/S) method enables additionally to detect surface discharges, when the signal can be airborne out of the AIS. This has proven a limitation in internal arc proof equipment, where PD acoustic signal detection has been possible only through vents (Fig. 4).
When compared to electrical system as a reference, TEV principle has a sensitivity in the range of 1-2 nC to light the orange warning led, flashing at 1 nC and >2.5 nC to enter

the red zone.

Fig 4. Ultrasonic (left led) and TEV (right led) detection active

The UltraTEV led reading enables to avoid confusing readings that are typical of PD activity erratic behaviour and can provide same meaning only when filtered by trending on a longer timescale. The latest has been the main limitation in using the MiniTEV, while the PDL1 instrument overcomes this limit by dual probe reading that enables to locate the source.

The other equipment tested, IPD16, has higher requirements, as sensors must be installed. Downtime is required to access compartments for antennas positioning, while Rogowski sensors on SWG grounding can be easily placed at SWG ends, providing an integral PD level (fig. 5). The use of several sensors and communication options enable easier location and trending.

Table 2 shows the different devices features versus the easiness to use on field, need of installation and how intrusive, i.e. if there is need of modification and downtime prior to use. In the second section aspects relevant to the PD source level reading, usefulness for a condition direct judgment and the capability to localize the defect location in switchgear are listed. The plus/minus ranking shows clearly as TEV instruments are more versatile for field surveys while IPD16 is more indicated for installation in critical application or when field surveys results require a continuous monitoring.

	UltraTEV	MiniTEV	PDL1	IDP16
Use easiness	++	-	-/+	
Installation	++	++	+	-
Intrusive	++	++	++	-/+
Reading Unit	traffic light	dB	dB	pC
Sensitivity	--	-/+	-/+	+
Read. Useful	++	-	-/+	+
Trending	--	-/+	-/+	+
Localization	-	-	++	+

Table 2: Commercial equipment features

Fig 5. IPD system, antenna and Rogowski installation detail

CONCLUSIONS

The use of non-intrusive PD detectors based on TEV and ultrasonic detection is proposed in the scheme of routine controls on installed SWG. While it is not possible to derive a definite judgement on time to failure, the surveying can provide a "first aid" to enhance confidence in the safety and reliability of installed switchgear. It can trigger further maintenance actions or the decision to install more complex equipment for permanent monitoring when signalling high PD activity. On long term it will support a wider adoption of condition based maintenance policy and investment decisions on plant replacement or refurbishment.

Acknowledgments

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REFERENCES

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