Neutral Corrosion-Significance, Causes & Mitigation

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I. Introduction

This paper reviews six neutral corrosion issues and provides data to shed some light on the overall significance of the phenomenon. The paper draws upon IEEE 1617 (IEEE Guide for the Detection, Mitigation, and Control of Concentric Neutral Corrosion in Medium Voltage Underground Cables) [1] and encompasses and expands upon the 1617 scope.

This paper defines the purposes of the neutral, the consequences of excessive corrosion, the causes and chemical dynamics of neutral corrosion, dimensions the severity of the issue in North America, describes how to detect neutral corrosion, and provides options to address neutral corrosion once discovered. The paper also suggests areas for future work to provide guidance to circuit owners on the likelihood of neutral corrosion issues in their service territories.

Figure 1. The neutral bleeds charging currents induced on the shield.

II. Neutral Purpose

The neutral has four primary purposes. The first purpose (IEEE 1617 4.1) is to bleed currents induced onto the cable shielding. This concept is illustrated in Figure 1. The cable is not a particularly good capacitor as the distance between the two electrodes is large and the dielectric constant of the insulation is quite low – about 2.3 for PE cables. Very little neutral conductor is required to bleed these small charging currents.

The second purpose (IEEE 1617 4.2) is to provide a low impedance path for fault currents. This fault current path is particularly important for protective devices such as fuses and circuit breakers to operate as quickly as possible. Figure 2 shows a cable fault. The melted copper illustrates the high current that jumped from the conductor to the neutral. If the neutral is corroded, the fault current will find alternate paths including the soil and other nearby utilities. Where the impedance is very high, protection tripping might be delayed.

The third purpose (IEEE 1617 4.4 – Note that we will circle back to 4.3 shortly.) is to provide a system neutral for return current. Except for well balanced three-phase loads, the return current can approach the conductor current.

Figure 2. Fault currents follow the lowest impedance path to ground. Ideally the neutrals provide that path.

Figure 3. Neutral shielding have been manufactured with a wide variety of configurations.

Figure 3 provides a sampling of a variety of neutral configurations that have been employed.

The fourth purpose of the neutral is to mitigate the consequences of a failure to successfully accomplish purposes 4.1, 4.2, and 4.4. A properly functioning neutral all but eliminates step potential and touch potential. Step potential, illustrated in Figure 4, is a difference in voltage between two feet – human or animal. Human step potential is quite low because our foot steps are close together. Potential unpleasantness is usually mitigated by shoes with nominal dielectric properties. Larger animals such as cows or horses have a greater distance between their feet and don't wear shoes. The charging current is too small to create any meaningful step potential, so return current and fault current are the primary causes of step potential. An ellipsoid of non-detectable or very close to zero potential will form around the damaged neutrals anchored at both vertices by a well-functioning neutral. If the distance between the two well functioning electrodes is great enough **and** the soil electrical conductivity is low, the ellipsoid may intersect the surface as depicted in Figure 4. As will be shown later in this paper, the length of corrosion sites is usually limited to less than about a meter. Consequently, the probability that human or animal-detectable voltage gradients exist at the surface is quite low. That is not to say that sensitive instruments cannot detect step potential, but rather that the potential is low enough not to evoke undue concern.

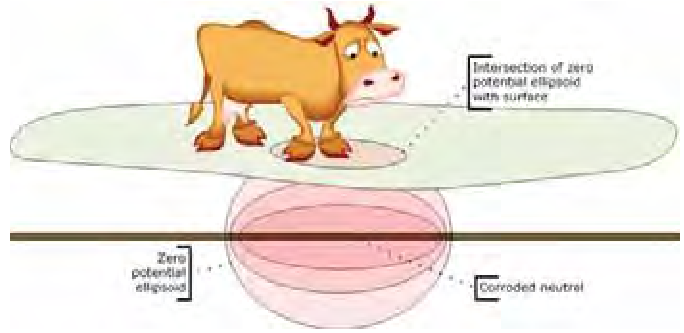

Figure 4. The cow's hind legs are at zero potential and her front legs have a non-zero potential. If the potential difference is high enough, the cow may suffer discomfort.

III. CONSEQUENCES

There are 5 potential consequences identified by 1617 for cables that suffer significant neutral corrosion. First, Section 5.1 explains that the loss of the defined, low-impedance path for charging currents may result in currents along "unintended" paths. The surface of the non-metallic shield layer may suffer significant local heating and erosion of the layer by arcing. Such events may ultimately expose the insulation. The result is concentrated electrical stress, localized heating, and potentially cable failure. Figure 5 provides two views of an example of a cable which failed by this mechanism.

Figure 5. Holes in the cable insulation shield were created by arching from compromised neutrals. The erosion reached the insulation; water trees and electrical trees formed. Images courtesy of Cable Technology Laboratories.

Section 5.2 explains that significant or total loss of the metallic shield layer results in increased circuit impedance. The increase in impedance may interfere with protective coordination, which may in turn result in more extensive damage associated with the fault. Significant loss of neutral can also make it more difficult to locate the fault as thumpers work best with a low impedance return.

Section 5.3 teaches that significant loss of the metallic shield/neutral may result in charging current, fault current, and system current flow on conducting paths presented by adjacent metallic facilities and the surrounding soil. The higher impedance increases step potential, touch potential and stray system voltages.

Section 5.4 indicates that significant loss of the neutral can result in voltage unbalances due to the uneven and elevated impedances in the neutral circuit. Unbalanced impedance can result in high voltages, low voltages, or a mixture of both from phase conductors to the neutral.

Section 5.5 states that National Codes, such as the National Electrical Safety Code® (NESC), are commonly referred to when looking at the requirements associated with the concentric neutral. The NESC does discuss the meaning of "insulation shielding" and "effectively grounded." IEEE 1617 interprets the NESC as follows: "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."

	1986	1987	1988	1989	1990	1991	1992	1993
AEIC Cable Report								
Failures	3,363	3,299	3,195	3,697	3,277	3,427		
Reported Mileage	47,804	49,078	54,399	54,790	50,854	51,876		
Failure Rate	7.0	6.7	5.9	6.9	6.4	6.6		
IEEE ICC Task Force 6-21 Cable Neutral Corrosion								
Neutral problems		612	468	552	539	154	209	94
Reported Mileage		89,949	78,494	80,225	78,346	62,475	58,960	32,100
Failure Rate		0.68	0.60	0.69	0.69	0.25	0.35	0.29
Ratio		9.9	9.9	10.0	9.4	26.8		

Figure 6. Survey comparison – AEIC Cable failure vs. IEEE/PES/ICC Task Force 6-21. Neutral issues are at least an order of magnitude lower than general cable reliability issues.

Dielectric failures of cables due to neutral corrosion as suggested by IEEE 1617 5.1 and of which Figure 5 is an example are not a common occurrence. In 1994, the ICC task force that was the forerunner of the IEEE 1617 writing effort published a seven-year survey of circuit owners reported neutral problems. There was a 5-year period where that survey overlapped with a similar survey called the "AEIC Cable Report." Those two reports are summarized in Figure 6 side-by-side. The table compares the reported incidents of cable failure to the reported incidents of neutral problems. The ratio of cable failures to neutral issues varies to between 10 and 25. Neutral corrosion is at least 10X less significant than cable failures. The Figure 6 table was published by Bob Gurniak of Pennsylvania Power & Light in T&D World in 1996 [2].

IV. Causes

There are five causes of neutral corrosion identified in IEEE 1617 – 6.1 through 6.5. The first, galvanic corrosion, involves the flow of positive ions (ionic current) off the surface of a first metal at an anode. These positive 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 electrons. These electrons are transported in the metal toward the anode region away from a second metal. The second metal is a cathode where the electrons can combine with positive ions existing in the environment.

Galvanic corrosion is not a significant phenomenon with power cable neutrals, because copper is a very cathodic material and is generally not bonded with metals that are more cathodic. Figure 6 presents a galvanic series of common metals and alloys. Only stainless steel is cathodic to copper.

Like galvanic corrosion, two other identified corrosion causes are not significant in most cases. The first of the two other identified causes is single metal corrosion (1617 6.2), where potential differences on the copper are created by microscopic defects like mill scale and scratches. These microscopic defects cause microscopic corrosion and have no meaningful impact on the neutral performance.

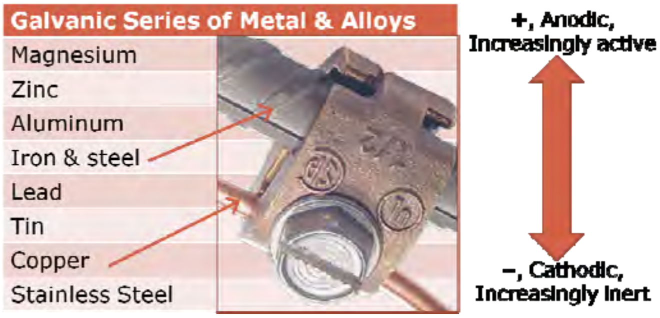

Figure 7. Except for stainless steel, other metals such as iron and steel are less cathodic than copper, and hence bonding copper to rebar poses no risk to the copper. Magnesium and zinc make particularly attractive sacrificial anodes.

Stray currents are identified by 1617 6.5 as a potential source of corrosion and indeed stray currents are a potential, but an insignificant corrosion source. Exposed neutrals in close proximity to DC current sources such as natural gas pipelines with active cathodic protection, DC powered railways, and welding shops should be isolated from these stray currents. In 25 years of experience with neutral corrosion detection, the author has experienced this circumstance only a single time.

The most significant causes of neutral corrosion are identified by IEEE 1617 as 6.3 and 6.4, namely soil corrosion and differential aeration. For the balance of this section, we will focus on these two "flavors" of corrosion as they likely account for more than 99% of all significant neutral corrosion. Corrosion in all its forms requires all of five elements. Figure 8 shows these five elements schematically.

The first element required is an anode. The anode is that portion of the neutral where the chemical potential induces a relative positive charge. The second requirement is a cathode, which is a portion of the copper with a chemical potential that induces a relatively negative charge. The word "relative" in the previous two sentences is mutual – that is, the anode is more positive than the cathode and the cathode is therefore less positive than the anode. The absolute voltage of the anode and cathode may be either positive or negative or the anode can be positive and the cathode negative, but the anode must be **more** positive than the cathode.

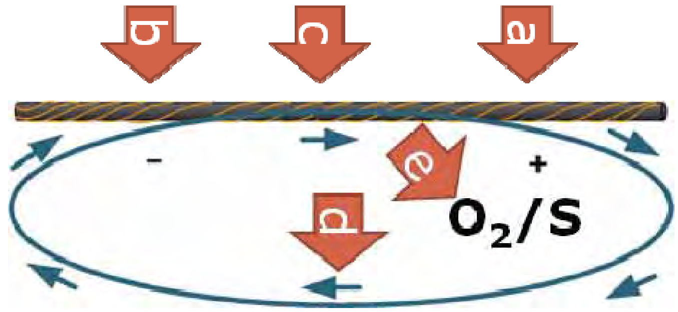

Figure 8. The following 5 elements must be present for corrosion to occur:

- **a. Anode (+)**
- **b. Cathode (–)**
- **c. Metallic connection**
- **d. Environment to transport ions**
- **e. Oxidizer**

For the two predominant causes of neutral corrosion, namely soil corrosion and differential aeration, differences in the soil chemistry and/or differences in the concentration of oxygen create the chemical potential differences along the cable length.

There are a wide variety of conditions that can create the necessary chemical conditions in the soil. We will consider a few of the more common scenarios to illustrate the concepts.

Scenario 1: Direct-buried cable enters a conduit for a road crossing. Oxygen is more prevalent in the conduit than in the adjacent compacted soil. Differential aeration creates an anode and a cathode.

Scenario 2: A fault occurs on a 38-year-old direct-buried cable and a pit is dug to repair the fault. New standards require the use of select backfill, which does not have the same soil chemistry as the native soil and compacts differently too. Differential aeration and/or soil corrosion occur near the interface between the native soil and select backfill.

Scenario 3: A cable traversed down a hill and the soil transitions from upland aerobic conditions to swampy anaerobic (i.e. little or no oxygen) conditions. Soil chemistry and the availability of oxygen changes as the cable enters the swamp. Differential aeration occurs where the cable transitions from upland to lowland.

Scenario 4: A direct-buried cable runs underneath a golf fairway and then across an unimproved field. The fairway is well watered, regularly doused with nitrogen and phosphate fertilizers, and well aerated. Differential aeration and/or soil corrosion occur near the interface between the fairway and unimproved field.

Scenario 5: A cable runs in a duct and the duct includes a low spot along its length. The low spot fills with water when there is rain and then slowly dries out during the dry season. For portions of the year, part of the neutral is submerged and adjacent portions are dry. Differential aeration and/or chemical corrosion occur near the interface between the submerged and unsubmerged portion of the cable. The interface between the submerged and unsubmerged portion of the cable is not static – it moves up and down with the seasons. Corrosion occurs at the interface and because the interface moves, the corrosion occurs over a substantial length of the cable.

It is easy to imagine many other such scenarios, but they would all share one common element. These modes of corrosion all occur at interfaces. In scenarios 1-4 where the cable is direct buried, the interfaces are quite static. Because they are static, the corrosion is highly localized. In contrast, Scenario 5 may lead to distributed corrosion.

Let's turn our attention now to the last three required elements of Figure 8. Element "c" is an electrically conductive connection between the anode and the cathode. This connection is the neutral itself. If the neutral corrodes sufficiently, corrosion must halt, because the circuit is disrupted.

Element "d" is a sufficient environment for the transport of ions. That is a fancy way of saying the soil has to be wet. At one meter depth where power cables are typically buried, the soil is generally wet throughout North America throughout the year as shown in [3].

The fifth element, "e," is oxidizer. The most common oxidizer is oxygen. A second oxidizer, worth mentioning because it occurs in anaerobic marine environments, is elemental sulfur. Setting aside deep ocean applications, oxygen is generally available at one meter of depth in upland soils, but becomes less available in swampy soils. The flora and fauna living in the soil compete for oxygen and hence the concentration of oxygen generally decreases with depth. Cables that are buried in perpetually wet soils that support bountiful microbial life often suffer no corrosion, except where the cable emerges from the anerobic environment near a termination.

The nature of these five required elements provides guidance on the how corrosion progresses over decades of service life. Consider that the current flow in the loop depicted in Figure 8 is determined by Ohm's Law.

$$I = E/R \qquad (1)$$

Consider the forces of nature and man that impact the numerator if Equation 1. First, in order for oxidation of the copper to occur at all, the potential must be above a threshold voltage. Second, to the extent current flows around the loop at all, it is using up the chemical potential that is available. The corrosion process is like a battery: as the chemical reactions take place that drive the electrical current, the chemical potential is decreased. The only way around this is if the battery can be recharged. While it is possible to over-fertilize a portion of landscaping, it is actually quite difficult to have a significant impact on the chemistry at 1 meter in depth. There is, however, one readily rechargeable mechanism – differential aeration. Where two very different soil types interface, the oxygen concentration can be steadily recharged by diffusion and other mass transport phenomena from the atmosphere. It is for this reason that differential aeration is likely the predominate cause of neutral corrosion.

The third factor that impacts the numerator of Equation 1 is the Second Law of Thermodynamics or entropy. Even in the absence of the current flowing in the loop of Figure 8, the factors that make the electrochemical potential higher near the anode and lower near the cathode will mitigate toward equilibrium. This is why even an unused battery loses voltage over time.

With the possible exception of differential aeration these factors drive the electrical potential down over time. A reduction in the numerator means the current too will decrease.

Consider how the denominator of Equation 1 is likely to change over the decades. There are two effects, which both increase the resistance over time. The first is by design – copper was chosen to be in contact with the soil because it develops a fairly stable patina which protects the native copper underneath. Figure 9 provides a microscopic photograph of copper patina on a buried neutral wire.

The red, black, and blue-green forms of the patina are non-conductive and all inhibit the transport of oxidizers to the native copper underneath. As the patina thickens, the resistance increases.

To the extent that any significant corrosion occurs, the corrosion itself increases the resistance to the flow of current in the corrosion loop. This decreases the rate of corrosion with time, and when the neutrals are entirely severed, all corrosion stops.

The numerator can only decrease or perhaps stay the same and the denominator can only increase with time. The current in the corrosion loop and therefore the rate of corrosion must decrease with time and is inherently self limiting under static condition. Most direct-buried, bare concentric neutral cables have generally static conditions.

Figure 10 shows a conceptual curve labeled decreasing that represents the most typical dynamic field behavior of direct buried cables. To the author's knowledge no researchers have ever tracked neutral corrosion over time.

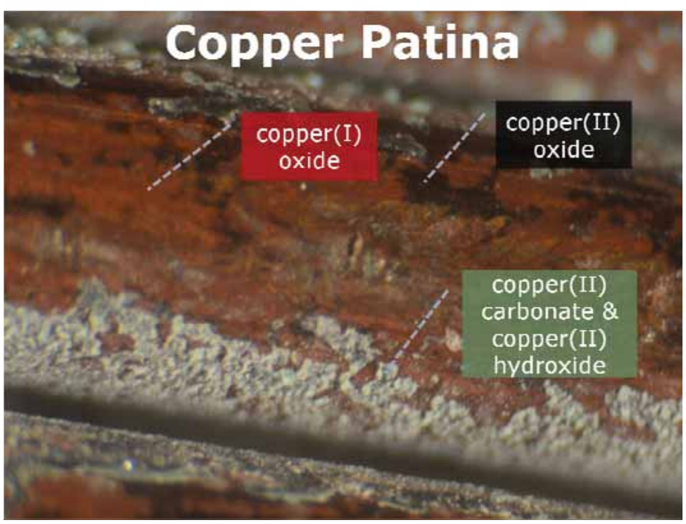

Figure 9. Copper patina in two?? different oxidation states form a protective layer over the native copper below. The patina may be red, black, or blue-green.

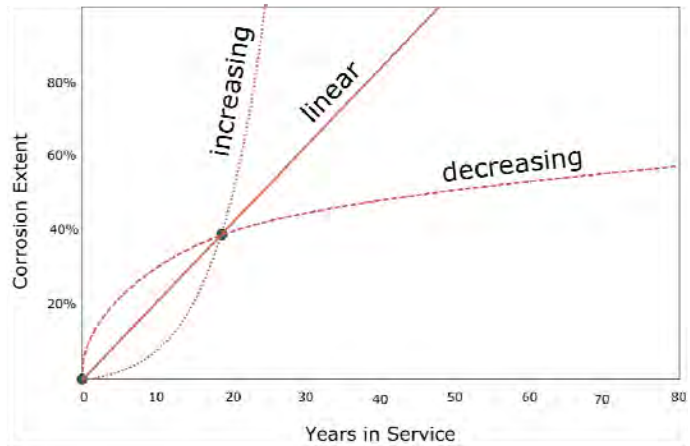

Figure 10. Of the three possible shapes of the corrosion progression curve, the decreasing rate curve is theoretically the most likely. Survey data and anecdotal observations are also consistent with a decreasing rate curve.

V. SIGNIFICANCE

We often ask our line personnel or technicians to check a box on a failure ticket to indicate if neutral corrosion was present. That box is generally checked because when excavating decades old cable, personnel will never see shiny copper. In short, almost all cables suffer from neutral corrosion. However the proper question should be: Is the level of corrosion sufficiently great to interfere with the intended purposes of the neutral? In order to be able to answer that question, the assessor would have to at least have a familiarity with the content of this paper.

Because neutral corrosion is a mystery to so many, it is often over-diagnosed.

Over the course of the last twenty-five years the author has worked for two firms that have systematically surveyed in excess of 100 million cable feet for the existence and extent of neutral corrosion in North America. For the first time ever, this paper will present a subset of that data.

In a subsequent section of this paper, we will explore how best to make neutral corrosion measurements, but for now we will examine the results. Figure 11 shows the results for a broad sample of the North American measurements. In Figures 12 and 13, those results will be further segregated into twenty-four representative U.S. states and Canadian provinces.

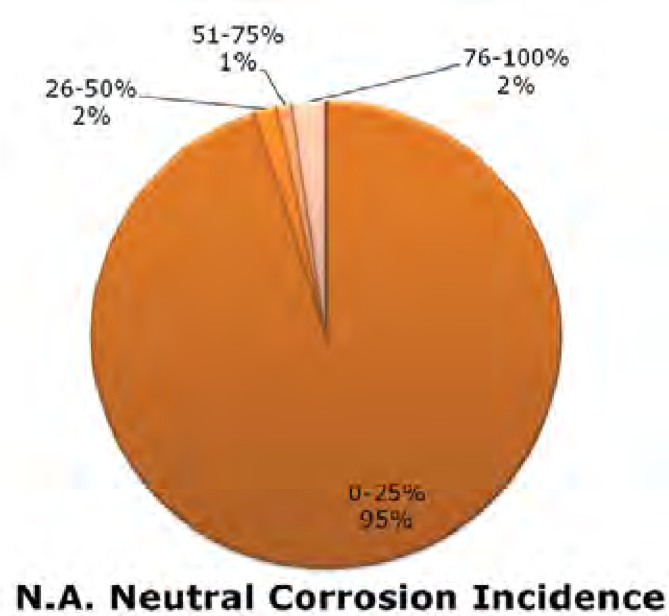

Figure 11. 95% of millions of feet of bare-concentric neutral cables in North America measured have no individual corrosion sites with more than 25% of the neutrals severed.

Figures 13 and 14 provide neutral corrosion measurements by state and province. In each case, a pie chart shows the distribution of cables into four categories of corrosion. These four levels are defined in Table 1 of P1816 and are reproduced in Figure 12.

Each pie chart includes a two-letter state or province code along with a value in parenthesis. The value is the number of cable segments included in the population. A cable segment is a single conductor from termination to termination.

The data for the contiguous 48 states are displayed over the U.S. Department of Agriculture, Ground Penetrating Radar (GPR) Soil Suitability Map [4]. This map was chosen, because there is a loose geospatial correlation between the incidence of corrosion and the suitability of soil as calculated for the production of this map. GPR suitability is a function of several variables including clay content and mineralogy, electrical conductivity, sodium absorption ratio, and calcium carbonate and calcium sulfate contents. The interested reader is referred to the USDA web site at [4].

Level	Wires Broken	Reflection size
1	0%→25%	None recognizable
2	25%→50%	< splice
3	50%→75%	> splice; < end-of-cable
4	75%→100%	> end-of-cable

Figure 12. The definitions of neutral corrosion levels 1 through 4 from Table 1 of IEEE P1816??.

In future work, the author shall perform geospatial correlation with the rich set of available measurements in the USDA database and publish a map specifically correlated to available neutral corrosion data.

In the end, all corrosion is local and hence the correlation will likely improve as the geospatial granularity is refined, but there will always be exceptions, because both nature and man introduce soil chemistry variations. Differential aeration in particular can be introduced in any soil type. On the other hand, there do appear to be some soil chemistries, which are much more forgiving. For circuit owners in these forgiving areas, less diligence may be required.

Going around the clock in Figure 14 and starting on the Eastern Seaboard, the corrosion levels in the Northeast are slightly higher than the national average. In the Southeast, Florida has a substantially higher corrosion level and Mississippi is substantially lower. In the Southwest, Texas and Colorado are below the mean, while Arizona is right at the mean. In the heartland, Missouri and Iowa experience very low corrosion rates. In the Northwestern U.S., the coastal states suffer corrosion rates above the norm. Idaho is near the norm and Montana is well below the norm. In the North Central states, most areas are at or below the norm, except Indiana suffers an anomalously high corrosion rate.

In Figure 13, north of the 48th parallel, the trend we saw in the U.S. Pacific Northwest may extend into British Columbia, but at least in Alaska, Alberta, Saskatchewan and Ontario, neutral corrosion is almost non-existent.

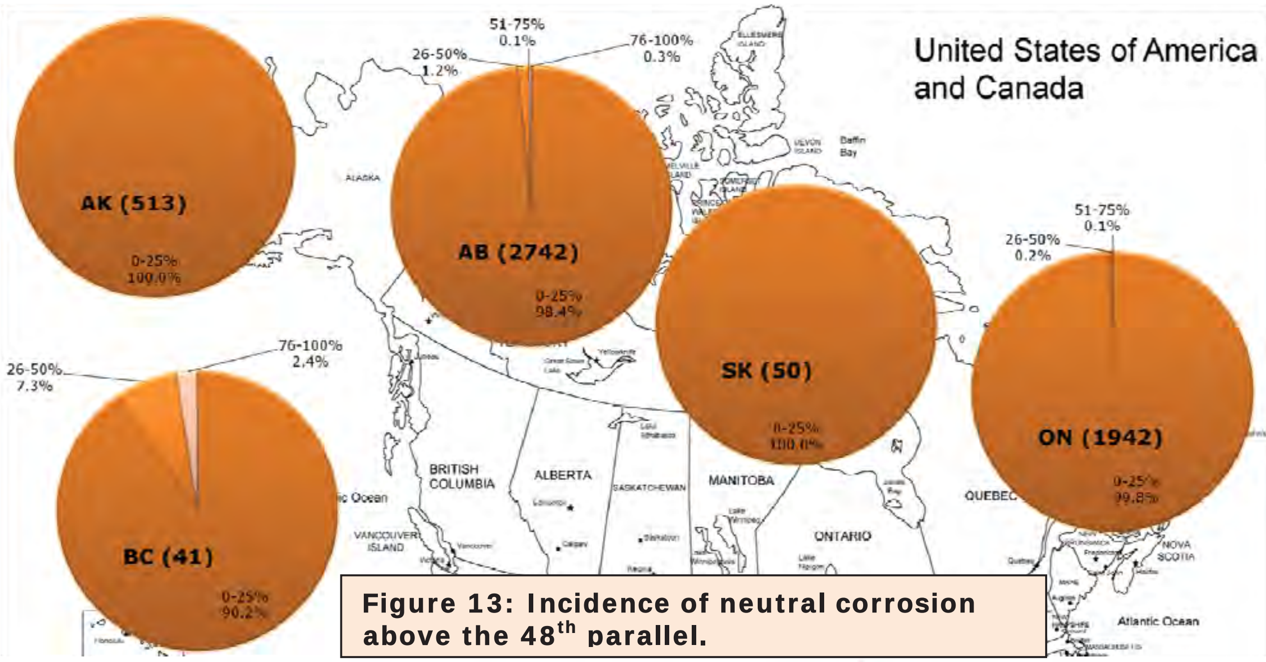

Figure 13: Incidence of neutral corrosion above the 48th parallel.

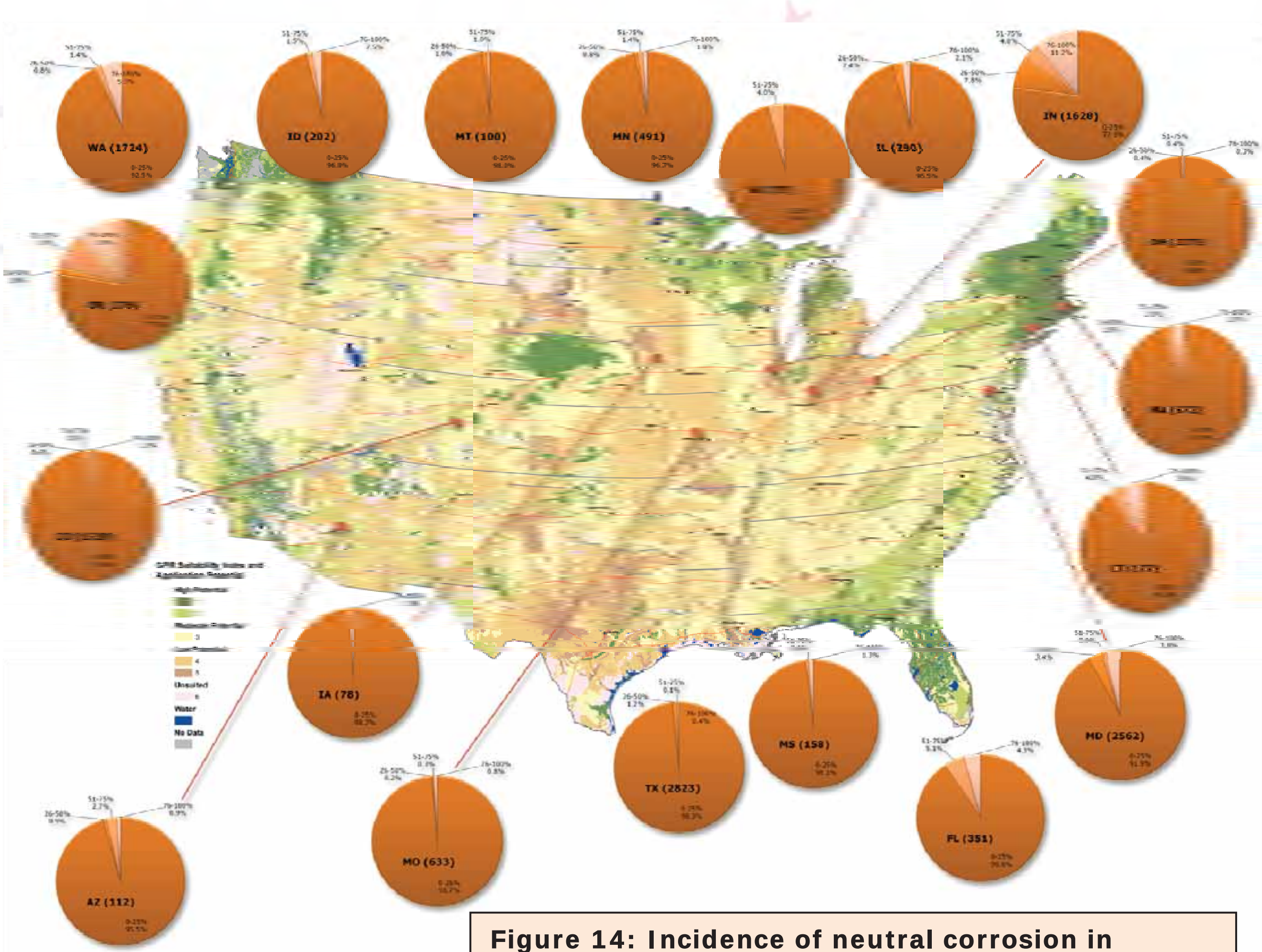

Figure 14: Incidence of neutral corrosion in selected U.S. States on USDA GPR suitability map.

VI. DETECTION

IEEE 1617 describes four methods of detecting neutral corrosion. The first enumerated method (7.1) is visual inspection. The inherent limitations of visual inspection include its subjective nature and the fact that it is only possible to inspect exposed cable.

The fourth method provided in IEEE 1617 7.4 is measurement of surface voltage or step potential. This method was utilized by a Wisconsin circuit owner and it does provide reasonable quantitative results. The method has not achieved commercial success, because the method requires a great deal of time and hence the economics of deployment are not favorable. The author believes that this method is no longer utilized.

The two commercially utilized approaches listed as 7.2 and 7.3 in IEEE 1617 are respectively, the use of a TDR or time-domain reflectometer and resistance measurements. Of the over 100 million feet of neutral survey data over 99% were obtained with TDR technology.

The resistance measuring technology has a small following and remains in use today, but never enjoyed significant commercial success. A device branded as Ω-check (Ohm-check) was the most common instrument and is no longer being manufactured. The device is pictured in Figure 15.

Figure 15. The front-end of an Ω-check. This device is no longer being produced or supported. A limited number remain in service.

In the 1990's, Georgia Tech's NEETRAC laboratory directly buried several cables with known amounts of service-acquired corrosion in a neutral corrosion test bed. The author's firm was invited to participate in a side-by-side blind test of available neutral corrosion technology. For each cable, the TDR and the Ω-Check accurately determined the actual amount of neutral corrosion within the four ranges defined in Figure 12. The TDR provides the distance to the corrosion from the cable ends, which is not available with the resistance measurement technique.

One advantage enjoyed by the resistance method is that it can be used on energized cables. Users are cautioned to create an equipotential zone around the instrument and its operator to ensure operator safety. The Ω-check device requires that a wire be run between transformers to complete the resistance loop. This requirement is not too cumbersome, if the cable is buried in front lots, but can hamper productivity in back-lot applications.

The balance of this section focuses upon the commercially predominant TDR neutral corrosion detection technology. Section 7.2 of IEEE 1617 provides an overview of TDR use. A more comprehensive step-by-step description of the use of a TDR to identify and pinpoint the location of neutral corrosion is publically available on my firm's website at [5]. Web based electronic learning on the use of TDRs will be available starting in 2013 at [6].

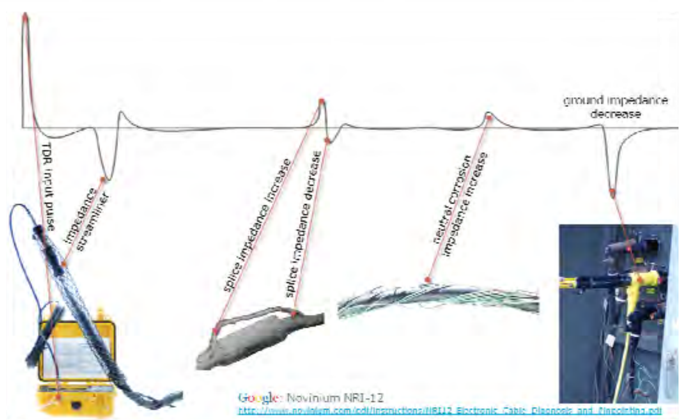

Figure 16. The principals of TDR used to identify and distinguish neutral corrosion impedance reflections from other anomalies such as splices. Virtual representations in the waveform are tied to their physical manifestations.

Figure 16 illustrates the principles of TDR use. Working from left to right in Figure 16, the TDR transmits a narrow low voltage pulse down a coaxial cable. The pulse is less than 20 volts and has a width of between 1 and 50 ns. The pulse travels at about half of the speed of light.

A device called an impedance streamliner facilitates a smooth transition from the impedance of the RG-coaxial cable to various sizes of co-axial power cables. The streamlined transition minimizes the reflection, attenuation, and dispersion of the signal as it enters the subject cable. The use of a streamliner improves the sensitivity and accuracy of the measurement. The default connection provided by TDR manufactures is a pair of alligator clips. While the clips make for simple connections, the loss of resolution is unacceptable for detecting neutral corrosion.

Where splices are present in the cable a characteristic S-wave is observed. Impedance includes resistance, capacitance and inductance. In the case of a splice, the neutrals are trained away from the conductor, which reflects a positive wave because the impedance increases. The subsequent negative wave is a result of the neutrals returning to a position closer to the conductor decreasing the impedance.

Where there is neutral corrosion, the resistance increases and the capacitance decreases, but the former dominates and a positive wave is created. The capacitance effect is generally too small to observe. A glance back at Figure 12 allows the operator to assess the extent of the corrosion anomaly. It is level 2 corrosion; 25% to 50% of the neutrals are severed.

Finally, at the far end of the cable, a ground is applied and the resistance is close to zero.

There are two kinds of noise which occur on TDR traces. Dynamic noise is easy to recognize, because the TDR sampling rate allows the operator to observe the random dynamic variations. Modern digital TDRs have various filters, which can remove the dynamic noise. Static noise is small variations in impedance, which is not significant corrosion or splices. The TDR includes a gain function, and inexperienced TDR operators might be tempted to "crank the gain." At too high a gain, one would incorrectly conclude that the cable is riddled with anomalies. The best way to set the gain is to limit the gain, so that the input pulse does not go off the scale of the display. Gains higher than this are likely to mislead the wave-form interpreter.

A trained TDR operator can identify the distance from the cable end to a neutral corrosion site with some precision. However, because the precise cable path is difficult to ascertain, the TDR is not a perfect pinpointing tool to begin an excavation. To pinpoint the precise location to dig, a radio frequency tone is applied to the conductor and the return tone is urged onto the neutrals with a jumper as shown in Figure 17. Much of the resulting electro-magnetic field is cancelled where the neutrals are in good condition. This cancelling occurs because the signal on the neutral return is 180-degrees out of phase with the conductor signal. Of course, where neutral wires are broken this cancellation is compromised and as consequence the neutral corrosion location "sings" loudly. An operator with a receiver walking over the cable and guided by the approximate physical location provided by the TDR can pinpoint the precise location of the corrosion. A description of the equipment and procedures for pinpointing neutral corrosion with a radio frequency transmitter and receiver are available in [5] and training will be available at [6] in 2013.

Figure 17. Pinpointing the precise location to excavate a neutral corrosion site is best accomplished with a radio frequency locator. A transmitter is connected to the conductor and the neutral at termination 1 and a jumper cable connects the conductor and neutral at termination 2. An operator carries a receiver over the cable path. The signal increases greatly where neutrals are corroded.

VII. Addressing Neutral Corrosion

Section 8 of IEEE 1617 provides two suggestions when unacceptably high neutral corrosion is identified. Replace the cable with new cable, or for direct buried cable, repair the neutral and supply cathodic protection to the repaired neutral. Most North American circuit owners use a “50% corroded” benchmark as the definition of “unacceptably high.” Section 4 of this paper provides the justification for that benchmark. Figure 10 and the accompanying text indicate that the neutral corrosion rate decreases with time, so a 100% severing of the neutral is likely to exceed two-times the current life of the cable.

To effectuate a repair a pit is excavated over the corrosion site as illustrated in Figure 18. Normally, the corrosion site spans less than one meter. New copper neutrals are wrapped tightly around the cable and clamped into place with special clamping hardware as illustrated. The clamps also have a dedicated lead to a sacrificial magnesium anode. The anode is bedded in bentonite clay within a linen bag.

Normally, when cathodic protection is applied to protect underground structures, placement of a sacrificial anode requires much consideration, but when doing a neutral repair of a decades-old cable, the optimum location has already been determined by history and reinforced with the disturbance of the soil to excavate the pit. A post-hole digger or auger is used to get the anode several feet away from the repair site. The bag can be placed at a depth below the cable, at the same depth as the cable, or anywhere in between. The neutral will be protected from corrosion for decades because the magnesium will sacrificially corrode and bias the electrical potential on the connected neutrals to a value well below its corrosion threshold.

VII. Summary

The primary purpose of the neutral is to carry return current and provide a low impedance path for fault current. Excess corrosion may create protective device coordination issues, power quality issues, compromise the safety of employees and the public, and in rare occurrences may even cause the cable to fault.

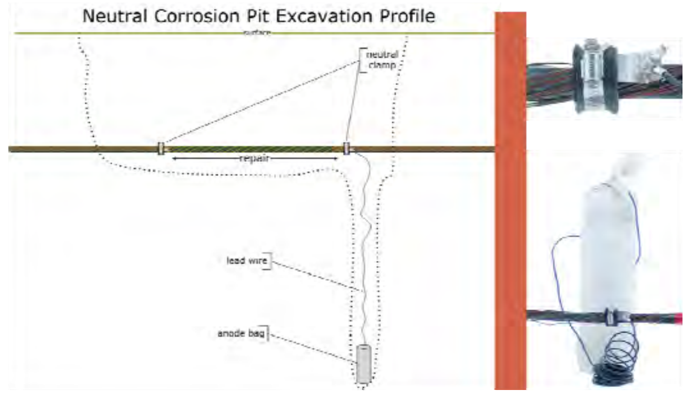

Figure 18. Profile and hardware typically employed to correct and protect local neutral corrosion. The typical length of the repair is less than one meter. The neutral clamp is designed to make a permanent and secure electrical connection with existing neutrals which have been wire brushed and repair neutrals.

Differential aeration and local changes in soil chemistry are the predominant causes of corrosion. The physical and chemical driving forces, which create corrosion, decrease with time. The decelerating corrosion rate provide circuit owners with some reassurance that neutral corrosion is not a run-away phenomenon.

A systematic field survey of millions of cable feet in over twenty North American states and provinces, together with an anecdotal survey conducted by the ICC, confirm that the overall incidence of neutral corrosion is less than about 5% on bare concentric neutral cables.

TDRs are used effectively and broadly to detect neutral corrosion. Repairs of neutral corrosion sites together with the application of passive cathodic protection are straightforward and much more capital efficient than wholesale replacement.

In future work, the author will explore the geospatial correlation of neutral corrosion with USDA soil survey data. A comprehensive comparison of TDR neutral diagnostic technology with the resistance method will also be undertaken. Some of this new work will appear in a paper to be presented at the Fall IEEE/PES/ICC meeting in November 2012.

References

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