NEW METHOD FOR IN-SERVICE PARTIAL DISCHARGE MEASUREMENT ON SOLID DIELECTRIC SWITCH

Nenad UZELAC
G&W Electric – USA
nuzelac@gwelec.com

Ana MILOSEVIC
Nikola Tesla Institute – Serbia
ana.milosevic@ieent.org

Srdjan MILOSAVLJEVIC
Nikola Tesla Institute – Serbia
smilos@ieent.org

ABSTRACT

This paper proposes the new method for performing ***non-intrusive, in-service*** *partial discharge (PD) measurements on solid dielectric (SD) medium voltage switchgear. Numerous concepts outlined in this paper were developed, tested and compared to standardized methods according to IEC 60270. One concept was chosen for further testing due to its non-intrusive nature, adequate measuring accuracy, ease of field installation and low cost. Baseline tests were conducted in a lab with low level background noise. After the extensive lab testing, field validation test was performed in 35 kV indoor substation. The Authors report encouraging results indicated that measuring PD in the field on SD switchgear is feasible even in the high background noise environment. This is an important parameter for condition assessment of SD equipment since increase of PD over time can lead to dielectric failure of the switch.*

INTRODUCTION

The term "partial discharge" is defined by IEC 60270 as a localized electrical discharge that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor [1]. PD can result from a number of different sources; breakdown of gas in cavity, breakdown along the interface, breakdown between energized electrode and a floating conductor, to name the few [2]. In the SD insulation, among the most common sources of PD are cavities – sometimes called "voids" [3]. There are many diagnostic techniques available today for the condition assessment of medium voltage (MV) switchgear, able to find voids [4], [5], [6]. Unfortunately, in many cases these techniques are intrusive since they require scheduled outages as the switchgear must be isolated of the network. Also, utilizing these diagnostic techniques on outdoor MV equipment is very limited. Taking into account that the MV switchgear designs are rapidly moving from SF_6 insulation to SD insulation, the importance of applying condition assessment methods on SD equipment in the field is increasing. This subject is currently being investigated by joint CIGRE/CIRED A3.32 working group "Non-intrusive methods for condition assessment of T&D switchgear". Technical report is due in 2016. A few authors of this paper are members of this working group. Compared with other monitoring techniques, it's been realized that PD monitoring seems the most promising methodology for detecting possible dielectric breakdown, aging and ultimately faults in power system components. In order to maximize the benefits of PD monitoring, it is important to do proper sensing, de-noising and interpretation of its PD signal [7].

PD METHODOLOGY SELECTION

PD methods (overview and selection)

The PD occurrence is accompanied by Electrical, Acoustical, Optical and Chemical phenomena, as depicted in Figure1:

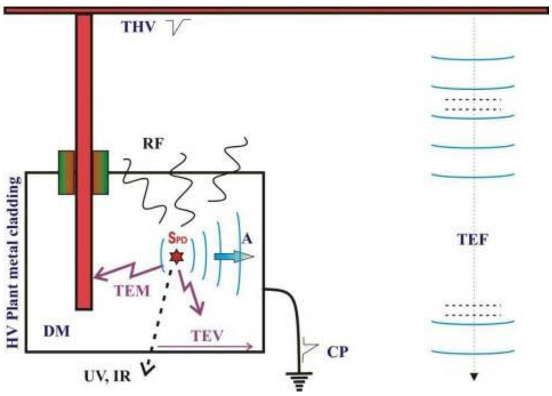


Fig. 1: *Physical phenomena of PD occurrence*

- Electrical (THV - transient high voltage, TEF – transient electrical field, CP – current pulse, TEV – transient earth voltage, TEM – transient electromagnetic, RF – radio frequency wave).
- Acoustical (acoustic wave)
- Optical (UV and IR radiation)
- Chemical (decomposition of the material).

After qualitative comparison of benefits and limitations (Table 1) and considering characteristics of a test object - MV switch with solid epoxy polymer system insulation - the Authors selected electrical methods for further investigation.

Method	*Benefits*	*Limitation*
Electrical (THV, TEF, CP, TEV, TEM, RF)	• Applicative for all kinds of High Voltage Equipme • Intensity, source, type, location of PD is assessable • The most suitable for continuous on-line PD monitoring	• High electromagnetic interference • Relative expensive cost
Acoustics (Acoustic Shock-wave)	• High sensitivity • Immunity against electrical noise • Very efficient for localization of PD • Relatively low cost	• Low signal intensity • Not good for continuous PD measurement
Optical (UV, IR)	• Immunity against electrical noise • High sensitivity • Location of PD is assessable (in some cases) • Test is possible for impulse voltage condition	• No information about magnitude of PD
Chemical (decomposition of material)	• Immunity against electrical noise • Easy to measure • Provide critical information for Go/No Go decision	• No information about location, source, intensity and type of PD

Table 1: *PD testing methods*

.Electrical PD measurement selection

Standardized electrical partial discharge measuring method is performed according standards IEC 60270 and IEEE 1434 [8]. Certain specificity related to partial discharge measurement on SD reclosers are described in IEEE C37.60 standard [9].

Standardized methods utilize HV capacitive coupler (on the HV terminal), shown in Figure 2 and HF Current transformer in Figure 3 as sensors. The main characteristic of those methods is possibility of calibration of measurement for certain test circuit and test object.

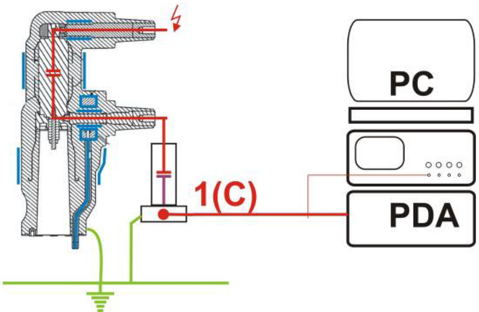


Fig. 2: *Standardized method with capacitive coupler*

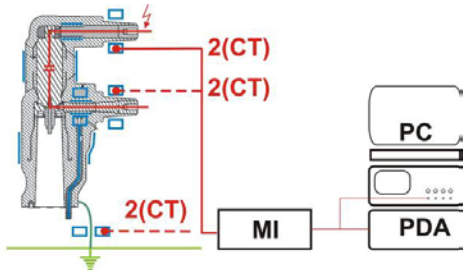


Fig. 3: *Standardized method with CT as a coupler*

In Paper was investigated the possibility of using non-standard sensors for the measurement of partial discharges on reclosers and the possibility of calibration. Number of PD sensors was tested on epoxy encapsulated Vacuum Interrupter switchgear module, as showed in Figure 4. The results were compared to the standardized PD method, as shown of Figure 4. Following figure illustrates additional (alternative) points of PD measurement.

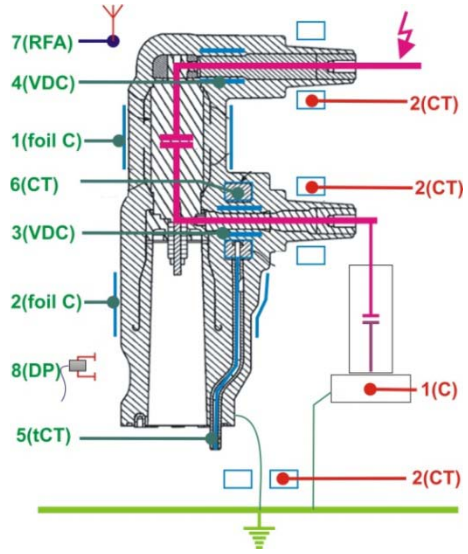


Fig. 4: *Additional coupling devices (PD sensors)*

1(C)	- external capacitive hv coupler
2(CT)	- external HF CT
1 and 2(foil C)	- external conductive foil (capacitance);
3 and 4(VDC)	- embedded voltage divider as capacitive sensor
5(tCT)	- CT tube and semicond. tape as capacitive sensor
6(CT)	- embedded CT as PD sensor
7(RFA)	- radio frequency antenna
8(DP)	- differential probe for transient electrical field.

PD Sensitivity measurement test

PD could happen somewhere inside solid dielectric material between HV electrodes and grounded semi conductive layer of the solid dielectric interrupting module. Attempting to mimic that real life situation, a new “PD spark” test was developed. It was used to compare and evaluate PD measuring sensitivity of different electrodes. PD spark is basically a HV electrode system with the thin layer of the insulation sandwiched between two conductors. The insulation has an internal void (as showed in Figure 5) and in presence of High Voltage, PD is generated inside of the insulation void. Two tests were conducted: In the first one, PD spark was applied on the HV contacts (Position A), and in the second test, PD spark was applied on the surface of the solid dielectric epoxy module (Position B). PD was measured using IEC 60270 standard and using alternative PD sensors, as depicted in Figure 4. Results of this test are presented in Table 2 below. Relative sensitivity measurement (Sensitivity coefficient - S_i) was derived by comparison of PD values between alternate PD sensors and PD measurement described by IEC 60270 (measuring point 1C).

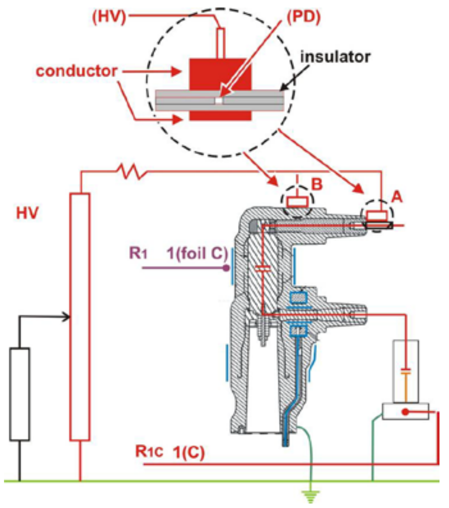


Fig. 5: *Simulation of PD spark in proximity of HV electrode (A) and grounded semi conductive layer of (B) module*

Measurement point	Ri (A) *pC*	S_A	Ri (B) *pC*	S_B
1(C)	255 (R_{1C})	1	255	1
1(foil C)	170.0	0.67	290.7	1.14
2(foil C)	147.9	0.58	250	0.98
3(VDC)	139.3	0.55	127.5	0.50
4(VDC)	112.2	0.44	446.3	1.75
5(tCT)	14.5	0.06	18.8	0.08
6(CT)	15.6	0.06	19.1	0.08
7 (RFA)	30.6	0.12	38.3	0.15
8(DP)	25.5	0.10	37.2	0.14

Table 2: *Response R_i at measuring point and relative sensitivity measurement S_i (R_{1C} - response at the 1(C), according to IEC 60270; R_i - response at the additional point i; $S_i = R_i / R_{1C}$ – sensitivity coefficient).*

As it can be seen in Table 2, PD sensors 5-8 have very low sensitivity coefficient. Thus, they were eliminated from further consideration.
On the contrary, PD sensors 1 (upper external conductive foil) and 4 (source side internal capacitive sensor) have even higher sensitivity than 1(C) standard measurement ($S_{1(foil)}>1$, $S_{4(VDC)}>1$). This suggests that the transient voltage is better coupled with alternative PD sensors 1 and 4 than the standard PD measurement 1(C).
Lastly, PD sensors 2 (bottom external conductive foil) and 3 (load side internal capacitive sensor) have sensitivity index S_i is below 1, but still reasonably attenuated.
Based on these results, authors decided to continue testing of PD sensors 1-4. Next, the PD test was conducted on the fully assembled 3 phase SD switch in the High Voltage lab with low background noise. Two phases assembled on the SD switch were in "good condition" – they've had PD readings within manufacturer's limits. Third phase was purposely selected with high PD readings as a controlled sample in order to verify the accuracy of measurement.

LAB TESTING WITH LOW BACKGROUND NOISE LEVEL

A test was carried out at HV Lab, with background noise level < 3 pC (Figure 6). PD levels on Module Phase 1 was very high, 27.28 nC. PD activity on Module Phase 2 and Phase 3 were 48.5 pC and 21.2 pC respectfully, within PD limits. Characteristics of the measurements were:

- HV applied to the Load Side conductor in Close position;
- Reference PD measurement per IEC is measured at point 1(C);
- Additional measurement are measured at 1(foil), 2(foil), 3(VDC) and 4(VDC) points, and compared to reference measurement.

Fig. 6: *Baseline test in the lab. PD measured with standardized method (sensor 1C) and alternative method: sensors 1(foil C), 2 (foil C), 3 (VDC) and 4(VDC)*

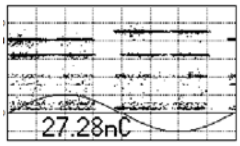
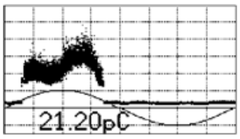
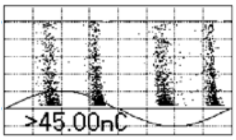
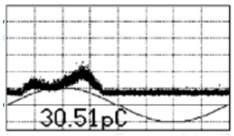
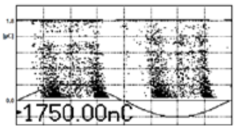
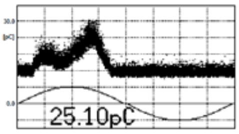
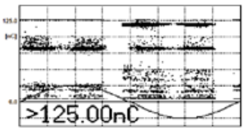
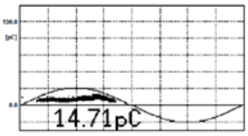
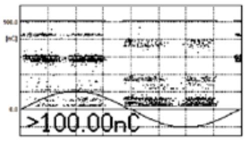
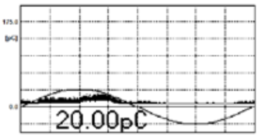
PHASE 1	PHASE 3	PD sensor
		*1 (C)*
		*1 (foil)*
		*2 (foil)*
		*3 (VDC)*
		*4 (VDC)*

Table 4: *PD pattern of Phase 1 and 3 (standardized and additional measurements).*

Table 4 summarizes results on Phase 1 (module with high PD levels) and Phase 3 (module with acceptable PD levels). It can be seen that in the lab with the low background noise PD sensors 1-4 closely replicated results from the reference PD test. Although the lab had a low background noise, a crosstalk noise was generated by Phase 1 and received on Phase 2 (in nC range) and Phase 3 (hundreds of pC). A principle of coincidence (or gating concept) [1], was used to eliminate the noise.

IN-SERVICE TESTING

In-service testing was conducted in order to confirm possibility of successful PD measurement under real conditions. Field testing was performed in 35kV indoor substation. In order to measure PD in the field, external disturbances - background noise (coming from the system) and crosstalk (coming from other phases) - must be filtered. Principle of coincidence gating concept) was used to eliminate external disturbances. Basic assumption of the gating principle is that PD signal at certain sensor consists of superimposed real PD activity and noise disturbance. By using two sensors per phase, both sensors will pick up external disturbances and subtraction of these two signals provides real PD activity. This subtraction is accomplished on logical level. Gating principle is illustrated in Figure 7. 2 sensors (1foil and 2foil), installed on the one phase of the SD switch, measured high levels of PD in nC range. After subtracting those two signals using the gating principle, the real PD activity was measured in pC range.

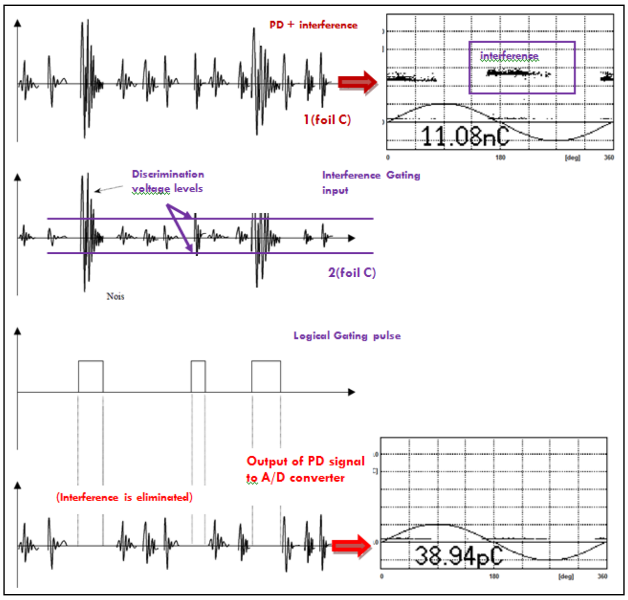


Fig. 7: *PD pattern of Phase 1 and 3 (standardized and additional measurements).*

First the background noise was measured on each phase prior to installation of SD switch. Results are reported in Table 6. Then SD switch was installed and the test was repeated in two configurations: A) without the gating principle B) with gating principle. Results are reported in Table 7.

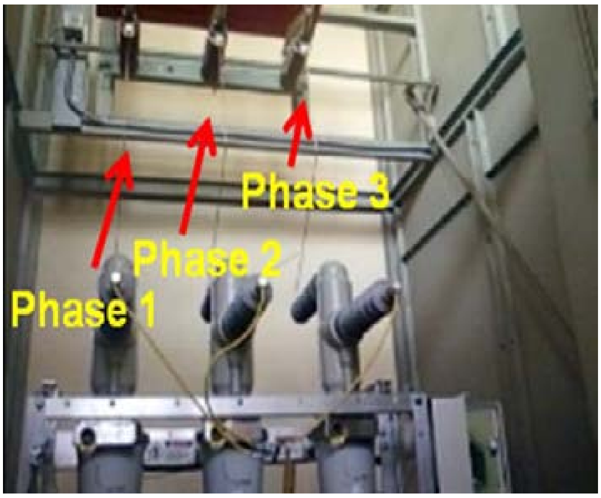


Fig. 8: *In-service testing*

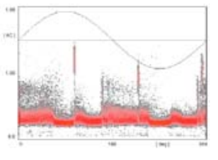
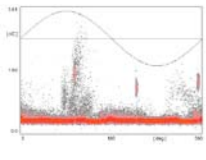
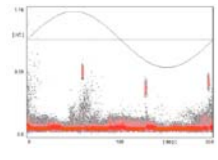
		
Phase 1	*Phase 2*	*Phase 1*

Table 6: *Background PD Activity on 35kV indoor substation*

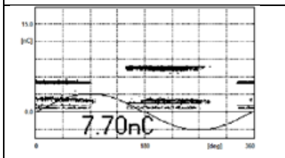
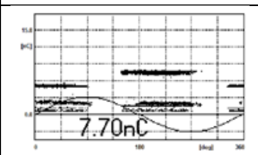
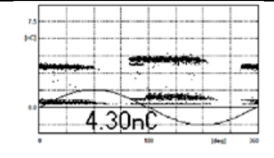
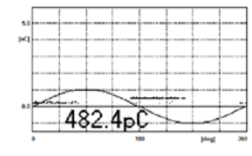
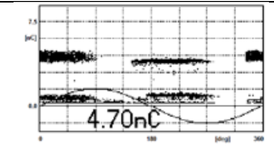
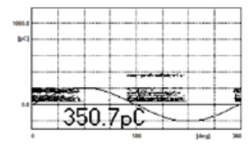
a) with gating principle	b) without gating principle	
		*Phase 1*
		*Phase 2*
		*Phase 3*

Table 7: *PD activities and interference on 35 kV line, with installed switch*

Table 6 shows PD background noise in 35 kV substation measured without switch (ranging between 1-3nC), and Table 7 shows PD levels with the installed switch. From columns 7a) and 7b) can be noticed that the level of PD activity is remained very high on Phase 1, which has inherent high PD values. PD levels on Phase 2 and Phase 3 (that have inherent low PD values) were reduced by order of magnitude by applying the gating principle. With this system in place, it can be detected when the PD levels inside solid dielectric modules increase from pC to nC range, which would indicates potential dielectric failure of the solid dielectric module.

CONSLUSION:

New method for non-intrusive, in-service PD measurements on SD medium voltage switchgear was developed based on its low cost, adequate measuring accuracy and ease of field installation. The system uses conductive foil sensors mounted on the outside of the solid dielectric interrupting module for PD detection. 3 phase solid dielectric switch was extensively tested in the lab before the field test. 2 phases on the switch had normal PD levels and 1 phase was had inherent high PD levels. That phase was used as a controlled sample. In this paper it was showed that it is possible to identify the phase with high inherent PD levels in the field, even though the external noise was in nC range. Principle of coincidence (gating concept) was used to filter the signal and eliminate external noise. Additional long term on-line PD measurements are planned for solid dielectric switch installed on 35 kV outdoor distribution line in order to further improve system of external noise elimination.

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