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Development of Deterioration Diagnosis System for Aged ACSR-OC Conductors in HV Overhead Distribution Lines

(고압 가공배전선의 노화된 ACSR-OC 도체에 대한 열화진단시스템 개발)

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Abstract

Design and experiments of a nondestructive testing system with a solenoid eddy current sensor to inspect deterioration of ACSR-OC (ACSR Outdoor Cross-linked Polyethylene Insulated Wires) usually used in HV overhead distribution lines in domestic areas is presented in this paper. Through corrosion mechanisms and deterioration results for ACSR-OC conductors are examined, it is shown that corrosion may lead to the reduction of the effective cross section area of conductors. A useful electromagnetic method to detect and quantify severe corrosion degree of aged conductors is proposed. The measurement system consisting of a constant current source with a RF frequency, a signal processing unit and a motor driver/ controller is designed and implemented. This instrument has such capabilities as detecting the sensor output and estimating diameter change of the testing conductors, continuously. As a result, it was verified that such corrosion detector system with an eddy current sensor can be shown good effectiveness for estimating the serious faults due to deterioration in overhead distribution lines and giving an early warning before severe aged conductor may lead to fail.

요 약

본 논문에서는 국내의 고압 가공배전선으로 일반적으로 사용되는 ACSR-OC의 열화를 검출하기 위하여, 솔레노이드 와류센서를 가진 비파괴 검사시스템의 설계와 실험을 다루었다. ACSR-OC 도체에 대한 부식기구와 열화 상태를 검토하므로써, 부식이 도체의 유효단면적을 감소시키는 것을 확인하였다. 노화도체의 극심한 부식정도를 검출하고 정량화하기 위한 실용적인 전기·자기적인 방법을 제시하였다. 고주파 정전류원, 신호처리 부와 모터 구동/제어기로 구성되는 계측시스템이 설계되고 시험되었다. 이 장치는 센서의 출력을 검출하고 검사도체의 직경변화를 연속적으로 추정하는 기능을 갖고 있다. 그 결과, 와류센서를 가진 부식검출시스템은 가공 배전선의 열화에 기인한 심각한 결함을 추정하고 극심한 노화도체가 단선되기 전에 사전 경고를 하는데 양호한 효용성을 나타내는 것을 확인하였다

1. Introduction

There are several kinds of conductors used in HV distribution lines in domestic areas, but most conductors, i.e., 22.9[kV] lines, have been used to ACSR-OC (ACSR Outdoor Cross-linked

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Polyethylene Insulated Wires) since 1978[1] Since this type conductor have insulators coating to polyethylene, they generally hold a good security from dangerous situations such as receiving electric shocks and further keep the power network on reliability from occurring troubles caused by short circuits However, ACSR-OC conductors built in domestic areas have almost been about 20 years so that most ACSR exposed to the big city or industrial region with heavily pollutant for a long duration may be severely corroded Especially, many cities in our country are located on the coastal areas and then, power lines are easily attacked by salt or chloride irons carried by moisture wind[2].

Overhead power lines exposed to the atmosphere for a long period may be slowly deteriorated by such corrosion factors as chloride, sulfur, soot or dust in the air Corrosion causes to reduce the mechanical performance and to increase power loss. Severe local corrosion on the overhead power lines sometimes leads to result in weakening of the conductors, overheating and eventually failure. Although most troubles or accidents in distribution lines may occurred by contacting other conducting materials with the live conductors or by impulsive energy such as strokes or lightning, it may be one of main factors that the conductors exposed to the atmosphere for a long period deteriorates slowly with age. Deterioration mechanism is dependent on material components of the conductor and its exposure environment factors. In general, ACSR-OC used to HV overhead distribution lines may be easily attacked by atmospheric corrosion as well as sometimes galvanic corrosion[3,4]

According to the regulations in KEPCO (Korea Electric Power Corporation)[5], the limiting life of the overhead power lines regardless of types of conductors is given as about 30 years. Most of overhead conductors are built in the atmospheric environment easily to corrode. Therefore, for any conductor exposed to serious pollutant area, its useful life may be reduced remarkably, compared to the rated life. Especially, HV distribution conductors built in an industrial region or big city may be rapidly deteriorated by pollutant and contaminant air. Therefore, it is necessary to assess corrosion degree of the aged conductors in service and to determine the replacement period of them before they may lead to failure.

In KEPCO, the overhead distribution lines or electrical equipment is regularly inspected to visual inspection method. Inspector can often find any serious fault in the live conductor such as broken wire but it is impossible to detect the internal corrosion in the conductor. In addition, this method always takes much labor and expense to inspect all spans of the conductors precisely and further, its inspection results show little reliability. In particular, it is hardly possible for ACSR-OC to inspect the corrosion of the conductor because of its polyethylene insulated coating. Hence, it is necessary to develop any nondestructive test system in order to detect internal or serious local corrosion for ACSR (Aluminum Stranded Conductors Steel Reinforced) or ACSR-OC conductors

This paper deals with a basic research result for a nondestructive detecting system to inspect and diagnose deterioration of distribution conductors. Structural scheme of corrosion detector, corrosion mechanism of the conductor and corrosion detecting methods will be discussed.

2. Deterioration of ACSR-OC and Its Detection

2.1 Deterioration Mechanism

As shown in Figure 2.1, ACSR-OC consists of galvanized steel strands with hot-dip in the inner layer, aluminum conductors with hard-drawn in the outer layer and polyethylene insulator coating Aluminum strands are used to conductors to transfer power current, while steel strands take charge of the most tensile strength of ACSR-OC The surface of steel strand is galvanized in order to prevent atmospheric corrosion and the galvanizing layer also presents iron-zinc alloy because it is made to hot-dip, which depth of zinc coating and iron-zinc alloy are at about 30~50[μm]

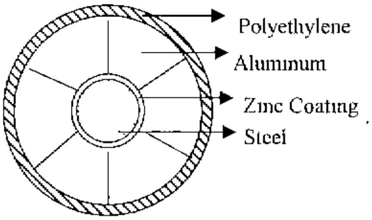


Figure 2.1 Cross section area of ACSR-OC

In HV distribution lines built in domestic areas, overhead power lines are about above 90[%]. Hence, most conductors are always exposed to the pollutant atmosphere easily to corrode[2]. Local corrosion or global corrosion in power lines can be verified through analyzing deterioration phenomenon and status of overhead ACSR-OC. Based on such results, it may be possible to estimate the remaining life of aged power lines. Corrosion and deterioration mechanism is mainly determined by material components contained in ACSR-OC and exposed environmental index. Therefore these factors play a main role to diagnose the remaining life of power lines.

Especially, Overhead ACSR-OC has a good condition to penetrate moisture or water into the strands because its surface is protected to polyethylene insulator. Therefore, at the early stage of installation, it has prominent protection to corrosion by the pollutants in the air. However, if the polyethylene coating is deteriorated or is damaged by any impact force to some extent, corrosion mechanism of ACSR-OC is similar to that of ACSR. If any corrosive gas or moisture may be pervious to the inner strands through any holes of the polyethylene insulator, the rate of corrosion would be more rapidly accelerated than that of general ACSR conductors.

Once aluminum strands of ACSR-OC are exposed in the atmosphere, they, then begin to be directly corroded by pollution air, shown in Figure 2.2 Even through aluminum is an active metal with high affinity to oxygen, it has high corrosion resistance in the air because a film oxide formed on its surface protects the aluminum strands. In any cases, however, its rate decreases with the elapse of time. Hence, aluminum appears a high corrosion resistance. Galvanizing on the surface of steel strand moderates the rate of corrosion as the ferrous may be directly exposed in air or moisture because it has strong chemical affinity with oxide irons. If zinc coating has been corroded, aluminum strands are in contacting with galvanized steel strands and then, they would be attacked by galvanic and crevice corrosion, especially in coastal areas where salt is carried by wind.

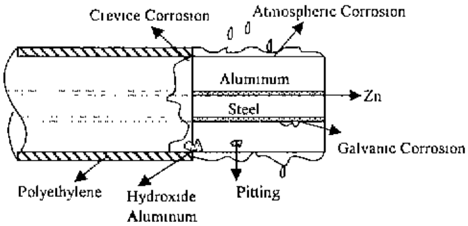


Figure 2.2 Corrosion mechanism

2.2 Detection of Deterioration

In general, it is obvious that there will appear to reduction of cross section area for the conductor due to corrosion. Of course, such reduction would not occur as equivalent shapes along the surface of all strands, but an effective cross section area of the corroded conductor could be available to inspect by using a suitable method.

Local and global corrosion caused by atmospheric and galvanic corrosion may appear all the spans of conductors exposed to the similar regions. To detect these corrosions to any quantified data, there have been several attempts. One of them is to detect the changes of cross section area in aged aluminum strands[6] or the zinc loss of the galvanized steel strands in the inner layer[7]. In addition, an infrared camera can be used, but it may be less sensitive and give low accuracy[8].

Eddy current method using a probe coil or an encircling coil has been widely applied in nondestructive test (NDT) of conductive materials. First of all, it could be possible for all conductive materials and then includes the inspection of the dimension of the test materials, the measurement of the thickness of metallic plates or non-metallic coating, and the assessment corrosion, deterioration or other metallic properties [9~11]. An important advantage of eddy current testing compared with other testing methods is that there is no need for physical contact with the surface of the object under testing and further its measurement speed is rapid. Therefore, we try in this research to apply such a magnetic sensor in detecting deterioration or any performance due to corrosion.

3. Design of Detection System

3.1 Magnetic Sensor

As shown in Fig. 3.1, a solenoid having a conducting material at the longitudinal axis such as ACSR conductor is excited by an alternating current. It is assumed that there is no search coil or probe to detect dimension of the testing material. In this sensor, thus, the electromagnetic performance of the material would appear as the impedance variation of the coil itself.

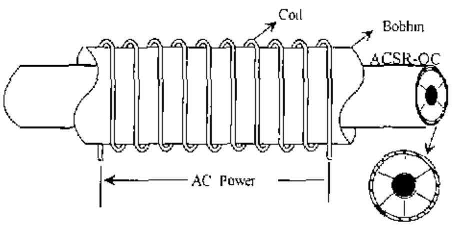


Figure 3.1 Solenoid coil and test conductor

If an alternating current is applied to a solenoid coil with a conducting material, eddy current is generated in this conductor with the same frequency. At this time, the magnetic flux due to eddy current reduces the main magnetic flux so that impedance of the solenoid coil varies with the electrical and magnetic property of the conductor. In general, magnetic sensor such a solenoid coil can be used in detecting the conductivity, permeability or diameter of metallic conductor as measuring the impedance of coil.

Magnetic flux generated by eddy current of conductor determines its magnitude according to the source frequency exciting the coil. Such magnetic property is explained by using the standard penetration depth of magnetic flux, defined as[11]

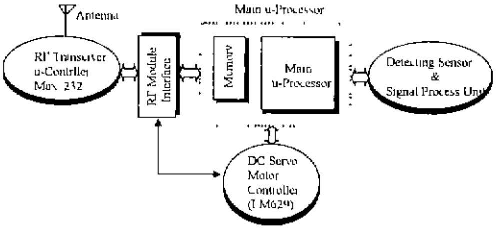
$$\delta = \frac{1}{\sqrt{\pi \sigma \mu f}} \qquad (1)$$

where σ and μ denotes the conductivity and relative permeability of the conductor, respectively and is the permeability in free space. As ACSR-OC comprises aluminum strands in the outer layer and galvanized steel strands in the inner layer, eddy current may represent complex shapes. Furthermore, it may be easily to describe the electromagnetic performance due to the eddy current in the conductor strands to a suitable representation.

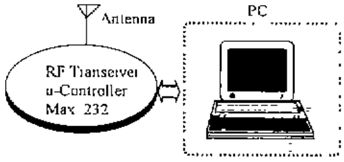
Under the assumption that the cross section of aluminum is changed by corrosion, its measurement using a solenoid coil would be possible for all frequencies. However, it is desirable to choose a higher frequency in order to increase measurement sensitivity or reduce signal noises in the sensor output. On the other hand, in measuring the cross section of a ferromagnetic rod like galvanized steel strand, the sensitivity may be good in a high frequency, but its detecting output is always dependent upon choosing the exciting frequency. In other word, cross section area of aluminum conductors and output of the solenoid coil with them would hold good correlation for all the exciting frequencies. However, the correlation between galvanized steel strand and impedance for them are relied on the frequency. For the simplicity of discuss, impedance analysis for eddy current sensor is omitted here[11,12].

3.2 Detecting System Design

An encircling coil as shown in Fig. 3.1 can not be applied to realistic corrosion detector system because of limiting its structure Since the sensing coil could be clipped around strung conductors to be able to detect corrosion along the conductors, it has to be split into two parts In this research, we propose a different type of sensing head that can be easily implemented by only one connector. For the purpose of this, the coil is designed to a PCB flexible cable. Its electrical performance always keeps stable and there occurs hardly any mechanical fault because it is protected to a laminated cable.



(a) overhead corrosion detector

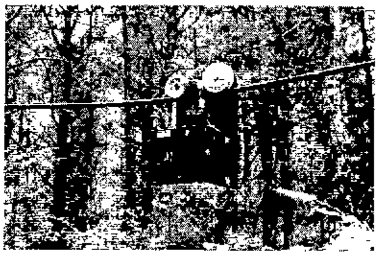


(b) ground control unit

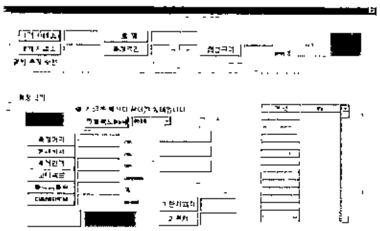
Fig. 3.2 Schematic diagram for corrosion detector

The detector system consists of a corrosion detector to the air and a control unit operated by inspector on the ground. The corrosion detector has the capabilities such as detecting sensor output, transforming it to digital data, driving a servo motor, counting distance and transmitting measurement data to the control unit and so on Fig. 3.2 shows the block diagram of corrosion detector unit and ground control station in the designed corrosion detector. Especially, in the corrosion detector shown in Fig 3.2(a), it mainly consists of sensor and its head, analog signal processing part, master microprocessor, motor driver and controller and a RF transceiver. In addition to these, there is a DC power supply set.

Sensor coil is excited by a constant current source with 100[㎑] sinusoidal signal and its amplitude is selected to 10[㎃]. As the output changes for corrosion of conductors are usually very small, it is necessary to amplify it to a suitable level and to convert it to DC voltage, which operations perform in signal processing unit. Measurement data transmit to the master processor and this data including distance data send to the ground control unit by an UHF RF transceiver which has 4,800[baud] and to distance about 100~200[m].



(a) overhead corrosion detector running on the conductor



(b) measurement program

Fig. 3.3 Implemented detector system

The corrosion detector moves along the conductor by a small size servo motor which can gives forward and reverse direction and speed control within 15[m/min]. The detector unit operates by the power supplied to batteries. Fig. 3.3 shows the developed system running on the conductor. Control unit at the ground comprises a lap-top (or notebook) computer and a RF transceiver. The computer has the capability of controlling the corrosion detector, receiving measurement data continuously and analyzing data.

It is necessary to design suitable programs in the corrosion detector system operated in practice field. In master processor, an assembly program is designed in order to measure sensor outputs, to control and communicate the detector system. Furthermore, to operate the detector on the ground, measurement and analysis programs are designed by using Visual C++.

4. Experiments and Discussions

4.1 Performance for Fault Conductor

To verify the utility of the implemented detector, a conductor with its length, 12[m], was tested. First, the prepared conductor was a sample under new condition which has several artificial faults on the surface of aluminum strands in the outer layer. Several faults with broken wires shows in distance, 0~4.5[m]. where a~e demonstrate such positions as cutting off one aluminum strand in ACSR-OC by 10,20,30,40 and 50[mm] lengths in order. And distance, 5.3~8.7[m], shows corroded parts(f~j) by hydrochloric acid solution for 1,5,10,20 and 30 minutes. Furthermore, positions, k~n are abrasion parts of aluminum strand.

Fig. 4.1 shows the output characteristic to be measured by the implemented system. From the outputs, abrasion for half of an aluminum strand may not be inspected by the corrosion detector but faults for broken wires or corroded strands can be detected correctly to some extend. As you can see from the result, the output of detector is linearly proportional to the variation of cross section area of aluminum strands. In general, it can be shown that there exist measurement deviations of 20~30 steps in the sensor output. Such deviations may occur due to dynamic perturbation of wheels, test sample position errors or practical local corrosion performances. Since the corrosion detector is designed to give an information for any severe local corrosion, despite of existing such deviations, it is sufficient to assess whether the test conductor is severely corroded or not.

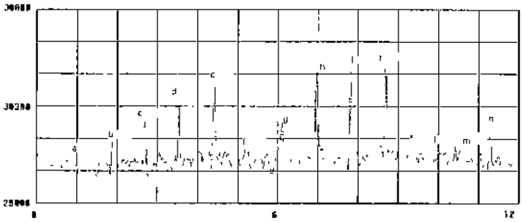


Fig. 4.1 Response for the test conductor

When an inspector uses the developed corrosion detector in the field, there are several operations to choose measurement parameters such as motor speed(v=0~15[m/min]), mea- surement distance (conductor length(L=0~655[m])), sampling interval (d=1~255[cm]) and average sample number(n=1~255) These parameters are given to default values(v=10[m/min], d=2[cm] and n=50) a priori before the inspector changes them. Since this system has the capability of RF data communication at over 100[m] distance, the operation parameters must be selected such that the corrosion detector can be operated properly for various measurement environments.

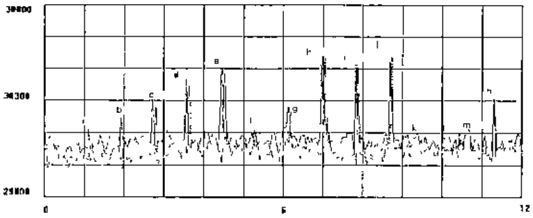


Fig. 4.2 Variations of sampling interval
(v=10[m/min], d=1,2,3[cm] and n=50)

Fig. 4.2 demonstrates the outputs when sampling interval is changed as 1,2 and 3[cm]. As the sensing coil implemented a flexible PCB cable is designed to having its length, 1[cm] and diameter, 3[cm], resolution of data is directly dependent upon these parameters and measurement interval. However, it can be known from Fig. 4.2 that the data shows relatively good resolutions, despite of varying sampling interval.

Fig. 4.3 shows the output of detector when varying motor speed as v=2,5 and 10[m/min] where d=2[cm] and n=50. From this result, we can know that the outputs of the implemented corrosion detector system may depend upon the measurement velocity. However, faults are detected on correct positions. Hence, under the assumption of constant motor speed, the degree of faults could be properly quantified.

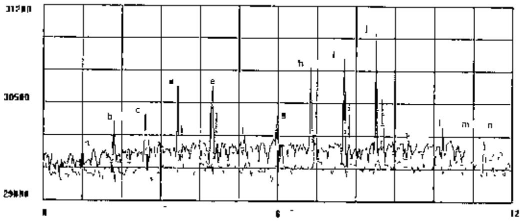


Fig. 4.3 Variation of motor speed
(v=2,5,10 [m/min] , d=2 [cm] and n=50)

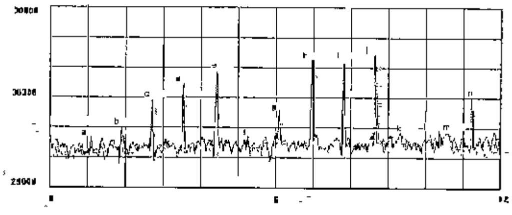


Fig. 4.4 Variation of averaging samples
(v=10 [m/min] , d=1 [cm] and n=50,100,200)

Fig. 4.4 demonstrates the result when motor speed and measurement interval are 10[m/min] and 1[cm], respectively, and average sample number is chosen by 50, 100 and 200. In general, sampling number can be adjusted to the range 1~255 by an integer and if it is increased, noises or harmonics included in the output signals would be reduced. Such property can be applied to inspecting local corrosion concentrated on a part of aged conductor with low speed and short measurement interval. However, as shown in Fig. 4.4, its behavior may not affect the output signals.

In general, the response of the zinc layer on the steel core may not appear to the eddy current variation of the sensor coil. As mentioned above, ACSR-OC comprises aluminum strands with smooth body and then, the zinc loss of steel core may be hardly affected to the output of corrosion detector despite of its serious status. However, it may not be a crucial issue provided that the detector could give a suitable output for aluminum strand corrosion. Although aluminum strand inside begins to corrode after all zinc layer would be removed off, the corrosion detector can present a response corresponding to the corrosion of aluminum strands at that time.

4.2 Field Tests

Based on the experimental results obtained in the laboratory, an aged ACSR-OC conductors in the field have been examined. It is seemed that the conductor and its polyethylene coating may not be any corrosion or faults before measuring it by the detecting system. Fig. 4.5 illustrates the detecting data for one conductor. In this result, there exists one location where its output appears higher than any other outputs for the test conductor. It means that these points may be progressed more serious or lead to some faults. As

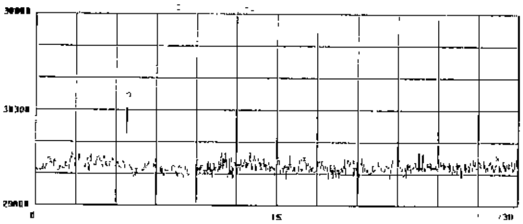


Fig. 4.5 Measurement data for an aged ACSR-OC

the result from visual inspection, it is verified that there exists any damage on the polyethylene coating and aluminum strands in the inner layer of ACSR-OC may be somewhat deformed.

We have discussed the corrosion detecting system to detect severe local corrosion of aged overhead ACSR-OC conductors It would be improved to a useful instrument to have reliable information to the line inspector. Of course, the developed corrosion detecting system may still have several difficulties or troubles to cope with, but it can be shown that the implemented detecting system has good effectiveness for giving an early warning before any aged conductor may lead to be broken.

5. Conclusions

This research deals with a design of nondestructive test system to diagnose deterioration of HV overhead distribution lines and some experimental results. Deterioration mechanisms are somewhat different to ACSR and ACSR-OC conductors used in distribution lines due to their structures. However, it is obvious that most of aged conductors would lead to local corrosion or change of cross section area of the conductors A detecting system with a solenoid eddy current sensor is designed and examined to detect the change of cross section area. Through some experiments for several artificially corroded conductors and aged conductors, it was shown that such corrosion detector with an eddy current sensor can readily be utilized in estimating the diameter change due to deterioration in overhead distribution lines and in giving an early warning or inform before severe aged conductor may lead to failure.

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