別紙４－１（課程博士（英文））

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Abstract (Doctor)

Title of Thesis	Development of Condition Monitoring Method for Power Cables by Means of Partial Discharge and Water Tree Detections (部分放電と水トリーの検出による電力ケーブルの状態モニタリング手法の開発)

Approx. 800 words

Electric power transmission and distribution depends on a vast and expensive network of high and medium voltage cables for power delivery. To support the system operates properly with high reliability; thus, it is necessary to maintain the power cable in good condition. The reliability and availability of the power cable are determined by the conditions of its insulation system. Defects and degradations are known to be the major factors which give harm to the insulation power cable leading to failure. Defects are mainly created before an operation is started, and lead to the failure of the cable line in the early stage. Partial discharge (PD) measurement is useful to detect such defects and local breakdown. On the other hand, water tree is a degradation mode that takes place several tens of years after the operation has been started (aged). The cable may cause electric breakdown when a water tree grows and bridges the insulation, as it is significantly conductive. Diagnostic testing by means of water tree detection is often employed for preventive measurement.

In early stage (aged stage as well), PD measurement is very useful but conventional methods cannot afford to approach the discharge source although the cable is usually as long as several kilometers. In the wear-out stage, water tree is the most significant degradation mode. As the cable is practically long and water trees are not uniformly distributed along the length, the conventional diagnosing methods cannot afford to locate the degradation. Based on these backgrounds, two components of the studies were performed. First, we proposed a PD detection method that can easily approach the origin of the discharge by newly proposed capacitive coupling electrode. As the PD takes place spontaneously under commercial voltage, this detection is classified as a passive diagnosis. Second, water tree detection method that can locate the degradation by considering charge behavior accompanied by water tree. As the behavior takes place by applying several different waveforms of high voltage, this detection is classified as an active diagnosis.

For a newly developed PD detection method, we assumed that the outer shield is not a perfect conductor, the change in potential due to the current discharge and shield resistance would be seen as PD signal propagating through the cable. This will be more significant because of skin effect when higher frequency component is targeted. The change in potential along the shield electrode can be detected by the capacitive coupling between the foil electrode and shield electrode itself. In order to retain a ground potential, another identical cable was used as referent cable. In practice, a pair of cables in three phases can be taken as the object and reference. Basic experiment and numerical analysis were carried out by using a coaxial cable (RG58A/U). In this study, a mimic PD with the width of 20 ns was applied to the target cable line with 50 Ω characteristic impedance. The intensity of the calibration can be modified by adjusting the charging voltage. The change in potential along the cable line was detected using a foil electrode made from aluminum. From the input of the mimic PD pulse signal, the detection point voltage signal appeared about 250 ns later.

A numerical simulation was performed in the same manner to measurement. As the pulse propagates, a displacement current is generated in the electric shielding layer, and the distribution of the voltage source appears. The detection signal is obtained by integrating the signals given to the output points by the respective voltage sources. This equivalent circuit is regarded as a lossless line, and the reflection of the signal is not considered. The experimental result and simulation result were compared, and it shows similar characteristics. In order to compare the sensitivity of this method, the same experiment was conducted on a mimic insulation joint. The detection intensity of the proposed method is almost 30 times lower than the conventional PD detection at the insulation joint, but the same intensity can be detected if an amplifier is installed during actual measurement on-site. Precise maintenance is needed as the cable gets old with time. Therefore, constant monitoring of PD is necessary. We decided to design and prototype an inexpensive PD monitoring instrument to monitor PD along the cable lines at all time, and the performance was satisfactory.

For the new water tree detection method, several different waveforms of high voltage were employed. A principle of this method is similar to the conventional residual charge method. In this method, the bias voltage is used for charge accumulation and depolarizing pulse voltage is used to release charge instead of AC voltage. If a pulse voltage is applied instead of the AC voltage in the residual charge method(conventional method), (1) a water-tree can be located based on the delay time of the residual charge signal from the pulse, and (2) By repeatedly applying the pulse and by averaging responses, the SN ratio can be improved. We named the method which measures the residual charge including information of the location by applying the pulse as "charge radar method" and we discussed the feasibility of this method.

In the active diagnosis measurement, a water-tree degraded cable with 5 m in length was inserted the 400-m-long communication coaxial cable in order to imitate a real cable line. Changing the location of the degraded section, we measured residual charge signals using the charge radar. Residual charge signals are observed at locations of degraded sections as time delay in every subtracted waveform. By integrating each residual charge signal, a few percents of the amount which is measured by the conventional method is calculated. Based on the proposed method, the degraded water-tree XLPE cable is detected.

The responses to high voltage pulse voltages were investigated in order to clarify the charge behavior with which the signal of newly proposed charge radar method is detected. The assessment of charge behavior under pulse voltages was studied by using a thin XLPE film sample contained water tree. Space charge measurement is performed by using Pulsed Electroacoustic method (PEA). A numerical simulation was also performed. Assuming the trapping and de-trapping process, the differences in pulse response were explained depending on the degree of water tree degradation. It was suggested that the degradation signal is based on the difference in a transient current through the water trees depending on the polarity of the bias pulse voltage applied prior to the pulse voltage.