Paper No.
7245

NACE INTERNATIONAL CORROSION 2016 CONFERENCE & EXPO

GALVANIZED STEEL POLE AND LATTICE TOWER CORROSION ASSESSMENT AND CORROSION MITIGATION

M. Zamanzadeh, C. Kempkes, D. Riley, MATCO Services Inc., a wholly owned subsidiary of Valmont Industries, Inc.,28800 Ida Street Valley, NE 68064-0358; and
A. Gilpin-Jackson, BC Hydro, Burnaby, British Columbia, Canada

ABSTRACT

The principal corrosion mechanisms for galvanized steel electric power utility transmission and distribution (T&D) structures (poles, lattice towers and anchor rods) are presented in this paper.

Several important factors often associated with corrosion of galvanized utility structures are deficiencies in corrosion control, improper coatings and not considering soil corrosivity conditions. In general, soil corrosivity, cathodic protection/coating, stray current, and copper grounding should be considered in corrosion mitigation and design of T&D structures. These factors are of primary consideration when accelerated corrosion attack occurs. If identified early on, potential failures can often be prevented. This paper includes a discussion on metallurgy of galvanized steel, soil corrosivity, T&D specific structural zones and system wide cathodic protection as a mitigation technique. This paper combines four past publications as well as presents new information and strategies for corrosion prevention for electric power utility T&D structures.

Keywords: Galvanized Steel Pole, Lattice Tower, Soil Corrosion, Corrosion Assessment, Corrosion Mitigation and Cathodic Protection (CP).

INTRODUCTION

Galvanized steel is one of the most often specified materials for the manufacturing of poles, lattice towers and other transmission and distribution (T&D) assets commonly used in the electric power utility industry. The galvanized poles and towers are often embedded with the depth dependent on soil strength and applied overturning moment. Galvanizing is to meet ASTM [(1)] specification A123 requirements for pole

[(1)] American Society for Testing and Methods (ASTM) International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA and A153 for hardware. Methods to mitigate corrosion, beginning from the manufacturing process and through the various life cycle phases are addressed in the following sections.

Metallurgical Aspects of Galvanized Steel Poles and Towers

Electric power T&D pole and lattice tower steel material typically conforms to the mechanical and chemical properties listed in ASTM specification A572-04. The minimum yield strength of this material is 65,000 PSI. The maximum silicon content of all steels is 0.06 % to ensure an adequate free zinc and uniform galvanized finish. The mechanical strength requirements for structural performance, such as tensile strength, (assuming the inherent material strength remains constant), is then dependent on the material cross-sectional area. If inadequate, tensile failures could occur at locations where corrosion has produced localized reductions in cross-sectional areas and created stress raisers. Higher tensile strength steels have less ductility and toughness, and these steels are considered notch sensitive. Normal constructional steels would not typically be notch sensitive but high strength low alloy (HSLA) steels can be notch sensitive. Corrosion pitting can create the notch which then may become the location of crack initiation. Pitting or reduced areas that are due to corrosion can also initiate mechanical fatigue cracks. As a quality control check to ensure a selected steel material has adequate notch sensitivity and toughness several tests are usually employed with the most common a ‘Charpy V-notch (CVN) Impact Test.

In general, steels from the mill should be guaranteed to have a minimum energy impact value of 15 ft-lb for utilize specimens at -20°F to -40 (depending on minimum temperatures at structure sites) as measured by a CVN testing accordance with ASTM A370 and A673. These standards specify that plate test specimens are to be taken after rolling and finishing operations. This procedure is used to detect slow strain rate embrittlement failure mechanisms, such a hydrogen embrittlement (HE) and grain boundary segregation (GBS). It should be noted that liquid metal embrittlement LME (loss of ductility) due to galvanizing is very rare and should be confirmed by metallurgical failure analysis.

Variations in heat treatment and associated cooling rates can affect the corrosion potential and even result in galvanic couples between different areas of the same steel component. Such examples would be welds and their heat affected zones and the adjacent unaffected steel. Magnetite, if present, can provide initial corrosion protection but at locations where the scaling produced from the welding process has cracked localized galvanic cells and accelerated corrosion can occur. Decarburized surface layers are also prone to accelerated corrosion but are not always present.

While the galvanized coating usually consists of several intermediate intermetallic (Fe-Zn) layers with the top surface layer being composed essentially of free zinc, as shown in Figure 1. This layer defines the appearance of galvanized structure. Typically freshly prepared hot-dip galvanized steel has a smooth, shiny surface with the well-known zinc spangle pattern, provided the steel substrate chemistry and galvanizing bath were adequately controlled. This ductile zinc surface layer commonly comprises at least 30 to 40% and sometimes as much as 70-80% of the total galvanized coating thickness. However, certain elements in the steel base or in the weld metal can promote the formation of a coating that is entirely composed of Fe-Zn intermetallic layers with limited or no free zinc barrier layers. When this occurs, the galvanized steel may look matte gray in color and have a rough surface. Through the addition of alloying elements and control of the galvanizing bath, large galvanizing operations have been able to produce utility poles and lattice towers that can last a long time and at the same time avoid intermetallic rust for decades.

The microstructure of hot-dip galvanized steel depends on the composition of steel and the galvanizing bath composition. In general, silicon composition less than 0.04% or between 0.15 and 0.25% is recommended. Si and P act synergistically, increasing the rate of the iron/zinc intermetallic reaction, which leads to thick coatings. Phosphorus less than 0.04% or manganese less than 1.35% are beneficial. Excessive silicon accelerates the reaction between Fe and Zn, resulting in a coating that can consist completely of Fe-Zn intermetallic layers. Higher Si concentrations can also lead to coatings that are much thicker overall than coating specifications require.

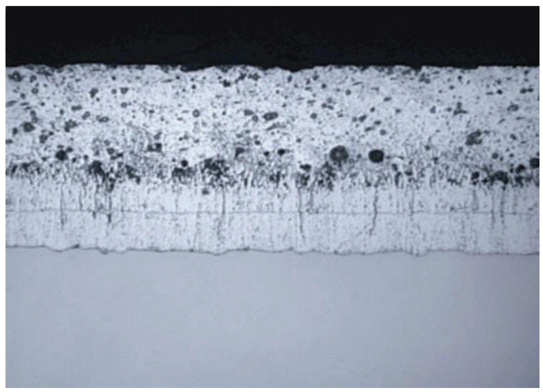

Figure 1: Galvanized steel intermetallic layers: Eta (100% Zn), Zeta (94% Zn), Delta (90% Zn), and Gamma (75% Zn).

Thick galvanizing on the order of 7 mils (178 μm) or more depending on free zinc layer thickness are especially brittle and will crack and peel off under mechanical stress or crack if severely impacted or subjected to cyclic loads. This may lower the fatigue resistance of pole components in general; however, experience indicates that cracking of embedded poles and lattice towers are rare.

Corrosion Characteristics of Galvanized Steel

In general, characterization and corrosion mitigation for the above ground sections of T&D structures will be defined by ISO [(2)] standard definitions for specific service environment according to 12944-2:1998 Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 2: Classification of environments. This includes time of wetness, sulfate and chloride deposition rates with consideration of wind velocity and direction. This will define maintenance coating requirements for the galvanized structure. Zinc is a highly reactive metal that exhibits a low corrosion rate only if a continuous passive film forms on the surface. An important aspect of corrosion control with galvanized steel is that the surface needs to remain in a soil environment that does not reduce or damage the protective surface

[2] International Organization for Standardization ISO Central Secretariat BIBC II
Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland

film. Galvanized steel T&D structures are exposed to a wide variety of different soil environments and grounding that can also accelerate corrosion activity depending on soil chemistry, soil resistivity, and the nature and surface area of the grounding materials. See Figure 2.

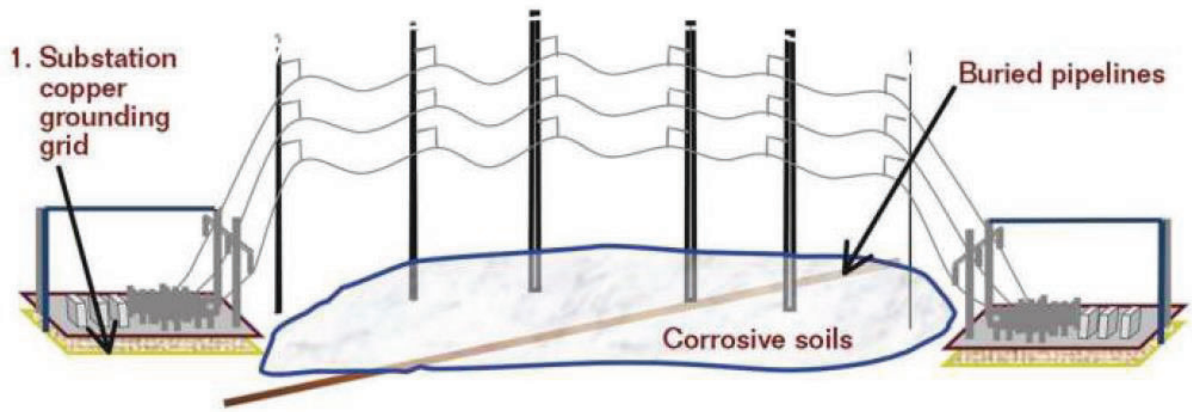

Figure 2: Transmission lines, corrosive soils, and substations form an integrated electrochemical system that accelerates corrosion.

Corrosion of Galvanized Steel Foundations

Under most soil environments, galvanized steel exhibits a low corrosion rate and performs well as it readily forms a protective file on the surface. Accelerated corrosion of the embedded portion of poles, lattice towers or other galvanized steel structures can occur, however, if exposed to highly corrosive or reducing soil environments (i.e., acidic chlorides or microbiologically infulenced corrosion [MIC]), Dry soil is not corrosive to galvanized steel. Water in soil may be present from water table, meteoric water and or capillary water. Salinity may vary from 80 to 1,500 ppm depending on location. Of special significance, it is important to realize accelerated corrosion can take place in absence of oxygen, due to presence of bacteria (MIC), acidic soil and stray currents. Outside electrical interference and stray currents can also accelerate corrosion of galvanized steel structures. CP and protective coatings can mitigate corrosion and extend the life of T&D structures in corrosive soils.

In near neutral environments, corrosion is retarded by compact, adherent, insoluble corrosion products. Conversely, in highly acidic or alkaline environments, soluble corrosion products are formed, which destroy protective films and permit corrosion to proceed. If basic carbonate forms, the increase in pH does not take place preventing the formation of corrosion products or oxides.

The corrosion resistance of galvanized coating increases because the formation of protective basic carbonate zinc extends the region of passivation toward neutral pH values. See Table 1.

Table 1
Cycle of Galvanized Steel Structure Corrosion

New Structure	Galvanized layer acts as a barrier and sacrificially protects the carbon steel substrate
Weathered Structure (zinc consumed) (corrosion rate dependent on soil corrosivity / atmosphere corrosivity and geometry, dry/wet cycles)	Corrosion products consist of zinc carbonate, zinc oxide, zinc hydroxide, zinc sulfate, zinc hydroxychloride, zinc chlorohydroxysulfate
Aged structure (galvanized consumed) (rate dependent on soil/atmosphere corrosivity, geometry, dry/wet cycles)	Corrosion products consist of hydrous ferrous oxide (red brown rust), hydrated magnetite and magnetite (black), ferrous hydroxide (blue/green)

Soil Corrosion and Forecasting Soil Corrosivity

Soils vary widely in their composition and behavior, even over short distances, which can make it difficult to obtain consistent data for designing a risk mitigation solution. While galvanized steel has considerable resistance to corrosion when buried, the greatest attack is caused by soils that are reducing, acidic, or contain large amounts of corrosive water-soluble salts. See Figures 3-6.

Figure 3: T&D structures may be exposed to all types of corrosion-induced environments, including MIC and stray current that require risk assessment.

Figure 4: T&D structures located in very corrosive and water-logged soils with active bacteria present.

Figure 5: Corrosive backfills lead to accelerate corrosion of T&D towers.

Figure 6: T&D towers in deep burial are subject to accelerated corrosion from corrosive ions.

In determining in the corrosiveness of a soil, the different constituent soil characteristics and relevant attributes of the physical environment should be considered. A ranking of the various factors is assigned in order of relevance to corrosion. The sum of those rating factors is a measure for the overall soil corrosiveness. Table 2 presents the key characteristics usually considered.

Table 2
Corrosion Parameters

Soil Characteristics
Factors / Attributes: Soil type, homogeneity, moisture content, pH, resistivity, chemical properties, buffer capacity, level of oxidation, organic content, excessive sulfates, chlorides and MIC .
Physical Environment Characteristics
Factors / Attributes: Time of wetness, ground water, and land use can indicate possible chemicals and salts, interference from electrical and impressed current CP (ICCP from gas lines), stray current, and galvanic action due to contamination.

It is important to have an understanding of the key factors that are measured or assessed to accurately and adequately interpret the results. For example, soil resistivity, which is an approximate measure of the concentration of reactant ions that lead to corrosion, typically decreases as the moisture and ionic as the moisture and ionic concentration increases. Generally, terrains with lower resistivity and reducing properties experience higher corrosion rates. All tests for the defined corrosion factors are typically performed using standard or modified methods developed from experience and testing.

ASTM has a different procedure as described in ASTM G57, *Standard Test Method For Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method*, which will be replaced by a two-part standard: Part A will cover the four-electrode method for in situ field measurements, and Part B will cover the use of a soil box for laboratory and field-test measurements.

According to this standard, corrosion tests on galvanized steel poles / towers buried at different sites are performed by measuring soil resistivity measurements at different depths, pH, total dissolved solids (TDS), chlorides and sulfates, redox potentials (where applicable), resistance polarization measurements, and corrosion rate. This data may be interpreted and compared using empirical methods such as Barne's Layer for soil corrosivity determinations at different depths. It has been found that galvanized steel resists corrosion far better than bare steel at most sites. Table 3 shows the zinc corrosion rate in mils per year for sixty different locations.

Table 3
Zinc Corrosion Rates for Corresponding Soil Types

Soil Type	Zinc Corrosion Rate (mpy)
Oxidizing clay	0.05 - 0.20
Reducing acidic soil	0.1 - 2.0
Salty Marsh	0.2 - 2.5
Moist natural clay	0.1 - 0.50

The corrosion rate for oxidizing soils decreases with the formation of protective layers on galvanized steel. In reducing soil, this layer does not form so the corrosion may increase over time. In this case, the structure should be adequately protected when located in reducing soils. For galvanized steel poles, protection should be applied both outside and inside the pole if the water table is high or is expected to be a concern. Agricultural soils are typically more corrosive because of the high concentration of corrosive ions in fertilizers. Likewise, structures exposed to excess amounts of road or ground water /seawater salts (sodium chloride (NaCL) experience higher corrosion rates from more exposure to chlorides. Based on past experience, the likelihood of accelerated corrosion will increase when chloride levels exceed 100ppm and sulfate levels exceed 1000ppm, or when corrosive bacteria is present (SRB) in the absence of oxygen.

Inspection Techniques and Confidence Level

The methods for determining corrosion risk of galvanized steel foundations include knowledge-based assessments that bring together materials science, metallurgy, electrochemical, and corrosion science with the understanding of how a structure is designed, built, and assembled. The key techniques involved are geared toward quantitatively determining the soil and physical characteristics in order to carry out a multi-factor risk based assessment of corrosion. The following tasks are recommended.

- Physical assessment of the soil service environment to rate corrosiveness
- Electrochemical testing of soil condition and steel interaction (potential values and soil resistivities to predict corrosion profile at lower depths)
- Focused visual, physical, and electrochemical assessment and testing of buried components at a shallow depth

In risk assessment, these test results should be taken into consideration along with structure age, size, design, function, and importance. Each structure is then assigned a below grade corrosion risk rating or condition assessment value. This rating is used to recommend appropriate remediation and mitigation procedures. Special attention should be given to tower designs that lead to accumulation of moisture and corrosive salts regardless of the foundation is buried in soil or encased in concrete. Depending on the method of evaluation, a level of confidence has been assigned to indicate the ability of that procedure to produce reliable corrosion risk data on their own without combining it with another form of assessment. It should be noted that non-destructive testing techniques (NDT) do not provide a high confidence level for corrosion assessment or stray current determination on their own.

Desk Study (Least Confidence)

A desk study can be carried out using GIS data with geological records outlining soil parameter and survey results for assets. Data collected should include any available soils classifications, resistivities, corrosivity, pH and other relevant information if available. The accuracy and reliability of desk studies is based on the data used and the ability of the user to integrate all the relevant aspects in order to determine risk. This method does not account for shifts in terrain or the coarseness of map and geological data. See Table 4.

Table 4
Soil Corrosiveness Parameters

	Corrosiveness	
Soil Condition	**Corrosive**	**Progressively Non-Corrrosive**
Texture	Fine	Coarse
Color	Dark (black or grey)	Light (red or brown)
Acidity	High	Low
Aeration	Poorly aerated	Well aerated
Resistivity	Low	High
Organic content	Present	Absent
Moisture content	High	Low
Redox potential	Low or negative	High or positive
Sulfides	Sulfides present	low
Chlorides	Chlorides present or high	Low or absent

Soil Testing and Soil Sampling (Moderate Confidence)

Soil testing and sampling can be conducted by testing resistivity and electrochemical potential of the soil around footings and anchors. These parameters are the two key factors in the soil corrosiveness equations. The resistivity measurements will express the capacity of the soil to act as an electrolyte. The electrochemical potential measurements will express the soil's corrosion activity or how active it is towards an oxidative/reductive corrosion reaction. Corrosion rate measurements can provide maximum thickness loss and life expectancy estimates or remaining life under worst possible condition. This is a quantitative assessment that depends on the skill of the inspector, the condition and calibration of the instruments, and the sample size of the tests.

Knowledge-Based Inspection (High Confidence)

The target structure is inspected usually to a depth of 36 inches (914 mm) below grade. Soil samples are collected in areas of concern based on soil resistivities <2000 ohm-cm and where structure-to-soil potentials exhibit accelerated corrosion activity. If corrosion on the excavated structure component shows signs of significant material loss, a more detailed and coating and steel substrate should be performed. Inspection of the protective coating consists of adhesion measurement, thickness measurement, and defect characterization. Measurement of corrosion rate (loss in thickness/unit time) is performed based on electrochemical polarization techniques, which determine the loss in thickness under worst wet conditions. The loss in thickness can be related to load bearing capacity and uplift resistance of the structure with a relationship established between member size reduction and uplift resistance. This is a quantitative assessment that focuses on each structure and allows engineers to determine the amount of galvanized steel thickness reduction (based on corrosion rate) a grillage foundation can sustain. Concrete inspection and, if required, petrographic analysis are performed for damaged or degraded concrete base structures. Soils with high sulfate content may also react unfavorably with concrete footing and foundations. This detailed quantitative assessment focuses on each structure and depends on the skill and training of the inspector. Because all the relevant corrosion and structural parameters are assessed in in addition to visual inspection during the detailed assessment, the level of confidence in the results from such knowledge-based inspections is high.

Assigning Soil Corrosivity Value

The soil around each selected structure can be assigned a soil corrosivity rating based on a number of parameters including soil resistivity, pH, chlorides, sulfates, and electrochemical polarization parameters.

We have developed an algorithm to rate the soil corrosivity as it relates to buried galvanized steel. According to this method the corrosion risk factor for underground assets is modeled by considering both soil corrosion indices and corrosion rate determination by linear polarization resistance (LPR) combined with focused measurement of the underground asset. In this approach, the dimensional measurements, LPR corrosion rate, stray current, electrochemical potentials are considered in corrosion risk assessment and risk factor calculations for below grade assets.

Data Collection, Sorting and Analysis

Data collection, sorting and analysis should be given special attention as it directly related to the quality of the assessment and subsequent analysis. A computerized platform with data capture, storage, and analysis should be used. In general, the computer platform should be designed with the following attributes:

- GIS capable

- Mobile device compatible
- Multi-platform and multi-format capability
- Ease of data entry (user interface is key) and retrieval
- Data validation and quality management
- Real-time risk analysis based on risk algorithms
- Data management strategy and administration

Corrosion Mitigation and Cathodic Protection

Cathodic protection is a method in which a sufficient amount of electrical DC is continuously supplied to a submerged or buried metallic structure to mitigate, slow down or temporarily stop the natural corrosion processes from occurring. CP systems pump electrons into the structure thus protecting them. There are two methods for supplying DC to protect a structure cathodically: a galvanic or sacrificial anode CP system, and an impressed current CP system. The designs are based on an empirical model that may consider current and potential distributions. Wrong currents and anode positions may lead to unprotected or under protected areas. Optimization methods combined with the boundary elements technique have become a useful tool to analyze such situations. The following items should be considered in the analysis:

- Concrete encasement cannot be ignored with regard to the mixed potential that results in varying current demand.
- Magnetite coated structural steel (because of corrosion) under the lattice can be anticipated, as this may be proportionally higher since the magnetite is even more electropositive than copper grounding.
- On a below grade structure that is galvanized, not coated, the potential difference between the magnetite and zinc is higher.
- Many structures do not have a protective coating at all.
- For high-resistance soils, only certain models are likely amenable to effective sacrificial CP design.
- Protection criterion for galvanized steel is different from that of carbon steel.
- Instant off potentials should be considered for cathodic protection monitoring.

Structure geometry, soil properties, environmental parameters and structure coating are salient factors that should be included in any CP design tool.

Corrosion Mitigation Case History

On-Site and Laboratory Testing of Aging Galvanized Poles with Corrosion Below-Grade and Application of System Wide Cathodic Protection

Accelerated corrosion on several galvanized steel utility poles was observed by a public electric utility, and a field and laboratory study was undertaken to determine the root cause of corrosion. Testing included excavation, photographic documentation, detailed electrochemical-potential field measurements, corroded galvanized steel metallurgical characterization, determination of the galvanized steel poles' corrosion rate, continuity testing and laboratory soil characterization. Enhanced corrosion effects from soil characteristics depend on low soil resistivity, the presence of corrosive ions and on the impingement of water tables — and other sources of moisture — on the embedded steel structure. A light microscopic and scanning electron microscopic-energy dispersive spectroscopic (SEM-EDS) analysis revealed several structures with the worst corrosion still had a galvanized coating protecting the underlying steel substrate. This means not all zinc was corroded and there was some protection present.

Service Life

Several factors affect the service life of buried steel utility pole structures:

- Service environment, including soil type and water table corrosivity
- External influences, including grounding effects, stray corrosion currents and weather factors
- Age of a structure
- Presence or absence of coating and CP.

Some direct-embedded steel poles and towers corrode quickly as a result of natural and manmade environmental effects. This is primarily because of corrosive soils and galvanic action, or dissimilar metal corrosion. Field inspections and studies have led to some interesting observations about corrosion activity. First, the copper used as grounding at substations can corrode. This is a serious safety issue. Galvanized poles and galvanized anchors corrode through galvanic effects. Shield wires make the lines electrically continuous. A balanced state that prevents corrosion can be induced by CP controlled by a rectifier. To inhibit corrosion to the greatest extent, CP should be deployed the full length of lines from substation to substation. See Figure 7.

Through its investigation, the utility came to the following conclusions:

- Galvanized anchors and poles exhibit corrosion due to soil corrosivity, copper grounding and stray currents.
- Soils and water tables are corrosive and, in certain locations, may induce extreme accelerated corrosion.
- The copper grounding at substations in corrosive soils adds to the corrosion potential of affected structures and reduces their life expectancy.
- A system wide CP system can eliminate the adverse effects of corrosive soil and copper grounding on protected structures and add relatively maintenance-free service life to a protected line.

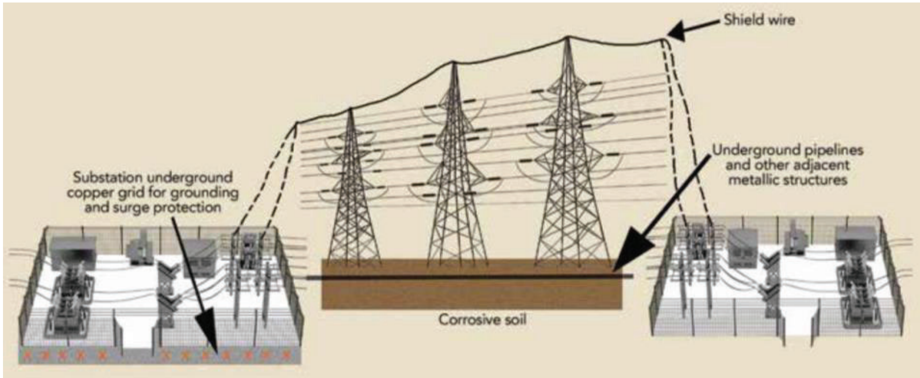

Figure 7: Typical causes of premature corrosion of direct-embedded galvanized steel poles.

Corrosion Protection

The utility's approach to protecting its galvanized steel utility pole structures involved implementing a system wide level of corrosion protection while emphasizing safety and the protection of assets at minimum cost. This approach was founded on the utility's ability to monitor all performance parameters in real time, by wireless telemetry and by providing access to collected data through the Internet. The solution for protecting the galvanized steel utility T&D structures at the substation level includes neutralizing the effect of copper while affording corrosion protection to the poles, anchors and copper grounding. See Figure 8.

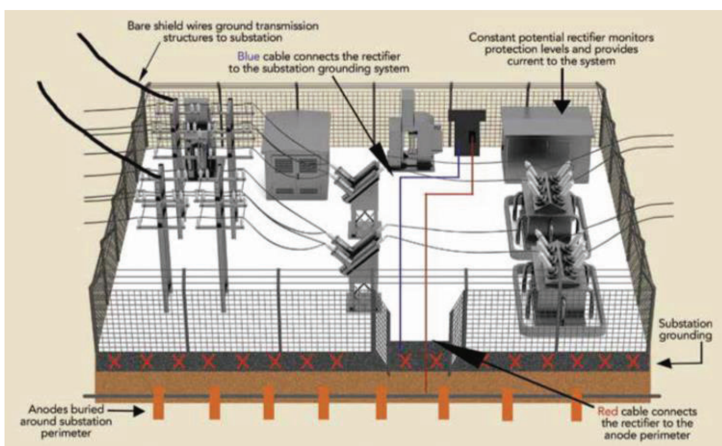

Figure 8: The CP system schematic for protecting galvanized steel transmission and distribution structures at the substation level.

This innovative CP system is designed for electrically connected lines (with shield line) and includes placement of anodes adjacent to the copper ground grid and establishing an impressed current sufficient to shift the effective potential of the grounding grid. With impressed current applied to the grounding grid, the metal structures no longer "see" the grounding grid as a large electropositive cathode, which eliminates the driving force for galvanic corrosion. That means that corrosion induced by corrosive soils and copper grounding can be mitigated without the need to apply CP at each structure location. Structures protected from accelerated corrosion include:

- Copper Grounding
- Galvanized Steel Structures
- Weathering Steel Structures

The above system can be applied provided electrical continuity exists and stray current issues are considered in the design. The system includes:

- A buried anode perimeter was established around the substation.
- The buried anode perimeter was electrically connected to the buried substation copper ground grid.
- An uninsulated overhead ground wire was continuously attached to each steel pole from one substation to the next.
- Separate cables connected the rectifier to both the substation grounding system and the anode perimeter.
- The rectifier measured differences in potential and impressed a balancing current into the system.
- A wireless test station (TS) was used to monitor cathodic protection.

It is important to realize the criteria for CP differs for new and aging structures. This aspect is often not considered; therefore, potential measurements can be misinterpreted after the installation of a CP system. The zinc and intermetallic layers of galvanized steel exhibit an active potential compared to carbon steel, and very high negative potentials (>-1.2 V) induced by CP may corrode the zinc layer on brand-new galvanized steel. Another important factor for protection is the bare surface area. The CP system can protect a full line for many years in corrosive soils if the structures are fully or partially coated, or if additional ground beds are placed in between substations.

Protection Trials

The utility conducted CP trials at three substations. Initial work included conducting potential surveys at the substations and at the poles between substations. This included both native and polarized potentials. Polarization methods were used to analyze the effect of CP on the reduction of corrosion current and increase in life expectancy of the galvanized poles in corrosive soil. Wireless corrosion reference electrodes were used to monitor the CP system. See Figure 9.

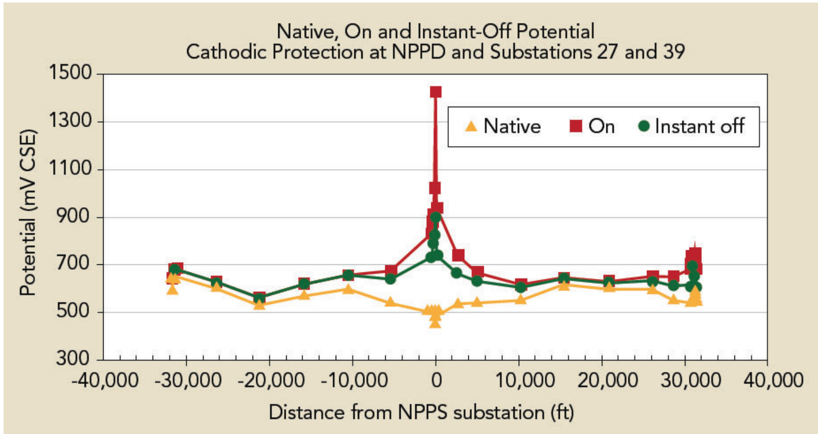

Figure 9: CP data for the three substations shows shift in potential of approximately 50mV indicating extending life for 30 to 40 years in low soil resistivity (2000 ohm-cm) areas.

An important aspect of this project is that the utility was among the first in the electric utility industry to implement wireless corrosion monitoring. The system collects and analyzes corrosion data from sensors or CP equipment at the site, and automatically passes that data to a web data center. The information is converted into alert messages, indicating changes of conditions at the site, along with regularly scheduled measurement data for archiving system wide CP system performance. As a result, users may access historical corrosion information and view graphical displays of corrosion activity.

Based on results from its trials, the utility has seen a substantial increase in the remaining life of its galvanized structures because of CP. If the poles are not coated by organic coating, additional CP may be required in between substations to provide adequate protection on poles distant from substations.

CONCLUSION

The corrosion prioritization program for electric power utility T&D structures may be developed based on the following:

- Age
- Geographical Region and In-Service Condition (corrosivity of environment)
- Circuit Condition Criticality
- Potential Impact of Structural Failure
- Galvanized Steel Vintage and Quality

Early on, or at later stages of service if galvanized structures exhibit accelerated corrosion, the following considerations may apply:

- Protective coating and CP can prevent thickness loss and extend life of the galvanized structure.

- However, if corrosion progresses to structural corrosion, load bearing members may need to be replaced to protect the integrity of the structure.
- Therefore it is important to assess and mitigate the corrosion before it becomes a structural issue and hazard.

REFERENCES

1. M. Zamanzadeh and Jackson, "Corrosion Risk Strategies for Below-Grade Foundations of Transmission and Distribution Structures – Parts 1 and 2." Materials Performance, April, 2014.
2. M. Zamanzadeh, C. Kempkes, D. Aichinger and D. Riley, "Laboratory and Field Corrosion Investigation of Galvanized Utility Poles." ASCE Electrical Transmission Conference, Oct. 17, 2006.
3. S. Fagot, M. Zamanzadeh and G. T. Bayer, "Don't Bury Your Problems." T&D World, February, 2015.
4. ASTM A123 / A123M - 15 Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
5. ASTM A153 / A153M - 09 Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
6. ASTM A572 / A572M - 15 Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
7. ASTM A370 - 15 Standard Test Methods and Definitions for Mechanical Testing of Steel Products
8. ASTM A673 / A673M - 07(2012) Standard Specification for Sampling Procedure for Impact Testing of Structural Steel
9. ISO 12944-2:1998 Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 2: Classification of environments
10. ASTM G57 - 06(2012) Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method