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Maintaining the Electric Grid: It's Time

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Part of protecting the infrastructure means maintenance planning and painting to preserve the backbone of our power delivery system

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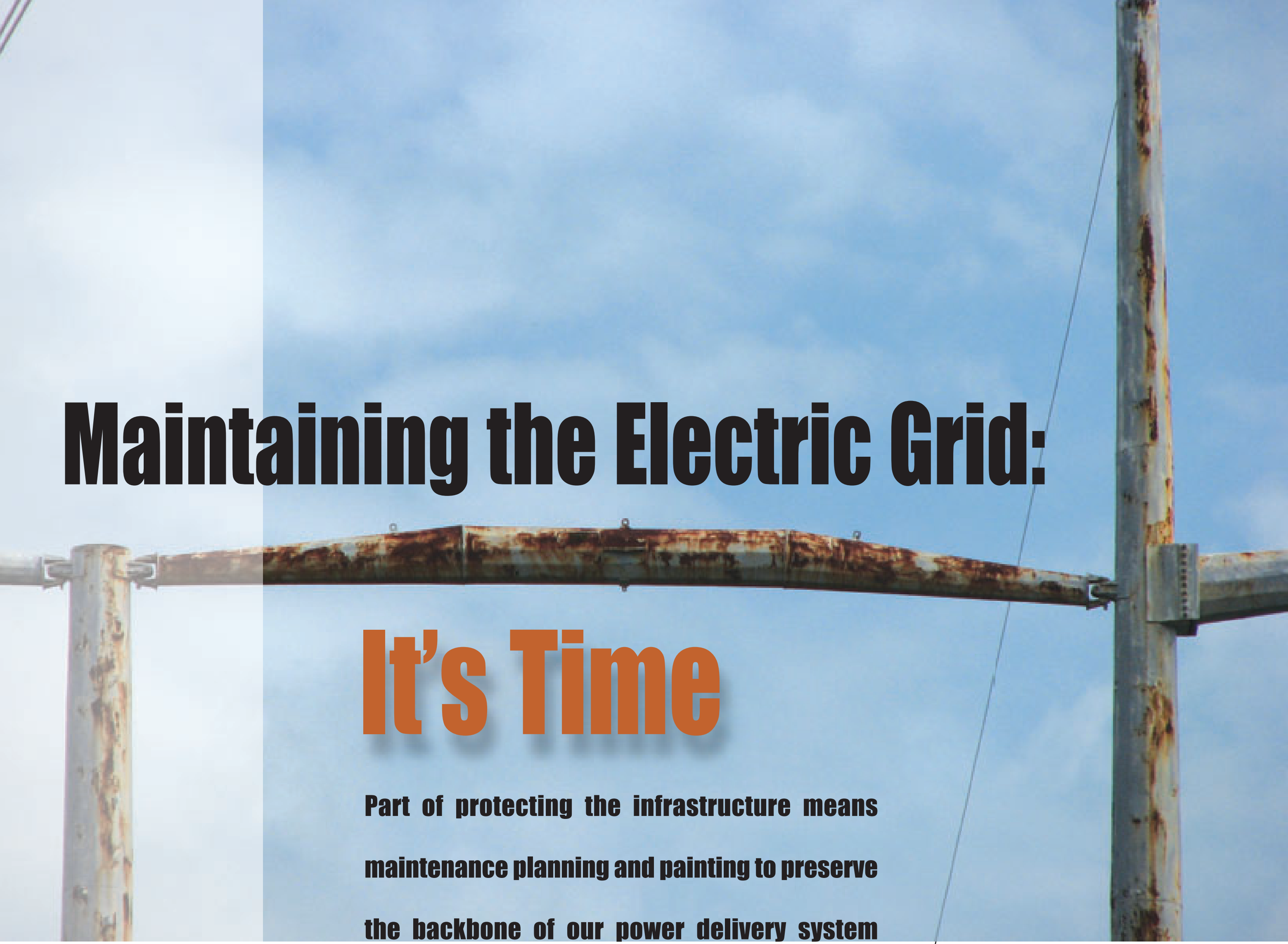


Courtesy of the author

The high voltage steel structure electric transmission system, also known as the electric grid, crisscrosses virtually all of North America, as well as most other regions of the world. It provides the line or circuits by which electricity is delivered from the generation plants to the substations and ultimately to homes and businesses. The system is the backbone of the power delivery system, connecting and interconnecting each utility company and each customer.

The worldwide electric transmission system has been called one of the greatest feats of engineering in history. When you consider the design and construction requirements and obstacles that have been overcome, the system is truly a marvel. But on the fast-approaching horizon is a large obstacle to the system's reliability—that of its aging infrastructure. As with most things, age brings its own set of issues. The issues are significant and, if left un-addressed, can have a far reaching and dangerous impact.

A Brief History of the Construction of the Electric Grid

Since the early 1900s through World War II, many materials have been used to construct transmission and distribution structures throughout North America. In the early years, wood was the predominant structural material due to its availability and the strength requirements of structures to hold the lines. Steel (black iron) was also used to construct select transmission line structures and most substation frames. The designs were basic in nature and were small in comparison to today's standards. Some utilities even ordered steel windmill structures from Sears Roebuck catalogues and made design changes to accommodate the transmission conductors. Many utilities still have some of these older structures in service today. These are what I will refer to as the first generation structures.

After the war, as the economy rapidly expanded, the demand for electricity grew in proportion. Power plants were built, and the transmission infrastructure had to keep up. The number of new line support structures exploded, and construction continued nearly unabated for the next 3 decades. Utilities were moving to higher voltage transmission line voltages with larger and heavier conductors to transport the electricity to meet this growth in demand. The need for a stronger structure to support these heavier conductors, an increased conductor spacing for higher voltages, and longer span lengths dictated the need for a material that could easily obtain height and strength requirements. This translated to erecting tens of thousands of steel structures throughout North America in a relatively short period. This period saw the largest number of steel structures installed on the transmission line system. These are the second generation structures and the second part of the equation.

The electric utility industry generates nearly 4,000 billion kilowatt hours of electricity from 2,100 power plants in the U.S. and Canada alone, delivering power through more than 300,000 miles of high voltage transmission line. If we assume an average of eight structures per mile on transmission lines alone, that would translate into approximately 2.5 million structures, conservatively speaking. Even with many transmission structures made of wood or concrete, it is reasonable to estimate that there would be hundreds of thousands of steel transmission structures and supports (such as stub poles) in just the U.S. and Canada.

In reality, transmission line failures are on the horizon unless we take action and take it soon. The electric utilities must have inspections that identify potential issues before they happen, allowing time for corrective repairs to be made prior to a facility failure. There are several contributing factors:

- Aging Infrastructure
- Past Design Practices
- Environmental Conditions
- Understanding
- Inspection and Maintenance Practices
- Maintenance Budgets

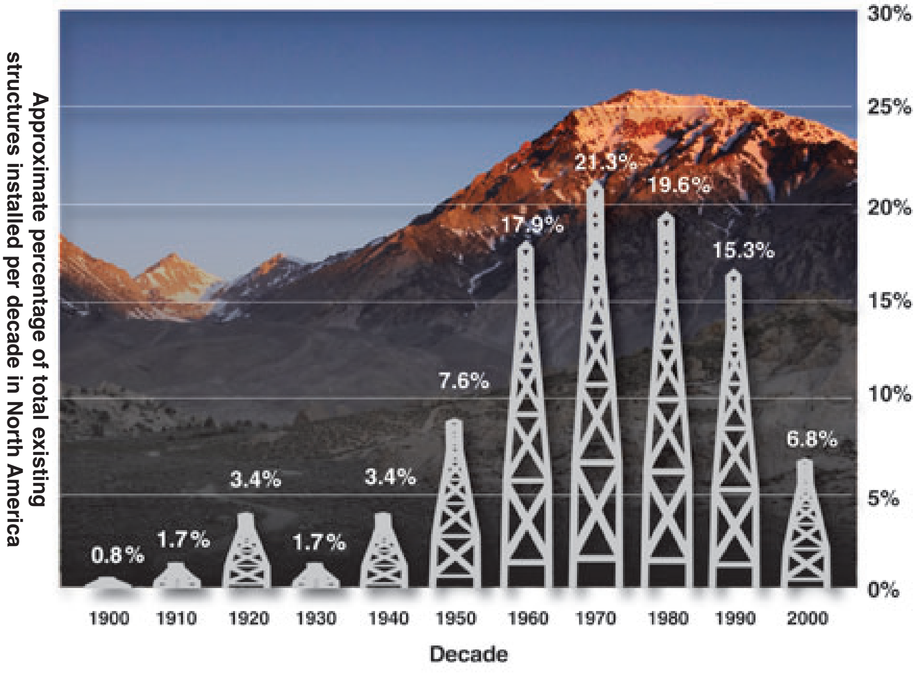
Aging Infrastructure

The aging infrastructure and the assumption that steel structures will last forever must be addressed. In reality, there are periodic maintenance requirements for these structures, carbon or galvanized steel. Utilities have been performing maintenance on their lines, but mostly on the first generation structures, those built in the first half of the 1900s. The bigger ticket items are usually 20 to 30 years into the life of the structure. Based on the grid's construction time line since the 1900s, an enormous number of structures are now 30 to 40 years of age (Fig. 1).

The majority of North American transmission lines were built from the 1960s thru the 1990s. Many utilities report a larger number of transmission structures erected during 4 decades than in the other 70 years since 1900 combined, with construction concentrated in the '60s through '80s. These second generation lines, due to their current age and large number of structures, will significantly increase the overall maintenance work required to keep the transmission system safe and reliable, as many structures will require attention all at once.

When discussing the maintenance of steel transmission structures, there are two major areas of concern: the above grade or atmospheric exposure portion of the structure and the below grade surfaces, commonly referred to as footings

Fig. 1: Construction timeline of the electric grid throughout the 20th century.



or foundations (Fig. 2). It is important to address both areas as part of a maintenance program. Protecting the above grade section of a structure does no good if it topples over due to failure from corrosion at the groundline, just as maintaining the footings does not succeed if the arms fall off from rust-through. A comprehensive program involving inspection, repair, and mainte-

Fig. 2: The below grade surface, often called the footing or foundation, is a major area of maintenance concern. Figs. 1-5 courtesy of the author.

nance of both structure sections is imperative. NACE International and IEEE (Institute of Electronic and Electrical Engineers) have recognized this and have formed two joint committees to author standards on corrosion control of existing structures addressing both areas of concern. These standards are well on their way to publication.

Past Design Practices

Many of the electric utility design practices did not take into consideration potential issues associated with maintaining steel structure components. Many of the earlier steel structures were designed with the steel footing in direct contact with the earth (Fig. 3). In many cases, depending on the chemical make-up of the soil, the steel footing in the earth may not be a big issue, but

Fig. 3: On some older steel structures, the steel footing is in direct contact with the ground.

with the simple addition of a copper ground field, the structure becomes exposed to galvanic reaction, which may cause the steel components to be compromised.

On other designs, with foundation, the specification was to have the reveal (portion of concrete footing above ground) 6 inches to 1 foot above the ground. With all of the activities along the utility line right-of-ways, combined with natural erosion, many foundations became covered by soil, thus allowing corrosion to begin.

Fig. 4: Steel latticework can trap moisture, causing accelerated corrosion.

Other aspects of structure design also often did not account for maintenance issues. Tight steel latticework was used many times, causing accelerated corrosion because of moisture trapped in the latticework, which itself is exceptionally difficult to properly clean and coat (Fig. 4). Ladder clips, arm attachments, and other design factors also contributed to maintenance difficulties and costs.

Environmental Conditions

In the early 1900s environmental conditions were not a major focus or concern. After WWII and the rapid economic growth, many factories were built and the economy was flourishing. Families that had traveled by foot and horse-drawn carriages were now buying automobiles. Large plants of all types were being built, and towns and cities were bursting as people moved in to fill the job market. From this time forward, the air quality would be an issue for steel structures, although its significance was not known originally. But the effects of atmospheric emissions from the rapid growth can be seen on many older steel structures.

Agricultural practices were continuing to change in an effort to grow more vegetables per acre of land. This effort introduced products to help speed up growth, but now we know that some of the chemicals used can also cause or accelerate corrosion of the structure, especially the critical groundline portion of steel structures.

Understanding

It is understandable that in an effort to keep up with the demand for new products, the North American economy was, and is, operating at full speed. With the increased demand for manufacturing also came the increased demand for electric power to run the factories. With the accelerated growth of computer and other electronic technology, we are even more energy hungry today. Thanks to extensive and continuing research, we better understand how to design and maintain the steel components of the electric system. We now have a better understanding of what to look for prior to selecting a groundline coating for a new structure and what type of footing for the steel structure will require the least maintenance while giving the utilities a more reliable and safe system. We have a better understanding of how stray currents can affect the steel structures and other design considerations that will ultimately result in longer structure service life, improved reliability, and significantly reduced maintenance costs.

Inspection and Maintenance Practices

With the large, second generation steel structures aging to the point at which many maintenance issues will become more noticeable, utilities must develop innovative inspection and maintenance practices that will save time as well as keep the system both safe and reliable. Many electrical utilities are spending research dollars to develop new inspection and maintenance tools and procedures. This research is helping to improve the way the industry identifies and evaluates age-related issues.

The costs associated with the maintenance of these second generation lines will be significant because of their large numbers, but with good inspection processes, tools, and innovation, along with thorough, long-lasting maintenance programs, the costs can be minimized. Because of the growing system needs, some of the older lines will be rebuilt to a higher standard than their original standard and others will have major maintenance projects performed on them. Crews will have to be trained to understand what to look for when performing inspection as well as to understand the critical aspects of a steel structure. Steel structures coating programs will have to be utilized more to decrease future maintenance expenditures and prevent premature failures of the system. A continued focus must be on the inspection and maintenance of the critical groundline termination of the structure.

New tools and technologies will be required to improve inspection and maintenance practices and many are currently being tested. The industry standards under development will help the industry understand key issues in maintaining the steel structure above and below ground. These standards will also provide best practices for the proper atmospheric and below ground coatings applications to better maintain and support the reliability of utility steel structures.

Purpose and Methods of Corrosion Control

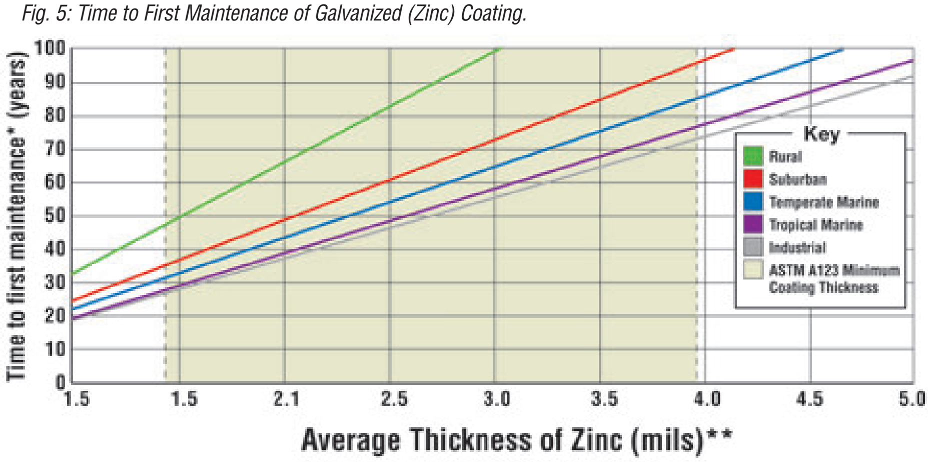
First and foremost, electrical utilities must keep the steel structures standing to deliver the electricity to the customer. One of the main tools to accomplish the task is corrosion protection. Most often, corrosion protection of electrical transmission structures involves the application of a protective coating over weathered and/or previously painted galvanized steel. Although many transmission structures, mainly tubular poles, are painted carbon steel, most structures, especially lattice-type towers, are galvanized and are either unpainted and weathered or previously painted.

The history of painting galvanized structures over the past 60 years and the evolution as well as usage of different paint systems play an important role in the selection of present day coating systems. Cost evaluation of different generic paint types is necessary, as is the application characteristics of each, because painting these structures is labor intensive. The ultimate goal is to minimize overall cost over the life span of the structure by applying coatings that will provide the lowest applied cost per year protection.

Galvanizing and paint serve the same function: the protection of the carbon steel substrate from corrosion attack. Each protective material works as a barrier to separate the components of the electrolytic cell that causes corrosion. When properly specified, manufactured, and applied, this barrier of paint or zinc iron alloy will keep the moisture (electrolyte) from contacting the anode and cathode (steel and its impurities—corroding surface). When this is successfully accomplished, corrosion cannot occur and the substrate will not be detrimentally affected.

Over time, both galvanizing and paint will degrade to a point at which they will not adequately protect the steel substrate. The rates of degradation will vary widely. Exposure conditions have the

Fig. 5: Time to First Maintenance of Galvanized (Zinc) Coating.



**Time to first maintenance is defined as the time to 5% rusting of the steel surface. 1 mil = 25.4μ = 0.58oz/ft²*
***Chart developed using the Zinc Coating Life Pedictor Model developed by Dr. Gregory Zhang of Teck Caminco.*

Courtesy of the American Galvanizers Association greatest effect on the longevity of protection, but the quality of product and its application are other critical factors (Fig. 5).

When the galvanizing or paint film can no longer adequately protect the substrate, a new barrier must be applied to fend off the costly ramifications associated with corrosion. The most practical and cost-effective method of "re-protecting" the structure is the application of a paint or coating specifically intended for this use. When properly formulated, specified, manufactured, and applied, certain coatings can protect a transmission structure for 25 years or more.

Surface Preparation and Repainting to Reduce Corrosion

The surface preparation methods recommended for weathered galvanized or previously painted structures normally entail hand tool cleaning (wire brushing or scraping) in accordance with SSPC-SP 2. Some structures may require more advanced methods, but because surface preparation is the slowest, hardest, and most costly aspect of painting a transmission structure, the primary objective is to paint with a coating designed for minimal surface preparation. The goal is to paint BEFORE the galvanizing or the existing coatings have deteriorated to the point where involved surface preparation and multiple coat paint systems are required. The most cost effective time to paint a transmission structure is when spot scraping or wire brushing is all that is required. This practice is one sure way of reducing system life cycle costs.

To further complicate the situation, the original coatings on transmission structures may contain lead. If the specification requires the removal of old paint from the structure, it is essential to determine whether or not there is lead present in the old coating. If present, procedures in accordance with the OSHA and other applicable regulations must be implemented to protect workers from overexposure to lead. A job-specific lead compliance program is a required submittal on today's transmission structure painting projects.

Fig. 6: State and Federal laws require containment of lead paint to protect workers, residential areas, and the environment.
Courtesy of Savannah River Crossing, Georgia Power Company

State and Federal environmental laws also require the contractor to take necessary steps—with an appropriate method of containing the lead paint, usually through an acceptable containment system—to prevent lead paint from polluting the environment (Fig. 6). On a complex structure such as a transmission tower or pole, this is extremely costly, not to mention the costs and ramifications due to required outages. For structures located in a residential area this issue becomes even more sensitive. The old paint, which is contained and collected, must be tested for its level of toxicity, and the waste must be handled in compliance with EPA requirements.

Furthermore, if lead is involved, total removal might be specified. More extensive surface preparation will result in much higher concentrations of airborne lead that put workers and the environment at risk. Protecting workers and the environment will require much more elaborate and expensive procedures. Again, costly circuit outages will also be required due to the use of power tools and other required equipment. Thus, total job costs will rise exponentially if significant surface preparation procedures are required.

The application of paint to a transmission structure is more complicated than it might seem. This type of painting involves climbing lattice type towers or tubular poles that vary in size and configuration depending on voltage. Most often, these structures are painted while energized when appropriate phase to structure distance, or the Minimum Approach Distance (the safe distance specified by OSHA or the utility that a worker must stay away from the energized conductor—varies depending on circuit voltage) can be satisfied. Painting a lattice-type structure is a team effort. For example, a crew of 3 or 4 painters will paint a standard 100 ft lattice tower in 2-3 hours.

For the most part, application is accomplished using a paint mitt. Brushes or rollers are used on certain structure components. Experience is an important factor in using either method of application as it very important that the specified film dimension is achieved and a smooth consistent film is obtained.

Protection of workers and the environment is paramount. Safety associated with the coating application to a structure involves, among other things, proper procedures and equipment for climbing elevated complex structures and working around energized lines. Additional safety and environmental protection measures must be taken because contact with potentially hazardous materials is possible during surface preparation as well.

Years ago, climbing and painting was accomplished generally without the aid of rigging and most of the time without safety belts. Each year, OSHA and/or power company safety regulations have become more stringent. Today, safety belts, hard hats, and safety glasses are mandatory, as are written safety programs, fall protection plans, hazard communication plans, and lead compliance plans. Workers must be thoroughly trained in the hazards associated with this work, especially the dangers of working around high electric voltages. Documented experience in performing this work should be required of any worker, especially when the painting of energized structures is involved.

Maintenance Budgets

Maintaining the system takes money. Maintenance budgets were developed based on expected maintenance needs. These budgets, for the most part, were developed based on past practice. Budgets must continue to grow to keep up with the massive expansion of steel structures from WWII to now. Utilities will have to be both forward and backward looking. Utilities must be backward looking from the standpoint that they need to see the large numbers of second-generation steel structures, many now over 40 years old and with little maintenance performed since construction, and the maintenance that is now required because of their age. This is where the utilities will need to be forward looking to develop maintenance budgets to address maintenance problems in a timely fashion. If performed correctly, these maintenance functions will save money for the utility owners by reducing outages and costly emergency repairs. It is always more cost effective to be proactive rather than reactive. The government has also begun to take notice of the need for maintenance to prevent and control corrosion, from both an economic perspective and a security standpoint. Talk of potential government mandates for structure corrosion control increases as the importance of the reliability of the electric grid is better understood.

The Good News

The reality of a transmission system comprising aging structures is here and that is just a natural process of time. Line failures can be prevented by a proactive approach that includes correct inspections and proper maintenance. The good news is there are proven methods of ensuring the long-term, cost-effective protection of these structures. Experience has proven the viability and benefits of formal atmospheric and groundline maintenance coatings programs for steel transmission structures.

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