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Detection of Multiple Partial Discharge Faults in Switchgear and Power Cables

G. Amjad Hussain, Detlef Hummes, Muhammad Shafiq, Madia Safdar

***Abstract*—Partial Discharge (PD) measurements are considered as the early detection of insulation degradation in power system equipment. In switchgear and power cables, multiple PD faults may exist, which make the detection and location of such incipient faults challenging. This paper deals with identification of multiple PD faults by a hybrid detection technique, by combining conventional and unconventional measurement methods.**

Unconventional PD measurements rely on detection of physical emissions due to such faults, e.g. detection of radio frequency (RF) electromagnetic (EM) fields in the vicinity of PD activity, ultrasonic waves, optical emissions and heat produced by the PD, whereas the conventional measurement methods are based on detection of high frequency current and voltage, superimposed on the power frequency current and voltage.

In this paper, the apparent charge of PD events is calculated by using conventional measurement technique and EM signal energy is calculated based on unconventional method. The high frequency electric field was measured using a *D*-dot sensor. The comparison between the two parameters show that a second degree polynomial relation exists between the EM energy and apparent charge. The scatter plots between the two variables show a number of patterns due to the number of PD faults. Therefore, the detection of multiple faults is possible.

***Index Terms*—Partial discharge, condition monitoring, switchgear, non-intrusive sensors and pattern classification.**

I. Introduction

Switchgear and cables are the integral components of an operational power system network. The critical parts in these equipment are electrical insulations which limit the abnormal flow of current to the ground or between lines, also called as leakage current. Partial discharge (PD) faults arise due to the manufacturing defects in such insulations, ageing or electrical and mechanical stresses. The most prominent electrical stress is overvoltage [1]-[5]. PD measurements are considered as one of the most reliable source of information which provide an early alarming signs for the remaining life of insulations and hence the power equipment. an integral part of the distribution network. However, the detection of multiple PD faults, their classification and location is still a tricky task, due to the widely probabilistic behavior of PD events. There are various PD detection techniques available commercially as well as in literatures. The most widely, they are classified into conventional and unconventional techniques. The conventional PD measurement techniques rely on the detection of high frequency current and voltage measurement using high frequency transducers such as Rogowski coil, high frequency current transformer, coupling capacitors, hall effect sensors etc. These sensors need to be installed in contact with the high voltage insulations which make their designs and implementation expensive and complicated. Unlike such techniques, there are unconventional methods of PD measurement which are based on measurement of physical emissions arising as a result of a PD activity. Such physical emissions include high frequency/ radio frequency electric and magnetic fields, ultrasonic waves, thermal emissions, optical/ ultraviolet (UV) emissions and chemical byproducts found in the vicinity of a PD event [6]-[8].

This paper deals with the detection of multiple PD events based on the measurement of a PD fault by using both the conventional and unconventional measurement technique. The conventional measurement technique adopted in this work uses coupling capacitor, whereas the high frequency electric field sensors is used for the measurement of high frequency E-fields, as an unconventional measurement tool. PD apparent charge is a measure to estimate the extent of a discharge. This parameter is calculated using the conventional measurement technique by integrating the area under the PD current pulse. The cumulative radio frequency energy is another parameter to quantify the PD activity and is calculated from the PD signal measured using the unconventional sensors, such as *D*-dot sensor [9]-[11]. The correlation between these two parameters provide a very useful information about the nature of a fault and hence indicate the presence of multiple faults with different location and different nature. This is the major contribution of the paper, to estimate the extent of discharge and the detection of multiple faults in a certain equipment.

The rest of the paper is organized as follows. Section II describes the experimental procedures and test setup for the conventional and unconventional measurements. The section III presents useful results and discussion, whereas the last section concludes the paper.

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II. Measurement Setup

The measurement setup used in the high voltage laboratory to carry out investigation about the PD events is given in the Figure 1, which is an energized medium voltage (20 kV) commercial switchgear. The three phase circuit breaker in the switchgear was put in the closed position and the outgoing terminals of the circuit breaker were used to connect various defective insulations. Only one phase of the line was energized and used for the study, mainly due to the limitation of the available power supply in the laboratory. The metallic body of the panel was grounded at one point. Visuals of physical components are given in Fig. 2. Three types of PD faults were created in the switchgear outgoing connection compartment including single corona due to a sharp edge, PD in voids, surface discharge and corona due to base conductors. These PD sources are given in Fig. 3.

The conventional measurement was done using a coupling capacitor with the main incoming line along with a coupling device, whereas unconventional measurement was done using D-dot sensor. An HFCT was used to verify the performance of the D-dot sensor. The *D*-dot sensor was fixed inside the switchgear compartment whereas the clamp-on HFCT was installed around the ground connection of the switchgear. The layout is clear in the Fig. 2.

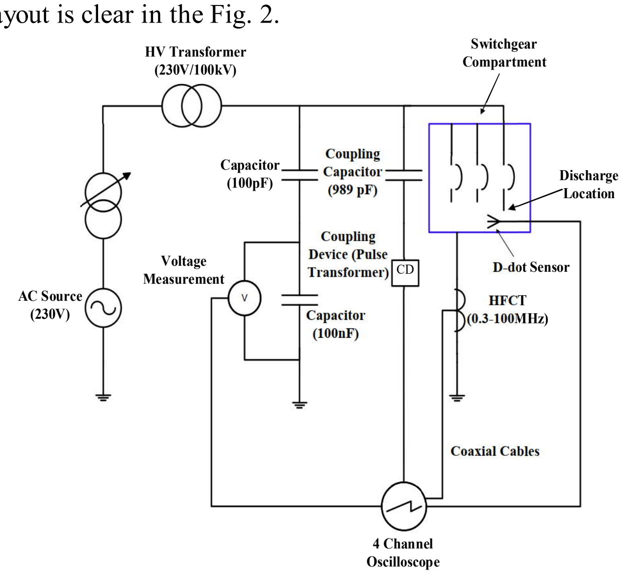


Fig. 1. Test setup for PD measurement (both conventional and unconventional)

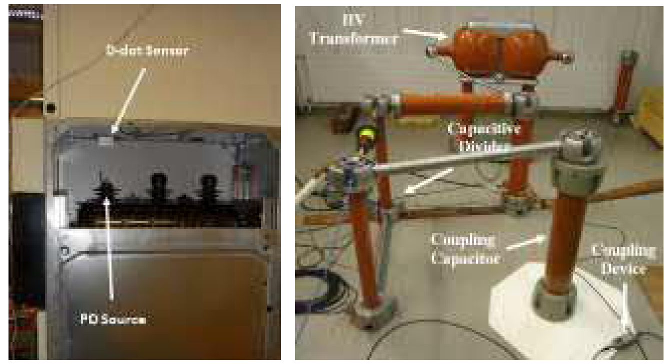


Fig. 2. (left) - Switchgear panel, (right) – Supply and auxiliary test equipment

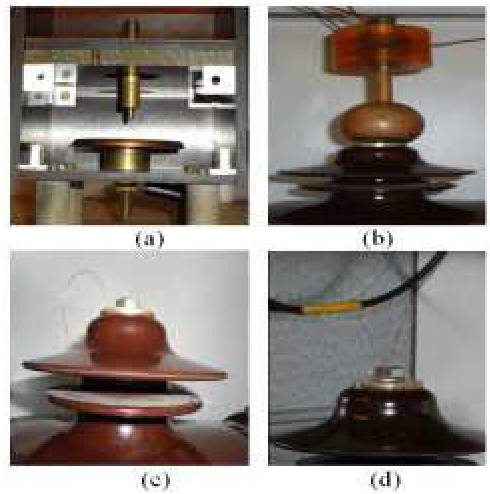


Fig. 3. PD sources: (a) Corona at needle, (b) PD in void, (c) Surface PD, (d) Corona around bare conductors.

The *D*-dot sensor is an electric field sensor, which is made by installing an SMA connector of male type onto a grounded plane. *D*-dot probes measure the time derivative of the electric flux density at the surface of the conductor [15]. The electric flux density D is related to the electric field intensity E by the expression $D = \varepsilon_0 E$, where ε_0 is the permittivity of free space [9], [10]. The sensor is physically shown in Fig. 4.

Fig. 4. *D*-dot sensor mounted on a grounded plane.

III. Results and Discussion

A. Calculation of Apparent Charge and Cumulative Energy

The measured signals by using conventional and unconventional techniques are given in the Fig. 5. The conventional measurement setup provides are damped PD pulse as shown by the dotted (green) plot, whereas the unconventionally measured signal using D-dot sensor is an oscillatory pulse. The oscillations arise due to the RLC nature of the sensors' parameters.

The apparent charge is determined by calibrating the whole setup for a known PD signal and then calculating the area under the curve of the damped pulse.

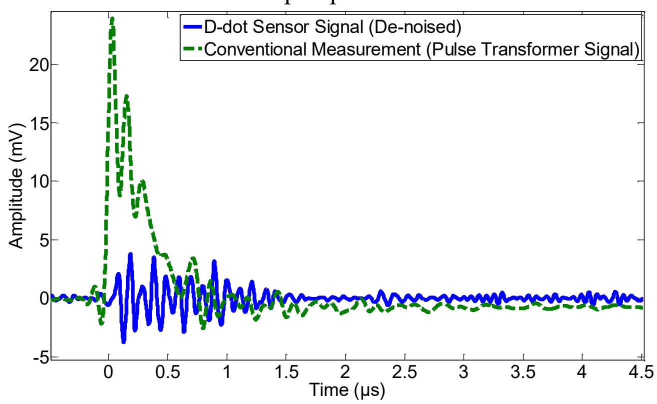


Fig. 5. Conventional and unconventional measured signals

The total cumulative energy (W_{Tot}) of the high frequency oscillatory signal is calculated by using the relations given below. [12], [13]

$$W_{Tot} = \frac{\Delta t}{R}\sum_{i=1}^{N} V_i^2 \quad (1)$$

where Δt is the sample duration, R is input resistance of oscilloscope, V_i is the sample voltage and N is the number of samples.

B. Calibration of the Measurement Setup

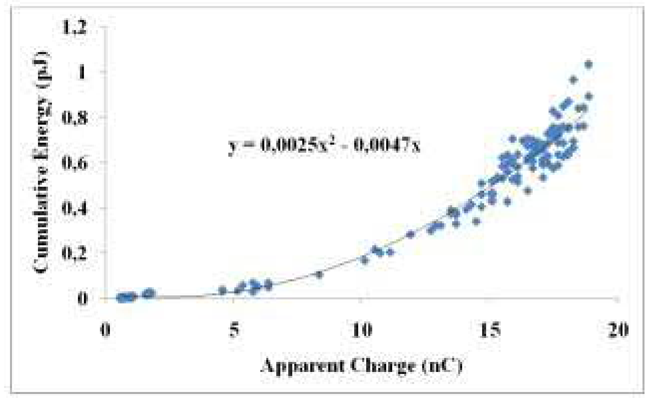
The system was calibrated as per the guidelines provided by IEC standard: IEC60270. A known amount of charge is injected as a current pulse into the system and the measured output pulse (PD pulse) is compared with this charge. Since the capacitance of the test object will affect the shape and amplitude of the measured pulse, hence it is always recommended to calibrate the test setup before carrying out measurements with different equipment. Once the calibration is done and the test setup is unchanged, the calibration doesn't need to be repeated. [14]

Both the measurements, i.e. PD current pulses and the high frequency electric field signals are done simultaneously. The measured signals are recorded by a high frequency oscilloscope with sampling rate of 2.5 GS/s at a time window of 5 µs to ensure the measurement of PD pulses more precisely without loss of information. The applied voltage was varied using a regulating single phase power supply between 3 kV to 20 kV in order to capture numerous PD signals with different extent of discharges. Hundreds of signals similar to Fig. 5 were recorded for the 4 types of PD faults described in Fig. 3.

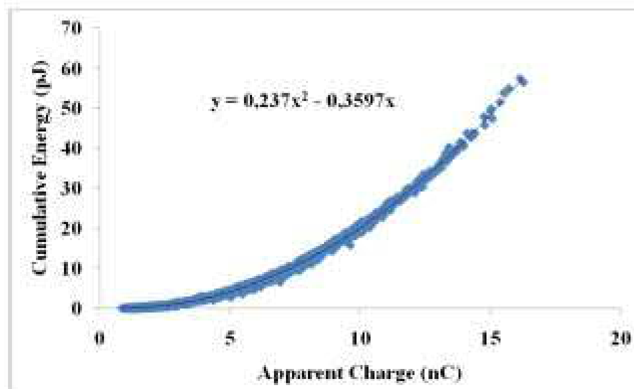
The apparent charge is calculated by integrating the PD pulses measured by conventional setup, and then multiplying with an appropriate calibration factor as described above. The cumulative energy was calculated using equation (1).

C. Correlation between Apparent Charge and Cumulative Energy

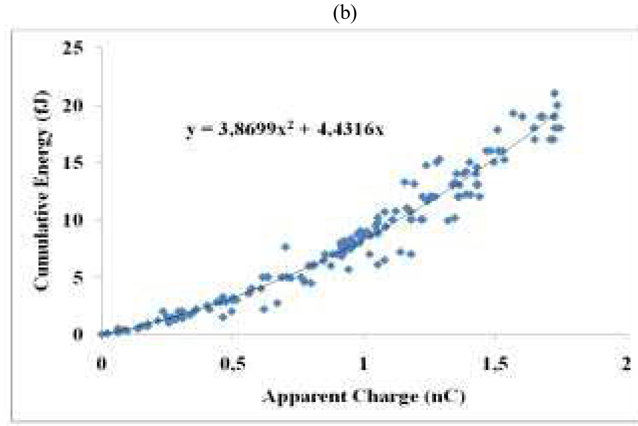
The correlation between apparent charge of conventional measurement and the cumulative energy of unconventional measurements has been plotted in Fig. 6.



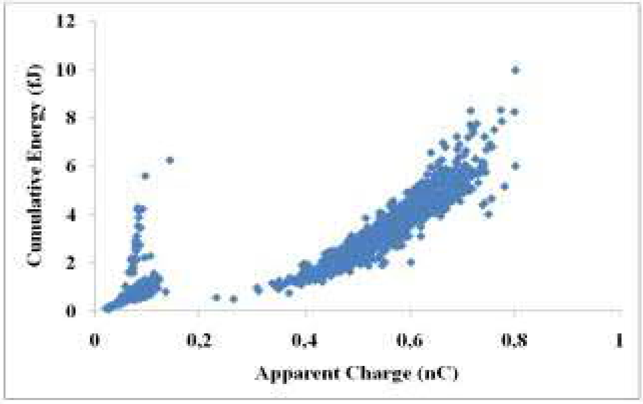
(a)



(b)



(c)



(d)

Fig.6. Cumulative energy vs. apparent charge: (a) Corona at needle, (b) PD in void, (c) Surface PD, (d) Corona around bare conductors

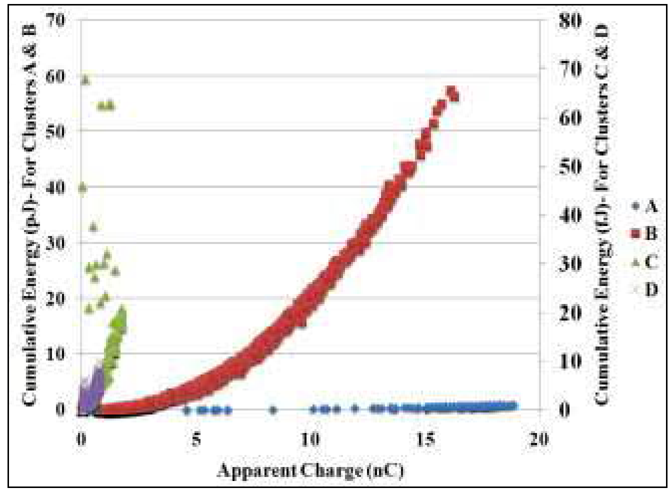


Fig. 7. Combined scatters given in Fig. 6

A distinct parabolic behaviour exists when the apparent charge is correlated with cumulative energy by taking apparent charge along the horizontal axis and cumulative energy along the vertical axis. It is clear from Fig. 6 (a-c), by using curve fitting command, the relationship between the apparent charge and the cumulative energy is a second order polynomial. However, the exact relationship varies from one type of fault to another and this is the key to identify and detect multiple faults in a switchgear or in power cables. The position of clusters define the extent of discharge as well. The clusters near the horizontal axis or near the vertical axis are weak PDs, but when the clusters are located away from the origin as well as away from either axis, the extent of discharge increases. In Fig. 6(d), three clusters can be seen, which is because of the fact that three conductors were used in PD source (d). Three bare conductors of 1 mm diameter were connected to one of the outgoing terminals. The corona around each of these conductors has different severity and extent, which resulted in three clusters.

When all the plots are combined together, a collective scatter plot shown in Fig. 7 is resulted, which further testifies the above statement, i.e. the location of the scatter patterns are based on the type/ nature of fault as well as their location on the power system network.

IV. Conclusions

The PD measurements are considered as a reliable source of information about the health of electrical insulations used in power system equipment including power cables, transformers and switchgear panels. The detection of multiple PD events in such equipment is a challenging task. Furthermore the exact location of such faults gets more trickier. The paper mainly presents the correlation between the apparent charge calculated from the conventional measurement method described by IEC standard (IEC60270) and electromagnetic energy of a signal measured by unconventional method. This correlation provides a useful information about the number of faults existing in an equipment as well as the extent of discharge. If the scatter plots are near the origin or near any axis, they are weak discharges, whereas if they are away from them, their severity is higher. More and more confidence is being developed on the unconventional PD measurement techniques. This idea further endorses the applicability of the unconventional techniques for the measurement of PD faults, as an early sign of degradation of insulation materials.

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References

[1] G. C. Stone, "Partial discharge diagnostics and electrical equipment insulation condition assessment," *IEEE Trans. Dielectrics and Electrical Insulation,* vol. 12, no. 5, pp. 891- 904, Oct. 2005.

[2] M. Hikita, S. Okabe, H. Murase and H. Okubo, "Cross-equipment evaluation of partial discharge measurement and diagnosis techniques in electric power apparatus for transmission and distribution," *IEEE Trans.*

Dielectrics and Electrical Insulation, vol. 15, no. 2, pp. 505-518, April 2008.

[3] E. Lemke and P. Schmiegel, "Introduction to fundamentals of PD diagnostics," *A Report, Lemke Diagnostics GmbH, Germany,* 2000.

[4] C. Sumereder and M. Muhr, "Estimation of residual lifetime – Theory and practical problems," *Conference Record of 8th Höfler's Days, Portoroz*, 6-8 Nov. 2005.

[5] M. Aro, J. Elovaara, M. Karttunen, K. Nousiainen and V. Palva, "Suurjännitetekniikka," Otatieto 568, 2nd edition, 2003.

[6] E. Lemke and P. Schmiegel, "Introduction to fundamentals of PD diagnostics," *A Report, Lemke Diagnostics GmbH, Germany,* 2000.

[7] S. Xiao, P. J. Moore, M. D. Judd and I. E. Portugues, "An investigation into electromagnetic radiation due to partial discharges in high voltage equipment," *IEEE Power Engineering Society General Meeting, 2007,* pp. 1-7, 24-28 June 2007.

[8] M. Muhr, "Non-conventional PD Measurements' (IEC TC42 WG14), (Last accessed on 05.02.2012). https://online.tugraz.at/tug_online/voe_main2.getvolltext?pCurrPk=33237 .

[9] J. V. Klüss, "Measuring picosecond flashover in pressurized sulfur hexafluoride (SF6)," *Doctoral Thesis, Aalto University*, 2011.

[10] G. A. Hussain, M. Shafiq, M. Lehtonen and M. Hashmi, "Online Condition Monitoring of MV Switchgear by D-dot Sensor to Predict Arc-faults," *IEEE Sensor Journal*, vol. 15, no. 12, pp. 7262-7272, Dec 2015.

[11] J. R. Andrews, "UWB signal sources, Antennas & propagation," *Application Note AN-14a*, *Picosecond Pulse Labs*, USA, pp. 7-8, 2003.

[12] N. de Kock, B. Coric, and R. Pietsch, "UHF PD detection in gas-insulated switchgear-suitability and sensitivity of the UHF method in comparison with the IEC 270 method," *IEEE Electrical Insulation Magazine,* vol. 12, no. 6, pp. 20-26, Nov.-Dec. 1996.

[13] A. J. Reid, L. Yang, M. D. Judd, B. G. Stewart and R. A. Fouracre, "An integrated measurement strategy for simultaneous fault identification: Combining the UHF and IEC60270 techniques," *14th International Symposium on High Voltage Engineering*, Beijing, Aug. 2005.

[14] IEC standard 60270, High voltage test techniques- Partial discharge measurements, 3rd Ed., 2000.