ON-LINE PARTIAL DISCHARGE DETECTION AND CONTROL ON MV CABLE NETWORKS WITH GROUND FAULT NEUTRALISER

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ABSTRACT

The technique of controlling neutral voltage and current is applied in medium- and high-voltage electricity networks as a means of eliminating earth fault currents. The complete compensation of earth fault currents is achieved using modern power electronics developed by Swedish Neutral. The GFN Ground Fault Neutralizer uses beside traditional Petersen Coil technology a novel Residual Current Compensator (RCC) to archive a very fast and complete elimination of the earth fault current.

Injection of voltage into the transformer neutral using this system, also allows control of the phase-ground voltages under normal operation. This in turn allows partial discharge (PD) activity in the cables and connected plant to be incepted and extinguished through voltage increase and reduction on a phase-by-phase basis, providing a very powerful diagnostic system.

The paper presents results from on-line partial discharge (OLPD) testing combined with neutral voltage displacement on MV networks. Case studies are presented from testing with fabricated defects and on two MV networks as part of GFN system commissioning.

INTRODUCTION

Injecting voltage into the neutral has the effect of displacing the phase to ground voltage applied to the power cables. Depending on the voltage magnitude and phase angle at which the neutral is displaced the equivalent phase-ground voltage on a phase can be brought to zero whilst the full phase-phase voltage is applied between the other phases and ground.

Partial discharge detection allows localised points of degradation in the insulation system to be identified. With respect to the operation of MV networks this is of interest for condition based maintenance, asset replacement programmes and improving overall network reliability.

The advent of on-line PD detection allows assessment to be done with normal operating voltage frequency applied. Partial discharge measurements with neutral voltage displacement is of interest as the ability to reduce the phase to earth voltages can allow large PDs on one phase to be extinguished on-line; for example when a rise in PD is observed that indicates worsening insulation condition. When the neutral point is displaced the voltage stress will be increased on one or two phases, possibly reaching the inception voltage of PDs on those phases. This allows the PD inception point with voltage at the normal operating frequency to be found and can aid the network operator in identifying weak spots on the network whilst keeping the circuits in service.

GFN GROUND FAULT NEUTRALISER

The GFN Ground Fault Neutralizer, originally developed to solve the problem with re-striking cable faults in resonant grounded networks, offers combined with on-line PD monitoring a powerful tool for grid insulation monitoring and pre-fault protection. By means of voltage/current injection into the neutral, the GFN controls phase-to-ground voltages and, if necessary, quickly quenches partial discharge activities, thus preventing further development into a full dielectric breakdown, see Figure 1 [1].

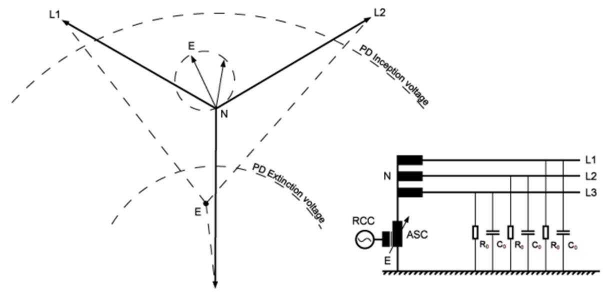

Figure 1 Quenching PD activity by controlling the ground potential (E) position

Furthermore the full control of phase-to-ground voltages also admits new online PD testing methods at levels above normal operating voltages, enabling systematic fore-checking strategies for the early detection of defective system components. This is done without at all affecting the power supply to end-users.

The Ground Fault Neutralizer is normally connected to the neutral of the supplying power transformer (Y-winding) or a separate grounding transformer (Z-winding). A complete GFN-system is composed of a modern solid core arc suppression coil (ASC, see Figure 2, a cabinet with power electronics for voltage/current injection (RCC - Residual Current Compensator) and the GFN control cabinet. Beside the controls for the RCC voltage/current injection the GFN also provides automatic retuning for the arc suppression coil and a new twin-scheme fault locator with superior detection capabilities. Distance-to-fault information can be obtained by feeder looping.

Figure 2 A modern fast tuning solid core arc suppression coil (right hand of picture) forming the high voltage part of the GFN system

The arc suppression coil forms a parallel resonant circuit with the phase-to-ground capacitive leakage (Co) of the network. By this resonant circuit the source impedance for single phase-to-ground faults increases in the order of ten to twenty times, sufficient to quench single-phase flashover faults on overhead lines. However line fracture faults, tree faults and other types of sustained faults, as well as all types of cable faults so far could not be cleared completely. Instead it was necessary to trip the faulty feeder, in order to minimize the risk for fire and personal hazards due to the remaining active current.

The GFN Ground Fault Neutralizer now provides fast and complete compensation of all remaining earth fault currents – both fundamental and harmonics – by injecting a 180 degree opposite current into the neutral. This is beneficial especially in industry- and urban cable grids where almost all faults start single phase-to-ground (cable screen). If not properly compensated, a re-striking cable fault quickly develops into a multi-phase or cross-country fault with subsequent long term outages.

Also with respect to personal safety and fire prevention the GFN offers premium protection [2]. A fault interception in less than three cycles in praxis can never be reached by traditional protection schemes working on breakers.

ON-LINE PARTIAL DISCHARGE (OLPD) DETECTION AND MONITORING

On-line PD measurements can be made as a short-duration spot-test or with continuous monitoring over an extended period, generally from 24 hours to permanently. After initial detection of PD activity on a cable circuit, it may be located to a position on the cable. This information is then used for maintenance and to help determine severity, as different parts of the cable system have different tolerances to PD; e.g. cable accessories can often tolerate higher levels of PD activity than cable insulation. The flow diagram in Figure 3 shows the different aspects of on-line PD detection.

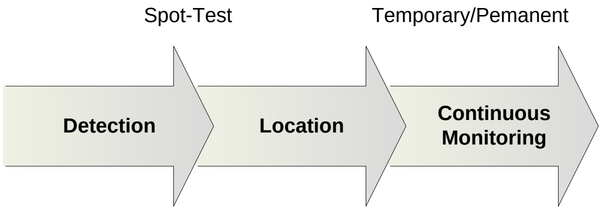

Figure 3 Aspects of On-line PD detection

On-line PD Measurement Hardware

The HVPD-Longshot measurement system was used in the measurements which utilises a wide band oscilloscope with the sampling rate set at 100 MS/s. Data traces of one power cycle duration were captured and processed in a loop with the on-board PD analysis software. The software discriminates PD and noise using PD event recognition based on the signal wave shapes [3]. The instrument was triggered by the line supply to allow synchronicity between the PD signals and voltage applied to the cable under test.

A schematic diagram of the system is shown Figure 4. For temporary or permanent monitoring applications similar hardware is used with the addition of signal multiplexers on the inputs to maximise the number of sensors which can be connected to a single system.

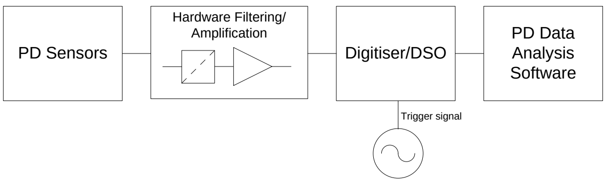

Figure 4 On-line PD Measurement System

OLPD SENSOR CONNECTIONS

Non-intrusive high frequency current transformers (HFCT) were used in this work for detection of the current impulses from PD in the cables and switchgear.
HFCT sensors may be attached onto the cable earth or cable with the earth sheath brought back through. Examples of sensor connections are shown in Figure 5.

Figure 5 Examples of HFCT sensor attachment

PARTIAL DISCHARGE DETECTION WITH NEUTRAL VOLTAGE DISPLACEMENT

Injecting voltage into the neutral has the effect of displacing the phase to ground voltage applied to the power cables. Depending on the phase angle at which the neutral is displaced the equivalent phase-ground voltage on a phase can be brought to zero whilst the full phase-phase voltage is applied between the other phases and ground.

Partial Discharge measurements on networks with RCC Ground Fault Neutraliser systems are of interest as the ability to reduce the phase to earth voltages could allow large PDs on one phase to be extinguished on-line, for example when a rise in PD is observed that indicates worsening insulation condition. When the neutral point is displaced the voltage stress will be increased on one or two phases, possibly reaching the inception voltage of PDs on those phases, see Figure 1.

PD measurements should also be made on these networks to ensure that the PD level is not rising significantly and that no new PDs are being created when neutral voltage displacement is being used either to quench a PD or more likely in its designated operation for ground fault protection.

CASE STUDY 1: 30KV NETWORK

PD measurements were made on a 30kV network with a GFN system installed. An XLPE cable sample with insufficient stress relief at the termination was attached to the L2 phase of a spare switchgear bay at a 10 panel AIS substation, no cables were connected to phases L1 and L3 on this bay. The test set-up is shown in Figure 6.

The insufficient stress relief at the cable termination caused surface discharges to be incepted and was used as a reference PD signal in the measurements. A power cycle captured from the HFCT sensor at 30kV is shown in Figure 7 along with details of the positive and negative half cycle PD pulse wave shapes.

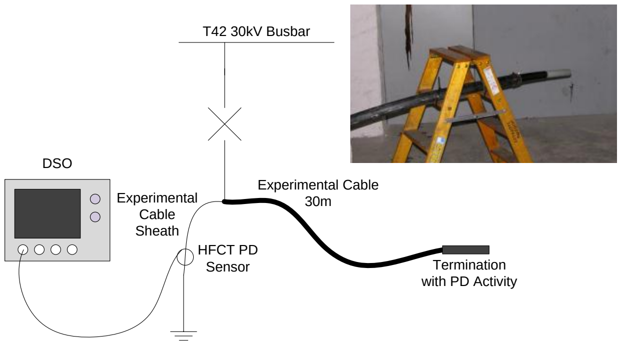

Figure 6 Test set-up with cable sample

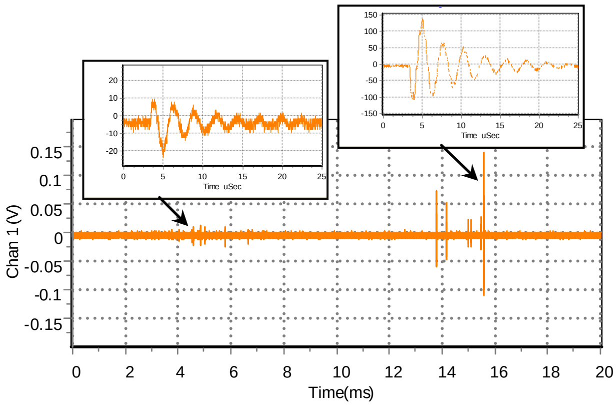

Figure 7 PD phase pattern and pulse waveforms (insets)

Neutral voltage displacement was used to reduce the voltage on L2, Figure 8 shows the reduction in peak PD signal over time as the voltage on L2 was reduced from U_0 to $0.78U_0$. It should be noted at this point the voltage on L1 and L3 was increased to $1.12U_0$. As expected the reduction in applied voltage was able to quench the PD activity from the cable sample on L2, with PD ceasing to be observable at $0.78U_0$.

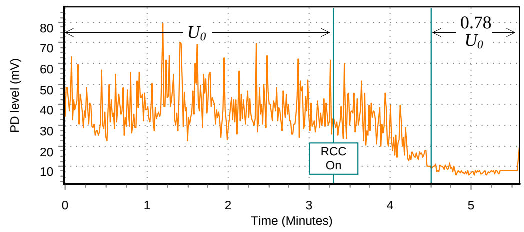

Figure 8 PD over time with decreasing U_0

The voltage on L2 was reduced further to $0.64U_0$, increasing the phase-earth voltage to $1.22U_0$ on L1 and L3. The resulting peak PD activity in time can be seen in Figure 9. It can be observed that there is an increase in PD activity on the L2 phase with this further reduced voltage level. The PD pulse shapes shown in the insets of Figure 9 are quite different for when L2 voltage is at U_0 and $<U_0$.
As the PD on L2 phase had already been quenched at $0.78U_0$ the PD activity at voltages $<0.78U_0$ was assumed to cross-coupled from L1 and L3 on the adjacent circuits.

The pulse waveforms at $0.64U_0$ have more high frequency content, indicating a source nearby to the sensor. A visual inspection and acoustic PD test on the switchgear panels revealed some water damage at the bushings which was deemed the likely source, as shown in Figure 10.

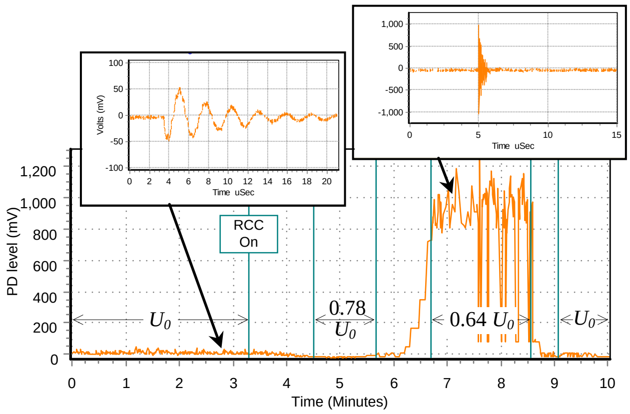

Figure 9 PD over time and pulse waveforms (insets) with decreasing U_0

The tests showed the measurement and extinction of partial discharge on-line, but also highlighted the inception PDs on other phases that are not normally present at U_0. This has significant benefits during network commissioning tests and also for routine assessment of circuits.

Figure 10 Evidence of water ingress at switchgear bushings.

CASE STUDY 2: 20 KV NETWORK

PD measurements with neutral voltage displacement were made during the commissioning of a GFN system at a 20kV substation. When the neutral point was moved close to L1 and voltage increased on phases L2 and L3, PD up to 1600pC was observed on L2 which was not present at U_0. The phase patterns before and after neutral voltage displacement are shown in Figure 11. In this case, the circuit subsequently had a fault five months later indicating the use of the measurements to obtain advance warnings of weak points in the network.

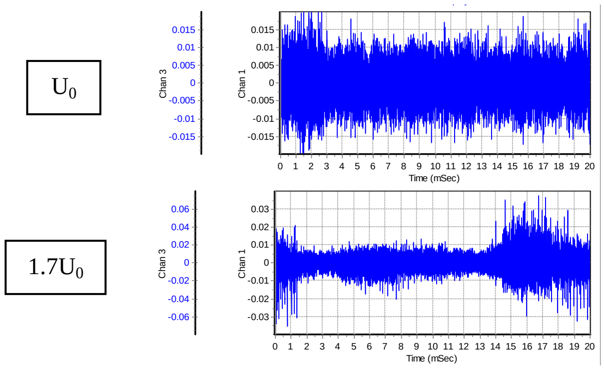

Figure 11 L2 PD phase pattern at U0 and 1.7U0

CASE STUDY 3: 11 KV GFN COMMISSIONING

PD tests were made as part of the commissioning procedure of newly installed GFN system at a five feeder 11kV substation. Using neutral displacement each phase was tested with U_0, 1.3, 1.5 and $1.73U_0$ across phase-ground. PD measurements were made both at the primary substation and at distributed points within the network. No significant change in PD level was observed with increasing voltage level on each phase indicating the network was in good health.

CONCLUSIONS

Neutral voltage displacement has been used in the past normally as part of an earth fault protection scheme. The ability to quench PD activity on-line through neutral voltage displacement (and subsequent reduction in phase-earth voltage on one phase) was measured.

The inception of PD was also shown. Future application may be to combine neutral voltage displacement with continuous PD monitoring and to displace the neutral point when the PD is observed to be rising and reaches a certain level to quench it.

Baseline PD tests are beneficial to find the PD that will be incepted when increased voltage is applied between any phase and ground as could occur in the operation of the neutral voltage displacement system.

REFERENCES

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