IEEE P1617/D4.0
Draft Guide for Detection, Mitigation and Control Of Concentric Neutral Corrosion in Medium Voltage Underground Cables

Prepared by the Cable Neutral Corrosion Working Group
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1. Overview

Since 1960, large quantities of unjacketed underground distribution cable have been installed direct buried and in conduit.

Uncoated and coated copper concentric neutral wires and straps (called only neutral wires in this guide) have been used for the metallic shield of these cables. The integrity of the neutral wires is important because, connected to the grounding system, these wires provide a path for the flow of charging, load and fault currents, and limit touch potential.

The concentric neutral wires, in direct contact with the environment, are susceptible to corrosion.

1.1 Scope

The primary focus of this guide is unjacketed, underground distribution cable installed direct buried or in conduit. The causes of corrosion in cable concentric neutral wires and straps and the methods available to detect this corrosion are described. The purpose of the concentric neutral and consequences of significant loss of the concentric neutral are discussed. Recommendations are made for the mitigation and control of the cable concentric neutral corrosion.

1.2 Purpose

This document is to provide guidance for the detection, mitigation and control of corrosion in medium voltage cable concentric neutral wires and straps.

2. References

1) ICEA S-94-649 “Concentric Neutral Cables Rated 5 - 46kV”
2) ANSI C2 “National Electrical Safety Code”
3) IEEE 532 “IEEE Guide for Selecting and Testing Jackets for Underground Cables”

3. Definitions

CIC: Cable In Conduit. A term that applies to a cable preinstalled in a continuous conduit. In this manner the CIC is buried together as a unit in a single operation.
URD: Underground Residential Distribution
UD: Underground Distribution

4. Purpose of the concentric neutral wires

The concentric neutral wires serve several purposes including; providing a path for the flow of charging currents, providing a path for the flow of fault currents, reducing the touch and step potential in the event of a dig into the cable and if of sufficient size, number and conductivity, to provide a path for the return currents (system neutral).

4.1 Path for flow of charging currents

The conductor polymeric stress relief layer (semiconducting or high relative permittivity, see Reference 1) and insulation polymeric stress relief layer separated by a layer of insulation comprising a medium or high voltage cable defines a capacitor. When alternating voltage is placed on the central conductor, charging current is induced in the insulation stress relief layer by capacitive action.

In order to provide a defined path for the flow of these charging currents, a metallic shield component is applied over the insulation stress relief layer and grounded at one or several points. The charging currents are relatively small and a small conductor would serve this purpose.

4.2 Path for flow of fault currents

The presence of a metallic conductor in the ground circuit necessarily results in this conductor being subjected to fault current requirements as well as the charging currents. The conductor must be large enough not to be damaged or result in cable damage due to the fault current flow. In fact, it is very important that this conductor remain intact as its impedance is used to determine the maximum and probable minimum fault current that will flow for different types of faults. This information is used to size protective devices such as fuses, reclosers and breakers protecting the circuit.

4.3 Reduce step and touch potential

The metallic shield conductor also provides a degree of personnel safety in the event of a dig into the cable by limiting touch potential on the object touching (digging into) the cable and the step potential experienced by nearby workers. The impedance of this conductor is a large determining factor in the dig-in potential that will be developed.

4.4 Provide a system neutral

In the case of electric utility multi grounded wye circuits, the ground fault currents are commonly high enough to require a significant amount of metal in the shield conductor. Thus, it was convenient to provide a system neutral as well in the URD/UD cable design. Of course a separate wire could be used to provide for the neutral and this is commonly done in industrial cables where fault current requirements tend to be lower. The point is that the charging current and fault current requirements must be integral to the cable while the neutral or load return requirements can optionally be a part of the metallic shield or as a separate conductor external to the cable.

4.5 Types of concentric wires

The most common concentric neutral in URD/UD cables has been comprised of a number of copper wires concentrically applied as a helix over the non-metallic insulation stress relief layer (shield). However, flat copper straps have also been used. In the past, it was common to utilize coated (lead-tin alloy) wires and straps, to facilitate solder connections and for what was then believed benefits to reduce corrosion. Limited (experimental) attempts were also made to use iron coated copper (for corrosion) and aluminum (for cost).

5. Consequences of significant neutral corrosion

5.1 Cable failures caused by loss of metallic shield component

The loss of the defined path of low impedance for the flow of charging currents results in the insulation shield capacitive "plate voltage" driving currents in "unintended" paths. This includes the surface of the non-metallic shield layer with significant heating and erosion (tracking) of the layer, ultimately exposing the insulation. Small air gaps between the non-metallic shield surface and a conducting path might result in arcing with pitting and burning of the non-metallic shield. The result is concentrated stress and localized heating resulting in cable failure.

5.2 Improper operation of protective devices

The significant or total loss of the metallic shield layer results in a higher ground circuit impedance than anticipated. This can result in missed protective coordination, which can in turn result in more extensive damage associated with the fault and possible difficulty in locating the fault and making repairs.

5.3 Stray currents and interference

The significant loss of the metallic shield/neutral may result in charging current, fault current and neutral current flow on the conducting paths presented by adjacent metallic facilities. The higher impedance can also present a much higher touch potential in connection with a dig in and stray system voltages.

5.4 Effects on power quality

Significant loss of the neutral can result in voltage unbalances due to the uneven and elevated impedances in the neutral circuit. These unbalances can result in high voltages, low voltages or a mix of both from phase conductors to the neutral.

5.5 National Codes

National Codes such as the National Electrical Safety Code (NESC) (Reference 2) are commonly referred to when looking at the requirements associated with the concentric neutral. The NESC does discuss such things as "insulation shielding" and "effectively grounded". Also discussed are requirements to design the shielding material to either resist excessive corrosion under expected operating conditions or to protect the shielding material. Jackets are referenced as a means of protecting the shielding. An apparent conclusion from reviewing the codes is that the cable shield is no longer considered functional if it has experienced excessive concentric neutral corrosion and laying a separate neutral conductor in the vicinity of the cable with excessive neutral corrosion does not make it functional.

6. Causes of neutral corrosion

Metallic corrosion may be described as the return of a metal to its natural state in the environment. Many elements are found in their natural state as oxides and sulfides, requiring the input of energy for their conversion to useable metals. These metals will then tend to use this internal energy to revert to their natural state through the process of corrosion. In effect, the energy used for extracting the pure metal from its ore state now becomes the force driving an electrochemical (corrosion) reaction with the surrounding environment.

The energy inherent in refined metals can be measured as an electrochemical potential. When placed in a corrosive (conductive) environment, the difference in potential between two different metals can be measured using a voltmeter. The amount of electrochemical driving force present in a metal can be considered a function of the amount of energy required to extract the metal from its ore. Thus magnesium, which requires a significant amount of heat energy for refinement, typically has a higher electrochemical driving force than, for example, zinc or steel. As a result, magnesium will tend to corrode at a greater rate than other metals.

6.1 Galvanic corrosion cell

Galvanic corrosion occurs when two different metals are in electrical contact with one another. The metal with the higher electrochemical potential will typically become the anode. In the case of copper there are few commercial metals with a lower electrochemical potential, except possibly brasses, nickel, and passivated stainless steels. In addition, there have been cases reported of intermetallic compounds (i.e. Cu_3Sn) formed during hot tinning that are cathodic to the copper.

Galvanic corrosion involves the flow of positive ions (ionic current) off the surface of the metal at the anode. These ions typically combine with negative ions existing in the environment at the surface of the anode to form an oxide. Corresponding to the loss of positive ions from the surface of the metal is the release of negative electrons. These electrons flow (electric current) in the metal away from the anode region to a location (the cathode region) where they can combine with positive ions existing in the environment. In an acidic environment this cathode reaction is manifested as the generation of hydrogen gas (the combination of free hydrogen ions in the environment with electrons from the metal).

The corrosion mechanism therefore requires 4 elements in a galvanic corrosion cell as follows:

a) An anode material
b) A cathode material
c) A metallic connection between the anode and cathode for electron current
d) An environment connecting the anode and cathode areas for ionic current

The removal of any one of the above four elements brakes the galvanic corrosion cell and prevents corrosion from occurring.

6.2 Corrosion Cell set up on a single metal

The corrosion of a single piece of metal occurs when potential differences are established on its surface. For example, the surface of a steel sample will contain defects such as mill scale, scratches, microscopic inclusions, etc. Each of these locations will have a slightly different potential than other areas, hence potential differences will exist on the surface. When placed in a corrosive environment, these potential differences will provide the driving force for the steel to begin to oxidize. Locations with a higher driving potential where corrosion then occurs are termed anodes. Surrounding non-corroding areas are termed cathodes.

As in the two-metal galvanic corrosion cell, the corrosion mechanism therefore requires 4 elements to occur:
e) An anode area on the metal
f) A cathode area on the metal
g) A metallic connection between the anode and cathode areas for electron current
h) An environment connecting the anode and cathode areas for ionic current

The removal of any one of the above four elements would prevent corrosion from occurring.

6.3 Soil Corrosion

Soils of different composition will cause different rates of corrosion to occur on copper neutral wires. In addition to certain soil types being more corrosive than others, corrosion can also be promoted by the potential differences that exist when the cable passes through two different soil types. Copper is more susceptible to corrosion in acidic soils, such as those containing cinders. Resistivity measurements provide a measure of the relative corrosivity of different soil types.

6.4 Differential Aeration

Similar to different soil types causing corrosion, differences in the soil oxygen content contacting the surface of the copper neutral wires can result in potential differences. For example, a bare cable passing from a clay soil of poor aeration into a gravel soil of greater aeration will form a differential aeration corrosion cell, with the soil of low oxygen content becoming anodic. Similarly, water that migrates through jacket defects will also tend to form differential aeration cells in contact with the copper neutral wires, since there will be less oxygen present in the occluded area under the jacket compared to the surrounding soil outside of the cable jacket. Another common situation that causes differential aeration is where a cable goes into a conduit for a short run (such as under a street) and where the cable runs through a puddle of water caused by a low spot in the conduit. Differential aeration is also the root cause of the mechanism known as crevice corrosion.

6.5 Unintended or stray electrical currents

Stray electrical currents, typically from proximate DC sources such as welding generators, impressed current cathodic protection systems operating on adjacent foreign structures, transit systems, etc., can be picked up on the copper neutral wires. The location where the DC currents discharge from the cable will be anodic.

Compared to DC, the discharge of stray or circulating AC currents from the neutral wires has typically not been considered. However, ac corrosion can be a very serious concern for buried cables where high current densities may be present in the neutral wires - such as feeder cables or heavily loaded URD circuits. Current densities above 1.5 mA/cm^2 can result in rapid deterioration of metallic neutral wires since the passage of ac current between the earth and the metallic neutral wires shifts the potential to earth of these wires. Where the ac current density varies along the cable route, the related shifts in potential produce a long-line corrosion cell. Those areas where the potential is shifted more negatively are anodic to those areas where the potential is shifted less negatively. Rapid deterioration of the neutral wires may result.

6.6 The coating of concentric neutral wires

Under normal conditions, tin is anodic to copper and is applied to provide a sacrificial layer of protection. However, the thin layer of tin would be soon consumed in a corrosive environment, only temporarily delaying the corrosion of the copper neutral wires. The light tin alloying is more for the protection of the cable from atmospheric corrosion during outdoors storage.

7. Detection and evaluation

7.1 Visual inspection

A simple visual inspection system can be a cost-effective means of starting an overall program to detect and evaluate concentric neutral corrosion. Field maintenance and construction crews can perform this inspection whenever they are doing work on the underground system. The following is a sample of useful information that can be easily reported.

Location __________________________

Color of CN (check one)
Normal ____
Green Spots ____
Lots of Green ____
Red Spots ____
Other (describe) _________________________

Pitted Wires (yes/no) ______

Broken Wires (yes/no) ______

Other Comments ___________________________

7.2 Test concentric neutral using a time domain reflectometer (TDR)

It is often necessary to find neutral corrosion in a power cable. The degree of corrosion and location can be used by a utility to determine whether to repair, rejuvenate, or replace a cable. In some cases, the cable's neutral wires may be corroded beyond the utility's acceptable limit. A technique has been developed to use a TDR to detect the presence and relative severity of neutral corrosion.

Using a TDR, the severity of corrosion on each cable can be categorized by comparison to other reflections found on cables. The amplitude of the corrosion reflection is compared to the reflection of the far end of the cable and to splices. Research has shown that a cable may have up to 25% of its neutral wires broken before any recognizable anomaly appears on the TDR. This condition is referred to as level 1. Additional levels were assigned according to Table 1.

	Wires broken	Reflection size
Level 1	0% to 25%	No recognizable reflection.
Level 2	25% to 50%	Recognizable but smaller than a splice.
Level 3	50% to 75%	Larger than a splice but smaller then the end of the cable.
Level 4	75% to 100%	Larger than the end of cable reflection.

Table 1: Corrosion categories.

7.2.1 Connection technique

The TDR sends a pulse of energy (difference in potential between two conductors) into a cable being tested. Any time this pulse encounters anything that changes the impedance of the cable, some of the energy is sent back as a reflection. The amplitude of the reflection depends on the magnitude of the impedance change. The polarity is inversely related to the direction of the change. If there is no change of impedance along a cable length, no reflection will be created.

7.2.2 How TDR's find neutral corrosion

When a TDR pulse encounters the end of a cable that is not grounded, a very large positive reflection is created and almost all of the pulse energy will be reflected. If the pulse encounters a break in either the conductor or the neutral wires, it reacts like it came to the end of the cable and generates a large positive reflection. However, neutral corrosion often does not sever all of the neutral wires at the same point.

Each individual neutral wire carries only a small fraction of the pulse's energy. If the pulse encounters one severed neutral wire, only the energy on that wire is reflected as a positive reflection. The remainder will travel past the single broken wire undisturbed. The reflection from the single broken wire is extremely small and cannot usually be recognized. If more than one neutral wire is severed at the same point, the reflection from each returns to the TDR at the same moment. The energy in each wire's reflection will add to each other. If enough return at the same time, the anomaly becomes large enough to be recognized on the TDR. These anomalies have a very distinctive shape as shown in Figure 1. They are positive with no negative overshoot.

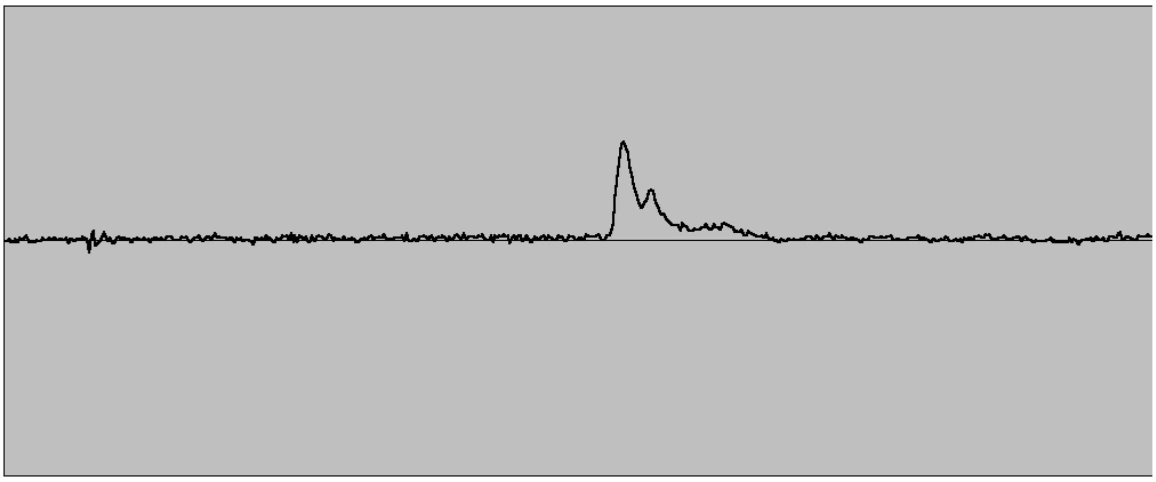

Figure 1: Example of a TDR trace indicating neutral corrosion

Individual severed neutral wires distributed along the cable length do not make reflections that can be recognized. However, the end of the cable reflection becomes smaller because of the loss of energy at each break, therefore the effect can be recognized as shown in Figure 2.

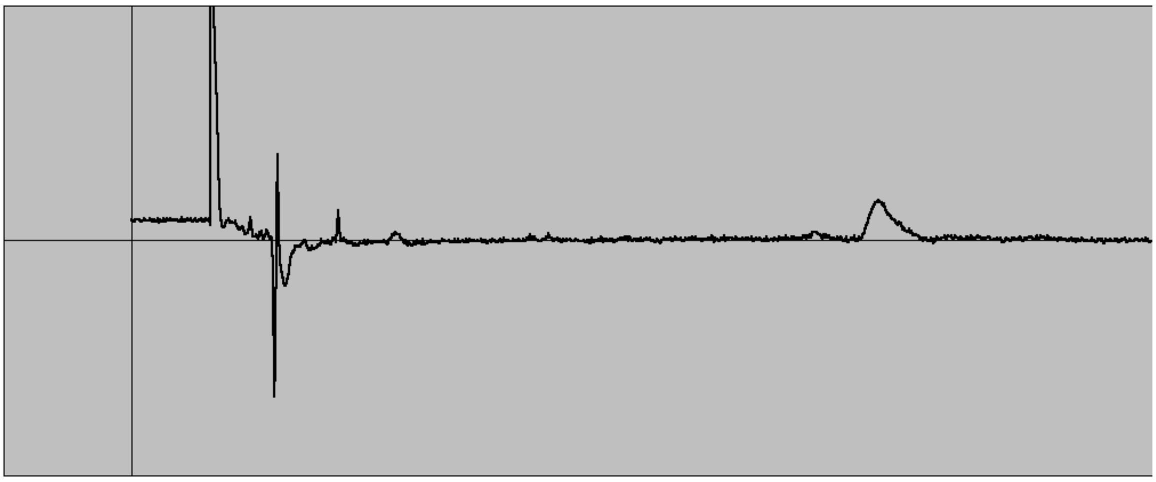

Figure 2: Example of a TDR trace indicating distributed corrosion

7.2.3 Advantages and Disadvantages

This method is relatively simple and can locate neutral corrosion as long as the several neutral wires are broken.

This test method requires cables under test to be de-energized. This can pose concerns such as potential customer outages, costs and labor involved with switching, as well us the time required to perform the test.

One broken neutral wire will not create a reflection that is recognizable on the TDR. The pulse must encounter several breaks at the same time for the reflections to combine and become recognizable.

7.3 Concentric neutral resistance measurement method

7.3.1 Introduction

Measurements of the resistance of a concentric neutral can be used to evaluate the integrity of the neutral. Neutral corrosion results in a reduction of the strand diameter at the point of corrosion. Points of corrosion may be localized in a small area or distributed along the cable. As the corrosion proceeds the neutral strands will eventually open. The overall resistance of the cable neutral does not increase significantly due to reduced strand diameters in localized areas. However, once they are open, the neutral resistance increases in predicable increments corresponding to the number of open strands. Comparison of the measured neutral resistance to the expected resistance of the neutral when new can be used to determine the number of neutral strands remaining intact. Since the transformer presents a very low impedance path to DC current, AC resistance measurements are normally used.

7.3.2 Measurement Technique

(NOTE: This method is patented #5,481,198 by Shashi Patel. I believe we need written permission to use this. If so Vern has Shasi's email address.) To measure the neutral resistance, it is necessary to pass a current though the cable neutral. Since the neutral strands are spirally applied to the cable, their inductance must be considered in determining the neutral resistance. The current flowing in the neutral, the voltage impressed across the neutral and phase angle between the current and voltage must be measured. A typical test setup is shown in Figure 3.

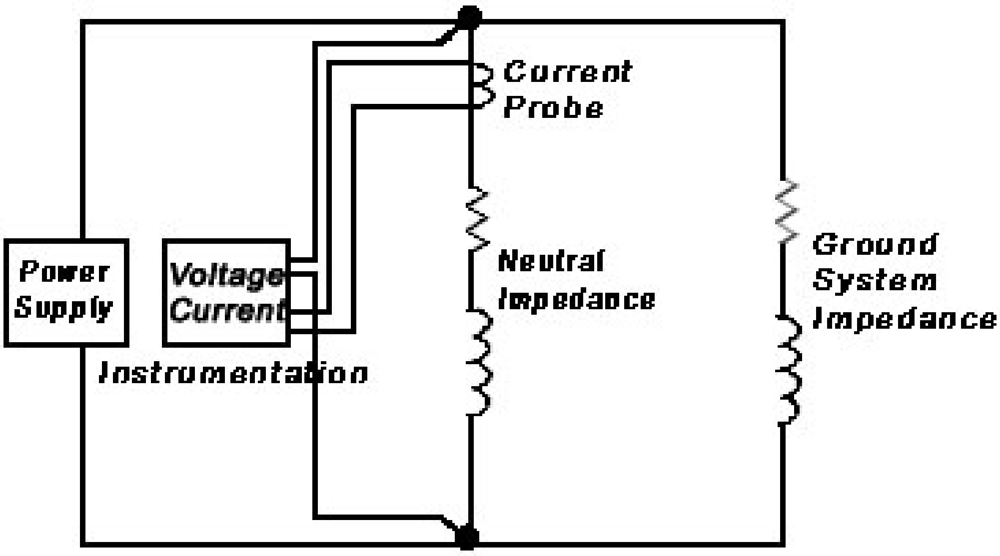

Figure 3. Typical Set-up for the resistance measurement technique

A power supply is used to inject a current into the ground system at the neutral terminations. Satisfactory results have been obtained using a 60 Hz power supply. If the neutral is left connected to the system ground, a portion of the power supply output will flow in the neutral being tested and remainder will flow though parallel ground paths. A power supply output of about 30 Amperes is normally sufficient for measurement of most neutrals while connected to the system ground.

The current flowing in the neutral under test can be measured using a current transformer to allow the neutral to remain connected. Tests can be performed with the cable energized. The voltage across the neutral terminations should be measured using a sensing lead to compensate for the resistance of the power supply leads. The neutral resistance can be calculated as follows:

$$R_n = V_n (\mathrm{Cos}\ ?\ )/I_n$$

Where: R_n = Neutral Resistance
V_n = Voltage across the neutral terminations
I_n = Current flowing in the neutral
? = Angle between V_n and I_n

The theoretical resistance of a neutral when new can be calculated as follows:

$$R_{new} = R_S (1.1)/N$$

Where: R_{new} = Resistance of neutral when new

R_S = Resistance of one neutral strand
N = Number of strands in the neutral

The constant of 1.1 accounts for the additional neutral length due to spiral application on the cable. Under applicable specifications, this factor may range from 1.05 to 1.13. The ratio of R_{new} to R_n provides an indication of the percentage of strands remaining intact. To simplify field measurements and data evaluation, it is helpful if the measurements and calculations are unitized per length. Resistances per 30 m of cable length yield numbers of convenient magnitude.

7.3.3 Advantages and Disadvantages

Neutral resistance measurements can be used to assess neutral integrity in instances where strands are broken at multiple locations distributed along the cable.

This test method does not require cables under test to be de-energized.

Neutral resistance measurements cannot be used to determine the location of the corrosion.

7.4 Surface Voltage Measurement Technique

7.4.1 Introduction

Breaks and corrosion of the concentric neutral wires can be detected by applying an alternating electrical signal across the phase conductor and neutral wires at one end of the cable while connecting the conductor and neutral wires together at the other end.

7.4.2 Measurement Technique

(NOTE: This method was formerly covered under U.S. Patent #4,839,598 by Calvert, Behrens, and Baver (Wisconsin Electric Power Company)). The patent has not been renewed.) To prepare for the test, cables to be tested are to be de-energized. The location of the cable(s) may be marked on the surface by conventional underground cable location means. Alternately for three phase systems, locating of the cables may take place during the test.

The test crew disconnects the phase conductor from the equipment at each end. The test crew also disconnects the neutral wires from any other cables and ground connections at both ends. At the remote end, a jumper is installed between the phase conductor and the neutral wires. At the near end, an alternating electrical signal is applied normally in the range of 500 Hz to 2000 Hz. If the route of three-phase system is to be determined during the test, the conductor of a cable not under test is grounded at the remote end. A signal is applied between the phase conductor and ground at the near end. Using a receiver tuned to the same frequency, the signal is traced above ground to locate the path of the circuit.

While the signal generator is injecting the signal to the cable, two metal probes are inserted into the ground on or substantially parallel to the path of the cable(s). The probes are inserted 75 to 100 mm below the surface at a predetermined spacing apart (usually around 30 m). A frequency selective voltmeter is used to measure the potential between the probes. When a change in voltage is detected between sequential probe locations, neutral corrosion or a broken neutral wire(s) is detected. The location of the problem can be pinpointed at this time by reducing the spacing between probes and monitoring the voltages at different locations.

The magnitude of differential voltage correlates to the degree of corrosion or number of broken wires. A differential voltage of two orders of magnitude or more is indicative of significant corrosion or several broken neutrals strands.

7.4.3 Advantages/Disadvantages

This method can pinpoint the location of localized corrosion or broken neutral strands.

As with the TDR method, this test method requires cables to be tested to be de-energized. It is also somewhat more time consuming that the TDR method and requires access to the land above where the cable is buried.

8. Control and mitigation

8.1 Cathodic protection using anodes and rectifiers

Corrosion can be prevented on a metal surface by making the entire surface a cathode. One example of how this can be achieved is by electrically connecting the metal to be protected to another metal of higher energy that is placed in the same environment. The metal with the higher electrochemical driving potential will become completely anodic, and the lower energy metal will become completely cathodic. An example of this galvanic cathodic protection would be connecting a piece of magnesium (anode) to a piece of steel (cathode). The soil would serve as the environment for ionic current to pass between the anode and cathode. Cathodic protection does not therefore stop corrosion; it only transfers the anodic corrosion reactions to a piece of metal that is intentionally sacrificed to protect a more valuable item.

Cathodic protection can also be achieved by connecting the metal to be protected (the cathode) to another metal upon which an electric current is applied (the anode). The electric current has the effect of increasing the electrochemical driving force of the anode metal. This impressed current method is analogous to having an array of many small anodes attached to a structure to be protected. As a result, this method can be used for the protection of large surface areas using a point source of metal, which is discharging large amounts of impressed current. Protection schemes, which use this active method, are generally known as rectified current methods. They are typically much more expensive than the passive, galvanic scheme described above.

Applying a cathodic protection solution to the problem of bare concentric neutrals on underground power distribution systems typically requires the services of a specialist who has developed simplifications and generalizations that allow the theory to be practically applied. Specialists may offer generalized solutions that can be applied with appropriate factors of safety to specific problems. For example, because of its ultimate position on the galvanic scale, magnesium or one of its alloys is nearly always used as the sacrificial anode in galvanic schemes. Also, in order to control the unknown electrolyte condition of the soil, most cathodic protection specialists or anode providers will supply anodes pre-packaged in a bag or box filled with a proprietary mix of bentonite and other constituents. This of course is an attempt to control the environment immediately surrounding the anode limiting the amount of environmental considerations that must be considered by the end user. Additionally anodes are pre-cast in a limited variety of sizes, reducing the amount of application optimization that is typically done.

A typical Cathodic Protection application would progress in the following manner. Using one of the methods discussed in Section 7, an active area of corrosion is located on the concentric neutrals of a direct buried, bare neutral cable. The corrosion site is excavated and inspected. If the corrosion is severe enough to warrant it, the neutrals are physically replaced with neutral material of adequate ampacity, and placed in such a manner to maintain both shielding and current carrying functions of the neutral. Even in the case where the neutrals are repaired, the location where the damage occurred is probably a corrosive hot spot and some corrective action is required to keep corrosion from proceeding again. The excavation area should be inspected for obvious causes (i.e. cable contact with other metallic structures). If the cause of the corrosion cannot be positively identified and corrected a sacrificial anode should be installed.

To perform this installation a technician will typically need to calculate the surface area of the neutrals along the total treatment length. Usually this would be the entire cable segment length, not just the area of corrosion. In addition, he will need to measure the resistivity of the ground soil in the area of concern. The soils resistivity is often taken to be a good indicator of its electrolytic properties. The resistance measurement is typically made using the Wenner 4-pin method. It is typical that anode selection can be made via a chart or consultation using these two data points. Once the anode is selected it is buried alongside the cable in a specified orientation. An electrical connection is made between the anode and the cable neutrals.

Continuing experience is demonstrating that the above application is fairly typical. It is common to find small lengths of corrosion on neutrals that are otherwise in good condition; such cases lend themselves well to the application of cathodic protection. Although the cost of this procedure can vary, a repair as described above should approximate that of a splice installation, with the costs of excavation exceeding the cost of materials. The cost/benefit analysis of performing this type of repair as opposed to replacing a cable would proceed on that basis. Clearly however cathodic protection will provide an increasingly important tool for system maintenance.

8.2 Cable replacement

The majority of all replacement cable is jacketed. The use of jacketed cable for replacement is driven by two factors - reduced potential for moisture penetration to protect the cable insulation from treeing and protection of the neutrals from corrosion. The use of jacketed UD cable began in the 1960's. With a greater understanding of the role of moisture in the treeing mechanism and widespread corrosion of the neutrals on unjacketed UD cable into the 1970's, the use of jacketed cable expanded. A 1993 survey of the 15-30 kV specifications for UD cable from the 25 largest investor utilities in the USA indicated that 96% specified a cable with a jacketed neutral. Of those specifying a jacket 92% specified an encapsulating jacket versus a sleeved jacket. The benefits and challenges in the choice between these two designs are covered in IEEE Guide 532 (Reference 3).

8.3 Use of jacketed cable

8.3.1 Introduction

The use of jacketed cable in a cable system has several benefits. Some of these are:

1) It can be used in a variety of soils with varying corrosion potentials
2) It provides mechanical protection
3) It allows for more effective testing for sheath faults.

There are two types of jacketed cable designs, encapsulated jacket and the sleeved jacket. Refer to IEEE guide 532 (Reference 3) for further details on jacket types and designs.

8.3.2 Soil conditions

Typically soil conditions vary widely over the service area in which cables are installed. Concentric neutral corrosion can occur when an unjacketed cable passes from one soil condition to the next, or when soil conditions in a particular location are more conducive to neutral corrosion. The use of jacketed cable eliminates the potential for long line differential aeration corrosion for example. The variation in cable depth that can occur during a buried installation can lead to corrosion cells if the soil type also varies with depth. Variations in soil pH, moisture content and the earth salts present along a given route are not corrosion issues when jacketed cable is used.

8.3.3 Preventing jacket faults

The jacket affords a significant amount of mechanical protection as compared to an unjacketed neutral cable. At times during installation, the cable may be given rougher handling than desired. The jacket better resists cable abuse and prevents damage to the working core of the cable. Backfill, for example, may contain small stones with sharp edges, which could compromise the integrity of the working core. Hand spades may damage the cable either during or after installation. The cable may be pulled into ducts or along the bottom of a trench and the resulting abrasion could decrease service life. Sometimes the cable may be forced around bends of minimum radius, which encourages the neutrals in an unjacketed cable to “birdcage” or kink. The jacket becomes a line of defense against such abuse.

By preventing contact between the soil and the neutral wires, the jacket removes one element of the corrosion triangle, the electrolyte, and thereby prevents neutral corrosion.

8.3.4 Testing for jacket faults

There appears to be no way to avoid a certain number of cable faults due to damage, cable defects, improper splicing procedures, or installation damage. Recognizing this, the use of jacketed cable allows the more efficient use of fault locating procedures. These procedures can be standardized for primary and secondary cables and eliminate the need for specialized crews; that is, a standardized procedure may allow its use by the lineman assigned to the field locations.

The earth gradient method can be used to locate faults on a jacketed neutral cable because the neutral conductor is insulated from the earth. When current is applied to a jacketed neutral, it can only flow to earth through a jacket fault and then return to the transmitter through the earth. This allows the search probes to detect the presence of current and locate the fault. With unjacketed neutral cable the current flowing out of the fault is attracted to the neutral such that the search probes cannot detect flow to the earth.

8.4 Economic considerations with existing and new cable

8.4.1 Introduction

For existing cable, the choice of remedy is generally limited to cathodic protection. There are three choices for cathodic protection, sacrificial anodes, rectifier and ground beds, or a combination of rectifiers and sacrificial anodes. The choice of anode and its service life become a major part of the economic picture. Typically the choice of sacrificial anode is between zinc and magnesium. Service life will then depend on the anode design and the soil conditions. Some elements of the cost for cathodic protection are described in the following clauses. Normally the costs of the alternatives are studied using the time value of money (net present value).

8.4.2 Corrosion surveys

To get at the soil condition, a corrosion survey is needed. Typically the following tests and examinations are recommended:

a) Measurement of concentric neutral potential to determine the degree of corrosion protection needed and to provide baseline data for the design and maintenance of the cathodic protection system
b) Soil resistivity tests to determine the locations where future cathodic protection systems are expected to be located, as discussed in Section 6.3

c) Stray current survey to determine potential stray current problems from other cathodic protection systems or electric railways, as discussed in Section 6.5.

8.4.3 Additional corrosion tests

Additional tests can involve inspection of the neutrals in bellholes, tests for stray currents, and a cathodic polarization field test involving the installation of a temporary cathodic protection system.

8.4.4 Cathodic protection design

There are many factors involved in the design of a cathodic protection system. Normally a firm involved directly in cathodic protection schemes is required to design the system. Some of the considerations are:

a) Determine optimum output of the cathodic protection system;
b) Determine optimum distances between the anode, the neutrals and other metallic structures connected to the neutrals;
c) Determine optimum distances between the anode and other metallic structures not connected to the neutral wires;
d) Design and install galvanic anodes if the use of sacrificial anodes will most effectively control the corrosion of the neutrals in localized areas. The advantages of this type of design are: a relatively uniform level of protective current flow, little maintenance, relatively simple installation, no detrimental corrosion to other structures, and low unit cost.
e) Design and install an impressed current system if the corrosion control is required in areas where the soil resistivity changes with time or where high resistivity soils are involved. The advantages with this type of design are fewer installation locations due to high output per installation; constant current available under changing environmental conditions, and the rectifier can usually be at a transformer pad location that is generally accessible to the utilities and/or their easement.
f) Design and install a combination sacrificial anode and impressed current system when both variable soil conditions and/or extreme corrosion conditions are encountered.

8.4.5 Maintenance of cathodic protection systems

The cathodic protection system generally requires yearly maintenance in which current output, the soil potential of the neutrals, and the soil potential of the neutrals midway between cathodic protection systems are determined. In addition interference tests should be run to determine if the neutrals are being affected by other cathodic protection systems. Data from the installation and maintenance of the system must be recorded so that evaluation of the efficiency of the cathodic protection system can be monitored over time.

8.4.6 Total cost for cathodic protection

To summarize, the total cost for cathodic protection involves the following cost factors:

a) Cost of Engineering
b) Corrosion Survey
c) Additional Corrosion Tests (Optional)
d) Cathodic Protection Design
e) Post Installation Adjustment
f) Capital Cost for Cathodic Protection
g) Equipment
h) Installation
i) Cost of Maintenance
j) Present Value of Estimated Cost of Monitoring for X years
k) Training and Equipment for Staking Crews to Measure Soil Resistivity

This cost converted into a conductor unit (foot or meter) must then be compared to the replacement cost of the cable. Generally cathodic protection is 10 to 15 times lower in cost than replacement.

8.4.7 New system cost

For a new system the choice is between jacketed and unjacketed cable. Typically jacketed cable is 5% more than bare neutral, unjacketed cable. For the jacketed cable the choice is between encapsulated and sleeved designs. For the sleeved designs the choice is between water blocked and non-water blocked. Since the decision to use jacketed cable is pretty much the norm for most utilities, the choice is really between encapsulated and sleeved jackets with water blocking. The difference in cost to use sleeved versus encapsulated is approximately 10-15% more.

From an overall economic point of view the choice of jacketed cable is the most cost effective way to address the concentric neutral corrosion issue. The cost of a jacket is less than 10-20% of a cathodic protection system, and is significantly lower than replacement cost.

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