ANALYSIS OF 3 PHASE PARTIAL DISCHARGE CHARACTERISTICS IN POWER CABLES INCLUDING 3 PHASE TRANSFORMER

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Abstract: In this study, 3 phase simultaneous PD(Partial Discharge) pulse characteristics were investigated for the 22.9kV CNCV cables combined with 3 phase transformer. As a defect, 5/20ns PD simulated pulse and void discharges were adopted simulating the defects inside the insulation. 3 RFCTs(Radio Frequency Current Transformers) with frequency band from 1 ~ 200MHz were used to measure PDs and were installed at each phase cables. The PD measurements were carried out at the termination using 500MHz digital oscilloscope. Pulse characteristics such as polarities, amplitudes, etc. were shown differently according to the PD source location, due to the different paths including 3 phase transformer windings. Based on the result, new PD analytic algorithm, 3PPAD(3 Phase Polarity and Amplitude related Diagram) was proposed in consideration of polarity characteristics of the first peak of the PD pulse combined with the amplitude comparison.

1 INTRODUCTION

In case of on-site situation, power cables are connected to other equipments such as transformers, circuit breaker, GIS, DS, bus bars, etc. Therefore, if partial discharges (PD) occur at some point they can propagate to the other equipments.

If the 3 phase circuit is composed with cable systems only, that is, both terminations of 3 phase cable systems are open, PDs generated from the phase A propagate rarely to the phase B or the phase C, even though all the phases are connected and commonly grounded at the normal joints and the terminations.[1] (If the cable systems have crossbonding systems in the joints, PDs are propagated to other phases.[2])

However, cables should be connected to other power equipments at the termination, which means that PDs can be propagated to other equipments. Especially, in case of connection with the 3 phase transformers, PD generated from one phase can be propagated to other phases through the transformer windings.[3] So, it is very complicated to measure and analyze PD on-site.

Therefore, in this study, 3 phase simultaneous PD pulse wave shape characteristics were investigated for the cables combined with 3 phase transformer. As PD sources, 5/20ns artificially PD simulated pulse and real PDs such as void discharges were adopted. Based on the result, new analysis algorithm was proposed for the 3 phase simultaneous PD detection.

2 EXPERIMENTAL SYSTEMS

3 phase voltage controller was designed and made to apply and to control 3 phase voltage. Figure 1 shows the 3 phase PD experimental system including the 3 phase voltage controller, 3 phase transformer, cables with defects, and PD measuring system such as sensors and the oscilloscope. The commercial oil-type 3 phase transformer was used with the specification of 22.9kV/380V Δ-Y windings. Also, 22.9kV CNCV cables in 3 phases were connected to the high voltage side of the transformer. The length of the cable was 10m where the normal joints were installed at 5m position.

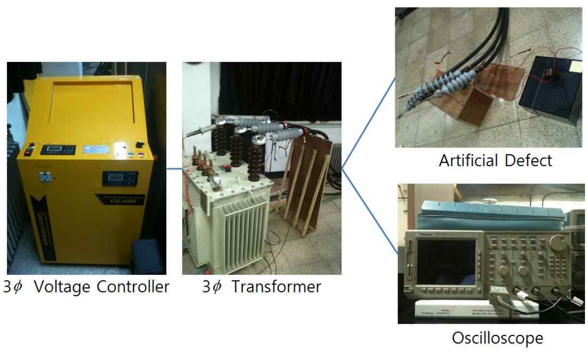


Figure 1: 3 phase PD experimental system

The layout of the experiment was shown in Figure 2, in which 3 RFCTs were installed at the transformer-side termination to measure PD.

PD measurements were carried out using 3 RFCTs (Radio Frequency Current Transformer) which had same performance. The RFCT had wide frequency band of 1~200MHz.

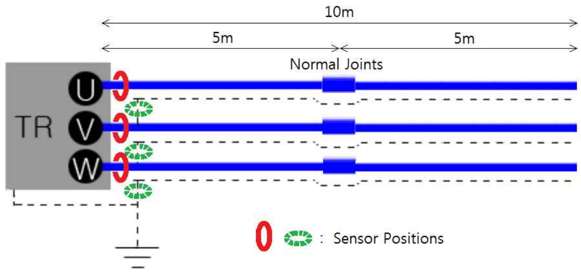


Figure 2: The layout of the 3 phase PD experiment

Before doing real PD detection, 5/20ns simulated PD pulse was applied to the composed system to find out the basic concept of PD pulse propagation. Then, high voltage was applied to the system with artificial defects and PD signals were detected such as void discharges. The void cell had a cylindrical type void with 1mm diameter and 1mm height inside the epoxy insulation. Also, PDs were measured for several locations of PD source such as at the cable-side termination (10m cable position), at the transformer-side termination (0m cable position), and between the two HV bushings (phases) of the transformer.

3 CHARACTERISTICS ACCORDING TO THE PD SOURCE LOCATIONS

3.1 The case of PD generation from the cable side (10m position)

(1) 5/20ns simulated PD pulse

Measurements at 0m position as injecting simulated signals at 10m position can be the situation for the detection of PDs propagating from the cable-side to the transformer-side. Figure 3 shows wave shapes at the 0m position when 1V 5/20ns pulses were injected to the W-phase(CH4) 10m position of the cable. The polarity of the pulse injected phase was opposite to those of other phases. The pulse of injected phase(CH4) was faster than those of other phases(CH2 & CH3), which implies that the signal was propagated from the injected phase to the other phases through the transformer. Therefore, the direction of the propagation in the injected phase became opposite to those of other phases.

The first peak of the pulse in injected phase(CH4) was decreased to 1/3 ~ 1/5 scale in the other phases(CH2 & CH3), which shows the attenuation in the transformer windings. The other phases showed similar wave shapes and amplitudes.

However, the second peak of other phases which was the reflected wave at the terminations and joints was rapidly decreased due to the impedance of the transformer windings. It means that the peaks after the first one depend on the characteristics of the propagation paths, that is, the composition of the electric power equipments. Therefore, the analysis of pulse propagation should be focused only on the first peak of the PD pulse.

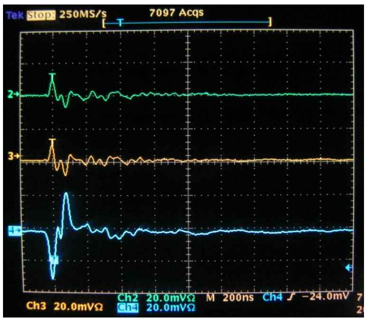
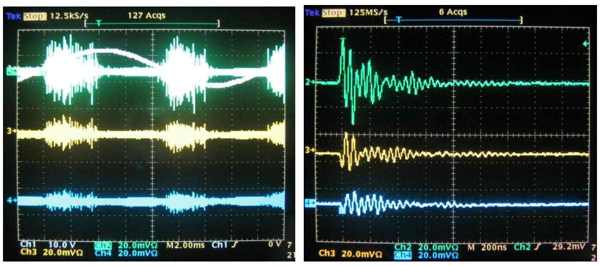


Figure 3: Characteristics of simulated pulse injected at 10m cable position

(2) Void discharges

Figure 4 shows the result of void discharges measured at the 0m position when the void cell was installed at the U-phase(CH2) 10m cable position. The PRPD(Phase Revolved Partial Discharge, Figure 4.(a)) showed the typical void discharge pattern. The first peak of U-phase(CH2) in the positive PD pulse(Figure 4.(b)) was appeared to be opposite to those of other phases(CH3 & CH4), which is the same as in Fig 3. The amplitudes of other phases were 1/3 ~ 1/5 scale compared with that of the U-phase, even though they were not the same.



(a) PRPD (b) Positive pulse

Figure 4: Void discharges from U-phase(CH2) 10m cable position

(3) Discussion on the PD pulse propagated from the cable side

As mentioned above, the polarity of PD generating phase is opposite to those of other phases in case of PD pulse propagated from the cable side, because the PD pulse in the generating phase is measured with the direction to the transformer side and those in other phases with the direction from the transformer side. The magnitude of the PD pulse in the generating phase is 3 ~ 5 times to those of other phases. These results can be used for the PD location technique as described later.

3.2 The case of PD generation from the transformer side (0m position)

(1) 5/20ns simulated PD pulse

Measurements at 0m position as injecting simulated signals at 0m position can be the situation for the detection of PDs propagating from the transformer side to the cable side, that is, the case of the problem of the cable termination or the transformer in one phase. Figure 5 shows wave shapes at the 0m position when 1V 5/20ns pulses were injected to the W-phase(CH4) 0m position of the cable. The polarity of the pulse-injected phase(CH4) was the same with those of other phases(CH2 & CH3). Because the signal was generated from the transformer side, the signal in the injected phase was detected as propagating to the cable directly whereas in other phases the signal was measured as propagating to the cable after passing through transformer windings. Therefore, in all phases the pulses show the same polarity. However, the amplitude of the first peak of the pulse in other phases (CH2 & CH3) was very small in 1/8 ~ 1/10 scale compared with that in the injected phase(CH4), due to the difference of the impedance of each phases.

Figure 5: Characteristics of simulated pulse injected at 0m cable position

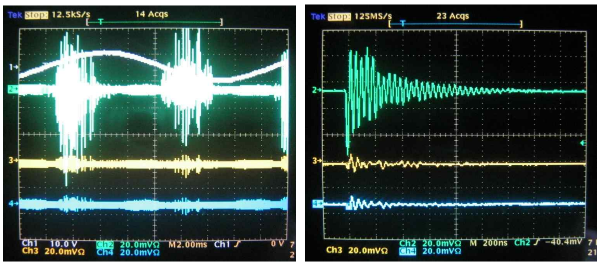
(2) Void discharges

Figure 6 shows the result of void discharges measured at the 0m position when the void cell was installed at the U-phase(CH2) 0m cable position. The PRPD(Figure 6.(a)) showed the void discharge pattern. From the single pulse wave shape(Figure 6.(b)) all the pulses showed the same polarity, which is the same as in Figure 5. Also, the amplitude of the U-phase(CH2) was very larger than those of other phases, which seems to be due to the difference of the impedance according to the propagation paths.

(3) Discussion on the PD pulse propagated from the transformer side

From the results above, the polarity of PD pulses in all the phases is same in case of PD pulse propagated from the transformer side. Because the signal is generated from the transformer side, all the signal in 3 phases is measured as propagating to the each phase cable. However, the amplitude of the first peak of the pulses between PD generating phase and other phases shows big difference which comes from the impedance according to the propagation paths. The impedance of the cable side is 1/ωC where C is the capacitance of the cable, on the contrary that of the transformer side becomes ωL where L is the inductance of the transformer windings. Usually the frequency of the PD pulse is so high that the impedance of the cable side becomes smaller than that of the transformer side, resulting in the larger signal in the cable side.

The characteristics in polarity and amplitude in case of PD pulse propagated from the transformer side shows very different compared with that in the case of the cable side.



(a) PRPD (b) Negative pulse

Figure 6: Void discharges from U-phase(CH2) 0m cable position

3.3 The case of PD generation between two phases of the transformer

(1) 5/20ns simulated PD pulse

In order to model the insulation problem between two phases in the transformer not concerned with the cable system, the simulated pulse was injected between two terminals (U-phase(CH2) & V-phase (CH3)) of the transformer. Figure 7 shows the result. The signals in U-phase and V-phase had similar magnitudes and wave shapes but opposite polarities, on the contrary the signal in W-phase (CH4) showed very weak, which is completely different from the results discussed above.

(2) Void discharges

Figure 8 shows the result of void discharges measured at the 0m position when the void cell was installed between two terminals of the transformer. Two wave shapes(U-phase(CH2) & V-phase(CH3)) with similar amplitude and opposite polarity were measured, whereas the other phase (W-phase (CH4)) showed very weak signal.

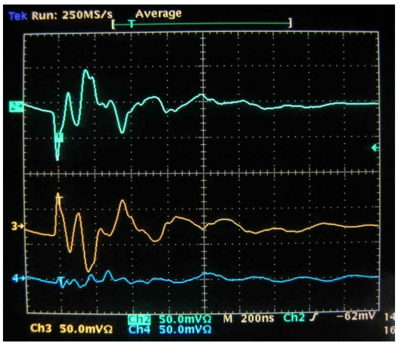
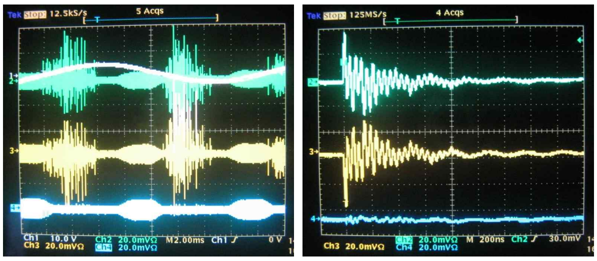


Figure 7: Characteristics of simulated pulse injected between two terminals of the transformer



(a) PRPD (b) Pulse wave shapes

Figure 8: Void discharges between two terminals of the transformer

(3) Discussion on the PD pulse between two terminals of the transformer

The case of PD generation between two terminals in the transformer shows very peculiar result compared with the case of the cable side or the transformer side. This is also the one of classifying types in on-site 3 phase simultaneous PD detection.

4 NEW ALGORITHM OF 3 PHASE SIMULTANEOUS PD ANALYSIS : 3PPAD (3 PHASE POLARITY AND AMPLITUDE RELATED DIAGRAM)

3PARD(3 Phase Amplitude Related Diagram) algorithm was suggested using the comparison of PD amplitudes in 3 phases and has been applied to the effective noise elimination method.[4] In this study, in addition to this method, new PD analysis algorithm was developed adopting polarity analysis.

Table 1 shows the result of this study. The concept of new algorithm which includes polarity characteristics was shown in Figure 9, whose name is 3PPAD(3 Phase Polarity and Amplitude related Diagram). In this figure, according to the polarity of the first peak of the PD pulse, the cluster of PD data should be differently located in the map.

In this algorithm, the first peak amplitude of the pulse is normalized based on the maximum value among 3 phases which is the dotted circle (normalized line; amplitude line of the largest phase) in Figure 9. Then, considering the polarity of the pulse, the sum of vectors in 3 phases is performed in the 3 phase map. If the polarity of the pulse would be opposite in case of the pulse propagation from the cable side, the vector sum becomes larger than the normalized line and the data cluster locates outside of the normalized line. On the contrary, if the polarity of the pulse would be same in case of the pulse propagation from the transformer side, the vector sum becomes smaller than the normalized line and the data cluster locates inside of the normalized line. Therefore, even though the clusters are located on the same phase, the propagation direction of the PD pulse can be easily noticed by the cluster location inside or outside the normalized circle line, which makes possible find out effectively where the signals come from. Also, in case of insulation problem between two phases of the transformer, the PD data cluster would be located between the two vector axes nearly on the normalized circle line.

Table 1: Comparison of various PD source locations in measuring PD at the transformer side termination of the cable

PD source location	Polarity of the pulse	Amplitude of the pulse	Data Cluster Location
Cable side	1 phase different	PD phase > other phases	Outside of the normalized line
Transformer side	same in all phase	PD phase >> other phases	Inside of the normalized line
Between 2 phase of Tr.	opposite in 2 phases	similar in 2 phases	On the normalized line

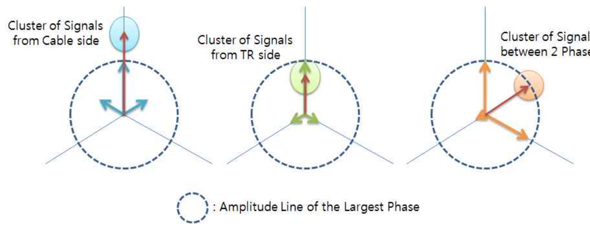


Figure 9: The new concept of 3PPAD considering pulse polarity and amplitude

5 CONCLUSION

In this study, the following conclusion was deduced from the analysis of PD propagation for cables combined with the 3 phase transformer.

The polarity of PD generating phase is opposite to those of other phases in case of PD pulse propagated from the cable side, whereas the polarities of all the phases are the same in case of PD pulse propagated from the transformer side. The amplitude of PD generating phase is larger than those of other phases, especially in the case propagated from the transformer side due to the difference of the impedance of each phases. Also, the signals of two phases in case of PD source between two terminals in the transformer show similar magnitudes and wave shapes but opposite polarities, on the contrary whereas the signal in the other phase is very weak.

Based on these results, new PD analytic algorithm, 3PPAD(3 Phase Polarity and Amplitude related Diagram) was proposed in consideration of polarity characteristics of the first peak of the PD pulse. It is expected that this algorithm shows better performance in on-site PD diagnosis for the cables in 3 phases.

6 ACKNOWLEDGMENTS

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