FIELD PD TESTING ON SOLID DIELECTRIC MV SWITCH

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ABSTRACT

This paper presents experience with field PD testing on solid dielectric switch. Testing was performedwithin project of improvement of condition assessment on MV equipment in the field. Method of testing was developed by few of authors of the paper. Field PD testing is very demanding in environment with high background noise, disturbances and cross talk between phases.Challenge was how to find the feasible solution for type of sensors and their simple coupling with test object.Special challenge was software for analysis and diagnostics. Measuring system with synchronous 3 channel PD data acquisition was used. Advanced noise and PD separation techniques 3PARD and 3CFRD/FREQ were used for reliable analysis and diagnostics.

INTRODUCTION

Over the past few years G&W has researched the feasibility of measuring PD on solid dielectric modules in the field. Foil sensors and test methods have been thoroughly tested in the lab environment as well as on one recloser installed in a substation [1].

Purpose of this testing was to gain more data points, both for offline and online measurements in order to further assess the capability and limitations of the proposed test methods.

Field PD diagnostic testing was perform at Manitoba Hydro substation on 4 installed 15kV reclosers (running at 12kV) and at substation on 27kV recloser (running at 12kV).

Test set up for off line and on line testing and procedures are in compliance with relevant standards [2,3,4] and method and experience previously developed [1].

PD testing was performed using portable on-line PD diagnostic and monitoring system for high voltage assets. The system has advanced diagnostics expert software [5].

For PD testing and diagnostics, it is important to have knowledge about test object and its surrounding.

Disturbances from environment and possible PD activity from test object were investigated. That allows narrow selection of possible PD types to be taken in consideration.

Inside the solid isolation, it is possible to have type of PD activity in voids, with variations of voids near the grounded electrode (module surfaces) or voids near the HV electrode. It is less likely to have a PD activity of type poor contact or a floating potential.

On HV insulators surface discharges are dominant due to contamination of the outside surface with non-conductive or conductive particles and moisture. Variations are PD with the dominant influence of the HV electrode, with the dominant influence of the grounded surface (electrode) or with no clear influence of the proximity of the electrodes.

In cases of poor installation of HV insulators, there is a possibility of PD appearance of the floating potential or surface discharge. In some cases, PDs in voids (filled with gas) are possible if they are formed during the installation of the insulator.

It is also possible to have discharges of corona type formed on the sharp edges of the conductors.

A special challenge for diagnostics is the case in which PD activities and intense disturbances are superimposed, where all individual types of discharges should be separated. For the diagnosis or interpretation of the PD pattern were used [5,6].

Typical disturbance signal sources in switchgear and bus ducts are [7]:

- deterioration of bus supporting structures
- bus insulation with dirty or moist surfaces
- defects in cable terminations
- pd in potential and current transformers
- locations where a ground is near a mv conductor
- insulation structure of the circuit breaker
- arcing contacts in the circuit breaker
- arcing primary contacts (finger clusters and stabs)
- arcing in loose high voltage and ground connections.

TEST SET UP

On line and off line measurements were performed in the field. Off line test allows calibration, background noise examination, test voltage variation, and gives baseline for PD activity at operation voltage. On line test enables the detection of noises and disturbances.

Figure 1shows layout of PD testing set up implemented in substation. Test object was 3 phase 15 kV recloser. The acquisition is performed according to the standard IEC 60270 by means of a coupling capacitor in series with measuring impedance (quadrupole). The output of the quadrupole is connected to the measuring instrument. Portable AC dielectric test set was used for energizing.

Figure 2. shows 3 phase recloser as test object, 1&2 are PD foil sensors (using 2 sensors for each module). Round metal conduit and aluminum foil were used as HV leads to reduce corona.On site recloser installations are not suitable for PD testing, because of many sharp edges, loose contacts; wires for grounding bring disturbances.

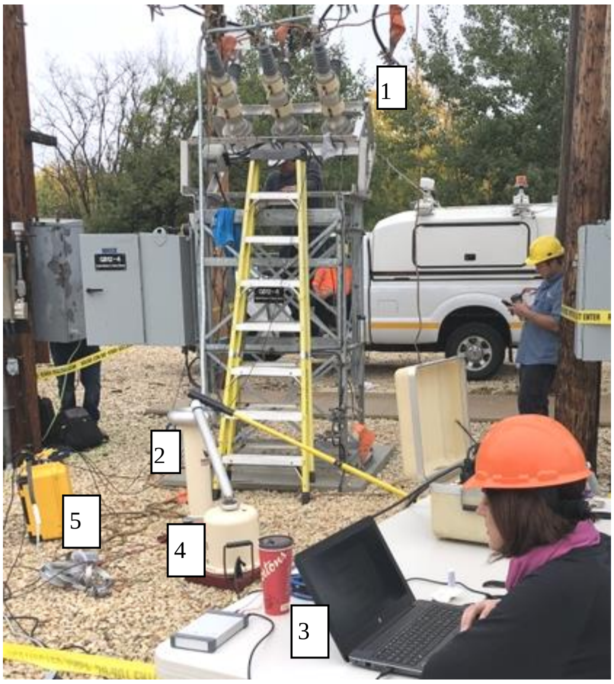


Figure 1. PD testing in substation. 1 –test object-recloser; 2 - Coupling capacitor; 3-computer; 4- portable AC dielectric test set; 5-PD measurement equipment.

Beside classical analysis, new approaches introduced by OMICRON are the usage of multi-band measurements on one channel for single phase source discrimination 3CFRD (3-Center frequency Relation Diagram) and the usage of time synchronous measurements on three channels-all three phases of a test object, 3PARD (3 phase-resolved partial discharge) [5].

A schematic representation of how 3PARD works can be found in Figure 3. Three synchronous channels – in this case the phases L1, L2 and L3 – detect the same partial discharge pulse at varying amplitudes within a user-defined time window. If we assume that the phenomenon occurs in L1, this is where the intensity will be highest.

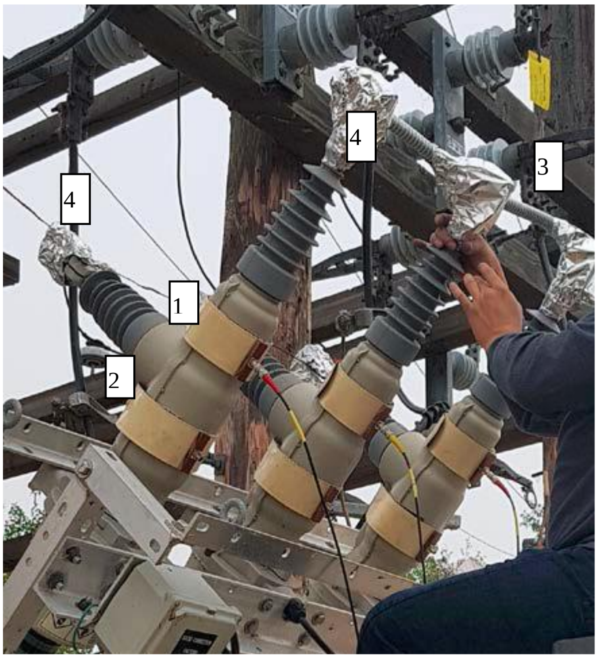
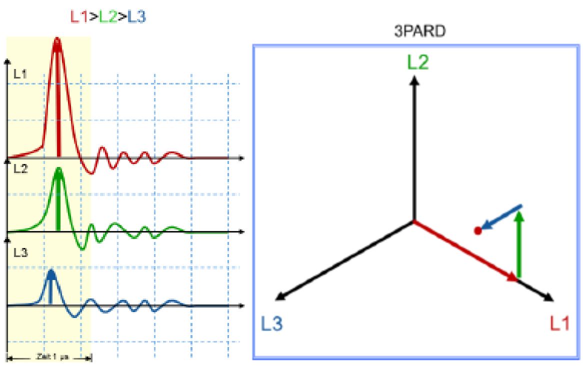


Figure 2. PD test object. 1, 2 - PD sensors (2 on each module); 3- Round metal conduit; 4) aluminum foil.

The two other channels also measure the pulse by cross-coupling in the winding. The amplitude is now transformed into a vector which, when graphically aggregated, gives a point, in the 3PARD star diagram. If the PD source crops up regularly, the various points form a cloud, also referred to as a "cluster". Differing PD sources form various clusters in the diagram. These clusters can then be separated and transformed back into a phase resolved pattern for further analysis [7].



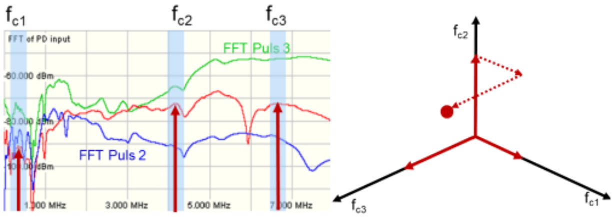
a) b)

Figure 3. 3PARD principle; a) varying pulse amplitudes in the three channels; b) vectors diagram [5].

The 3CFRD method separates the PD sources in a similar manner and is primarily used in situations where it is not possible to measure using three channels, or where an additional decision criterion apart from 3FREQ is required. This method measures the PD pulses at the same time using three different filter bandwidths.

Depending on the creation mechanism, signal propagation and attenuation, different PD sources also have different amplitudes in the respective filter settings, Figure 4.

These in turn are entered into the star diagram described above and, after graphical aggregation, form clusters for the various PD phenomena. [5].



a) b)

Figure 4. 3CFRD principle; a) varying pulse amplitudes in the three filter settings; b) corresponding vectors diagram [5].

Each PD event has been graphically aggregated in the vector diagram. Depending on the nature of the PD source or frequency vectors, appropriate clusters are formed.

TEST RESULTS

Off line tests

Off line tests are worthwhile, while they allow baseline diagnostics of the modules. Base pattern at rated voltage level, characteristics of noise and disturbance and system calibration could be obtained from off line tests.

As Figures 5 and 6 show, at measurements at voltage levels bellow 15kV, no significant level of PD was recorded. Also, it is confirmed that no external interference is present during the off line measurement.

Figure 6. shows uniform distribution of PD signal at recloser operating voltage 7.2kV.

Figure 5. Time - voltage/PD diagram.

Further analysis goes to voltage level at 20 kV in period marked by an arrow. In Figures 7,8,9 and 10 are represented the results of PD analysis.

Figure 7. shows FFT diagram of PD signal and chosen measurement frequencies for PD source separation. Figure 8 represent PD pattern with PD sources and background noise obtained from measurement on f_I=2MHz.

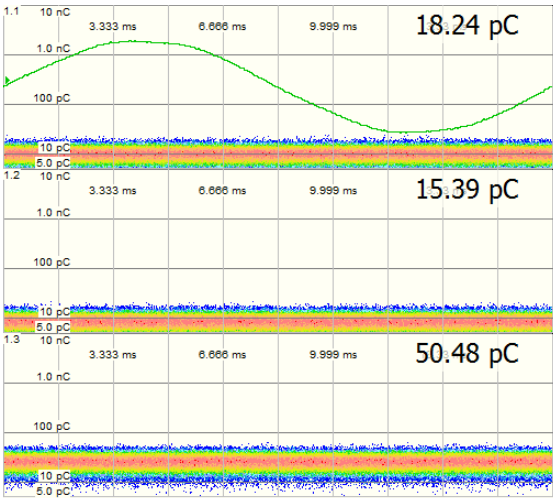


Figure 6. PRPD patterns of PD signal at 7.2kV, frequency bandwidth (100kHz-400kHz).

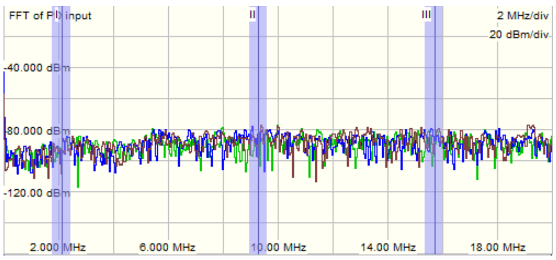


Figure 7. FFT diagram of PD signal; f_I=2MHz, f_{II}=10MHz, f_{III}=16MHz; bandwidth Δf= 650kHz.

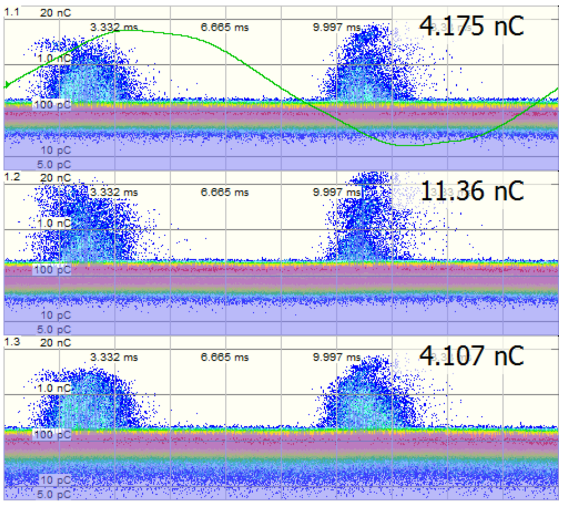
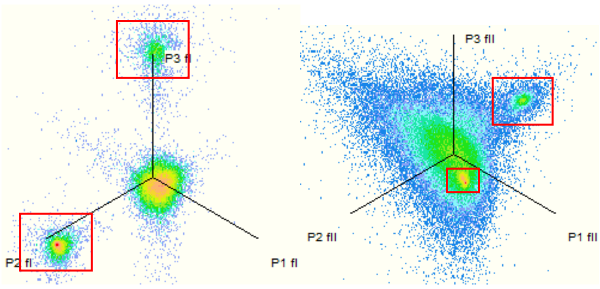


Figure 8 PD pattern obtained from test on f_I=2MHz

In order to compensate interference from environment and to get better signal to noise ratio, measurements were performed at higher frequencies: f_I=2MHz, f_{II}=10MHz.
Figures 9a) and 9b) show PD sources which were separated at 3PARD diagrams. The observed PDs are most likely surface discharge.



a) b)

Figure 9. 3PARD diagrams for frequencies: a) f_I=2MHz, b) f_{II}=10MHz. Identified PD sources are marked.

Analysis of 3PARD diagram at measurement frequency f_{II}=10MHz identify two PD sources.

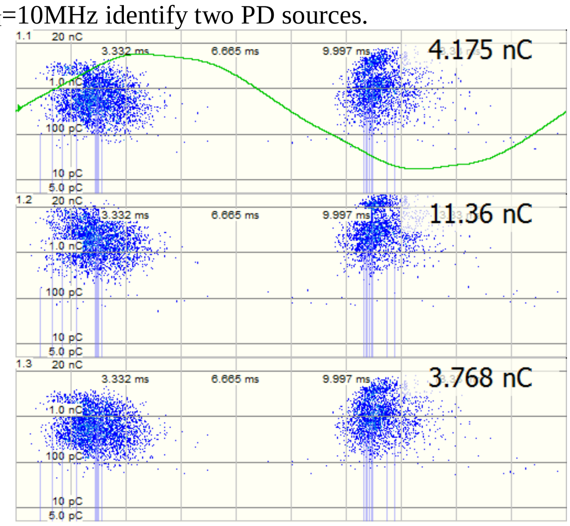
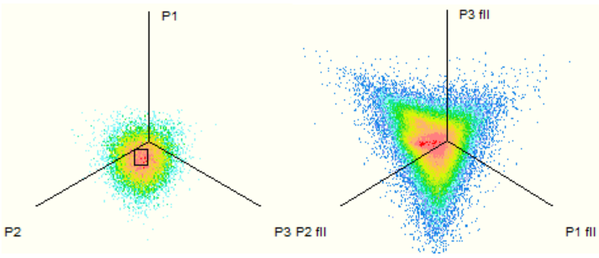


Figure 10. One of PD sources identified at f_{II}=10MHz.

On line tests

Figure 11. shows 3PARD diagrams for two frequencies. First diagram was obtained from measurement on frequency according to IEC standard [4], which enables calibration and comparisons of different tests.



a) b)

Figure 11. 3PARD diagrams for frequencies: a) (100kHz-400kHz), b) f_{II}=10MHz.

At Figure 12. is shown corresponding PRPD pattern of noise signal detected in Figure 11.a. Figure 13. shows instability of disturbances, which was also observed during the analysis of PRPD and 3PARD.

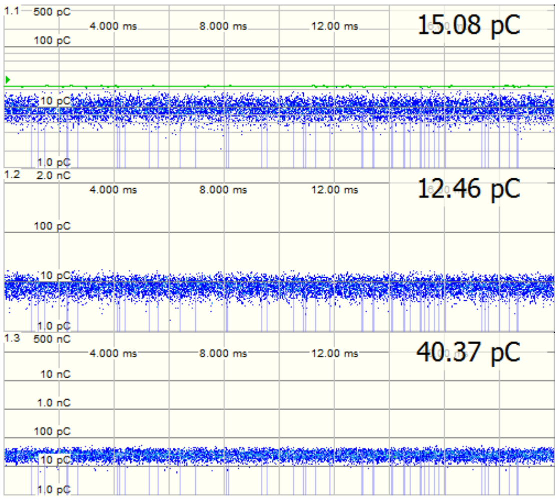


Figure 12. PRPD patterns of PD source identified at (100kHz-400kHz).

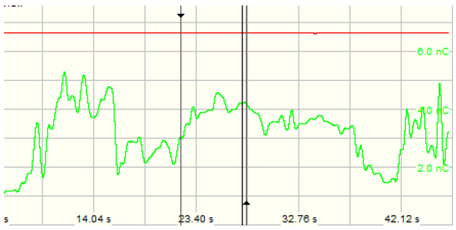


Figure 13. Magnitude - time diagram of disturbances.

Using Antenna for disturbance detection

The possibility of using antennas for detecting disturbances from the environment was investigated. Phase 2 was examined and sensors from phases 1 and 3 were used as antennas.

Figure14 shows je FFT diagram of PD signal. Blue line represents signal from phase 2and red i green lines aresignal from antennas. Figure15 shows 3PARD diagrams for different frequencies. There is a significant difference in diagrams depending on the selected frequency.

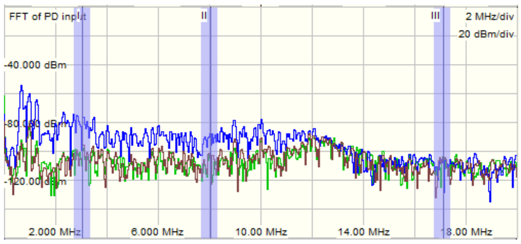


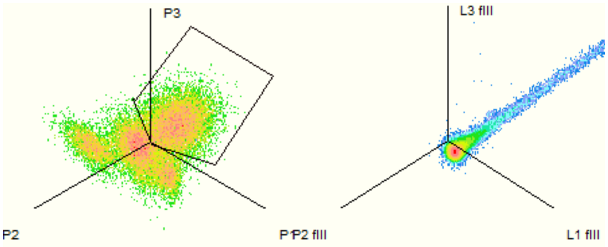
Figure 14. FFT diagram of PD signal; f_I=3MHz, f_{II}=8MHz, f_{III}=17MHz; bandwidth Δf= 650kHz.

PRPD diagram of PD signal separated in Figure 15,b, marked with red square, is shown in Figure 16. Uniform distribution of disturbances could be noticed.

Marked cluster in Figure 15a shows high correlation of signals from two antennas in the frequency bandwidth

(100-400)kHz. An even stronger correlation is observed at 17 MHz frequency (bandwidth 650 kHz), in Figure 15b, sharp diagonal claster between L1 and L2 axes. Separated clusters come from the surroundings equally on both antennas and represent disturbance.

By analysis of PD pattern of clusters identified in Figure 15 a and b, uniform distribution of noise and disturbances is obtained, as shown in Figure 16.



a) b)

Figure 15. 3PARD diagrams for frequencies:
a) (100kHz-400kHz), b) f_{II}=17MHz.

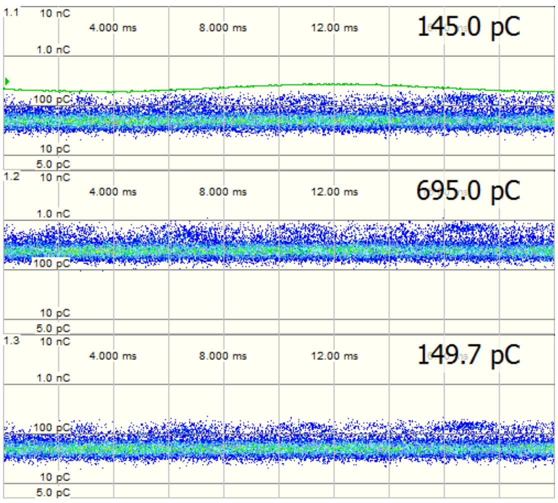


Figure 16. PD source identified at f_{II}=17MHz.

The results show that it is possible to use antennas for suppression of background noise and disturbance.

CONCLUSIONS AND FUTURE WORK

With more and more solid dielectric switchgear installed on the distribution system, there is a need to find an easy way to assess the condition of their insulation system in service by means of PD testing. However, PD testing and diagnostics in the field is challenging for several reasons. First, gaining permissions to access equipment on the operator's grid to carry out testing is difficult.

Second, it might need to take several outages, which is not favorable. Lastly, it requires high expertise to analyze results.

With that said, the paper has shown that field PD measurements on solid dielectric switchgear can be done with proper planning and with cross function technical team from manufacturer, utility and PD expert members.

Off-line field PD testing provides good baseline for characteristics of background noise and disturbance. This data improved on-line testing in the field. The results of the analysis showed that it is possible to successfully perform field PD testing and diagnostics.

From this test the authors determined the following:

- off-line PD measurements can be accurately performed, and determined the source of PD;
- antenna can be used for measuring background noise;
- on-line measurements can separate background noise and disturbances from environment

The next enhancement of this PD test method would be the development of sensors that could be placed on the modules in normal operating conditions, using a hook-stick, and without requiring power outage.

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REFERENCES

[1] Nenad Uzelac, Ana Milosevic, Srdjan Milosavljevic, "New Method For In-Service Partial Discharge Measurement On Solid Dielectric Switch", *23rdinternational Conference On Electricity Distribution*, Lyon, 15-18 June 2015 Paper 1436.

[2] IEC 62271-111:2012(E) /IEEE Std. C37.60-2012, *High-voltage switchgear and controlgear – Part 111: Automatic circuit reclosers and fault interrupters for alternating current systems up to 38 kV*.

[3] IEEE Std 1434-2000, *Use Guide to the Measurement of Partial Discharges in Rotating Machinery*.

[4] CEI/IEC 60270:2000, *High-voltage test techniques-Partial discharge measurements*.

[5] Alexander Kraetge, Kay Rethmeier, Michael Krüger, Paul Winter, "Synchronous Multi-Channel PD Measurements and the Benefits for PD Analyses", *IEEE PES T&D 2010*, 19-22 April 2010,

[6] Rene Hummel, Stephan Korber, Daniel Gebhardt, Ulrike Broniecki, "Interpretation of PRPD Pattern, Omicron Academy".

[7] Z. Berler, I. Blokhintsev, A. Golubev, G. Paoletti, V. Rashkes, A. Romashkov, "Practical Experience in On-Line Partial Discharge Measurements of MV Switchgear Systems", *IEEE International Symposium on Electrical Insulation*, April 2-5, 2000, Anaheim, CA,USA.