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Sweden Confronts Ground-Line Corrosion

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STEEL IN SOIL IS SUBJECTED TO COMPLICATED CORROSION CONDITIONS THAT DO NOT EXIST IN AIR. Corrosivity of soil differs with its composition and humidity, and can be estimated by measuring its conductivity, pH value and oxygen content. Soil corrosivity varies from country to country, from parts within a country and even in individual locations. Different soil layers below ground level can increase the problem of estimating corrosivity. In Sweden, some soils are particularly corrosive to steel.

The National Grid System in Sweden is supported by some 30,000 steel towers and about 22,000 wood poles. The oldest structure still in service is more than 80 years old. The first steel towers were built above ground on concrete foundations, but tower construction standards soon changed. Tower legs were elongated, buried in the soil and placed on a foundation 2 m to 3 m (6.5 ft to 10 ft) below ground level (grillages). The steel towers comprise two or three tower legs linked at the top by a steel crossarm, and often both steel-tower and wood-pole supports have steel stays. A large section of each steel tower and stay are buried in the ground and, therefore, directly exposed to a variety of different soils.

METHODS OF CORROSION PROTECTION

To protect sections of buried steel from corrosion, a variety of methods have been tried and evaluated in Sweden. For a short period, steel foundations were dipped in hot tar. After five years, investigation of these towers showed corrosion of the buried sections and that method was abandoned.

Following the introduction in the 1930s of grillages, the main sections of the steel towers were hot galvanized with 110 µm of zinc, a practice that continued until 1954. Analyses of soils and corrosivity measurements were taken on each selected tower position. Additionally, the conductivity (soil resistivity), pH value and type of soil were determined on layers below ground level. Each tower was then considered individually in terms of the corrosion protection to be employed.

Towers exposed to the most corrosive soils were protected with an extra rust allowance of the steel, hot galvanizing and two layers of 0.5-mm-thick zinc plate welded to the tower leg and wrapped around the sections buried in soil. Finally, the whole “package” was dipped in hot tar. The towers subjected to this protection would likely have a long life, but this method was expensive and intensive development took place to increase the thickness of galvanized zinc.

Between 1955 and the late 1980s, the corrosion protection consisted of increased tower steel sections combined with a zinc layer of a minimum 200 µm. Another method involved taping the steel. These methods proved unsuccessful due to seasonal motions caused by frozen soil cycles. As a result, Sweden's towers today are often erected above ground on a concrete foundation, even though the stays are constructed in hot-galvanized steel rods directly buried and exposed to the soil.

CORROSION CAUSES

All steel in contact with soil is subject to corrosion. Also, local conditions can cause unequal corrosion; the rate is normally around 5 µm/year to 10 µm/year, but can vary between 0 µm/year and 50 µm/year.

The copper earth mats can cause galvanic corrosion. Copper in direct electrical contact with the tower steel increases the rate of the corrosion: 500 µm/year and even higher have been measured. Steel stays on wood poles have broken due to galvanic corrosion after only 10 years in service. The corrosion rate on steel towers caused by galvanic action is much smaller than that of the stays. The tower has a much larger area exposed to the soil, and corrosion proceeds more evenly on this large area.

MEASURES TO DECREASE CORROSION

Svenska Kraftnät, owner of the national grid in Sweden, started a project in 1994 to determine if Sweden would have severe problems with corroded steel towers in the near future, and if it would be possible to identify those towers at risk without screening every tower.

To address these issues, four transmission lines from different locations, built since 1955, were chosen to represent different circuits up to 40 years old. Older lines were omitted as they were deemed to have a longer life because of the careful analyses of the soil and individual treatment during construction. The selected transmission lines were systematically investigated starting with a study of geological maps and construction drawings. Field measurements of soil conductivity, pH value and electrochemical potential were made, and the steel below ground level was visually inspected.

This investigation concluded that a significant number of towers were in excellent condition and could be left without any concern for several years. However, a large number of towers had lost their corrosion protection and remedial action was required. The investigation also revealed that measurement at tower positions together with theoretical investigations can indicate lines and towers with severe corrosion exposure without doing extensive below ground level screening.

Thus, a large-proportion corrosion study can be done theoretically, minimizing expensive fieldwork. The exception is towers sited in saturated clay: corrosion is evenly spread on the buried sections and cannot be identified without local excavation.

On towers where corrosion has substantially decreased the dimensions, mechanical reinforcement has to be used to maintain the structural strength of the tower. To date, this practice has been limited to reinforcing the tower in the area just above and below ground level where a new steel section can be bolted to the corroded tower leg. Steel stays can simply be replaced if corroded.

FURTHER WORK

The result of this project indicated the need for further study. A larger three-part project was established to optimize the maintenance of the aging buried tower sections. The principal parts of this project are as follows:

1. **Identify towers with severe corrosion**

   This objective has led to a working scheme, including theoretical work and fieldwork, to identify so-called “risk towers,” while minimizing the number of tower footings to be excavated. Currently, the procedure often used starts by surveying 10% of the towers supporting the line under investigation. These towers are subjected to theoretical investigation (for example, geological maps and construction drawings) and are visually inspected with the footings excavated. Based on the results, a corrosion treatment is determined. All of the towers are then inspected, further measurements are taken if required and treatment is performed where necessary. Following inspection and treatment, the towers are expected to remain in service for another 20 years without maintenance.

2. **Investigate different abatement methods**

   Sweden has determined different methods to stop or suppress corrosion damage:

   - Mechanical strengthening of the structure
   - Cathodic protection with local and remotely located anodes
   - Spray painting with zinc
   - Local filling with concrete
   - Replacement of the underground sections of the tower
   - Painting.

3. **Awareness**

   To increase knowledge among utility procurement staff about corrosion-protection methods and provide support for contracts involving transmission line construction or rebuilds.

CATHODIC PROTECTION

One of the most promising methods of protecting the underground tower sections is cathodic protection. This method has been used for many years in other industries such as pipelines and harbors. The corroding object (the tower) is the cathode in an electrochemical cell. The electrode potential of the metal is then displaced in negative direction to a value below its steady-state corrosion potential. This way, the dissolution is prevented (complete cathodic protection) or at least counteracted. Cathodic protection is divided into galvanic and electrolytic according to the following scheme:

Galvanic cathodic protection of steel

The corroding object is made the cathode of a galvanic cell, the anode of which is a base metal (for example, magnesium, zinc and aluminum) that is sacrificed to protect valuable construction.

Electrolytic cathodic protection of steel

The corroding object is made the cathode of an electrolytic cell, which is supplied with impressed direct current from an external current source. The anode of this cell is usually insoluble (platinum, lead, carbon, nickel).

Galvanic cathodic protection with remotely located anodes has been tested in Sweden on several occasions since the mid-1950s. Since 1995, sacrificial anodes have been buried close to the towers and the oldest installations are still running successfully. As the anodes are consumed, they have to be replaced after some years. This has proven to be a safe and economical method, and applications of this form of protection in Sweden are increasing. Recently, the method using sacrificing anodes has been installed on numerous towers on two transmission lines. On one line, the anodes are placed at the intersection between air and soil. On the other line, the anodes are placed in special soil backfills to protect all the tower steel below ground level.

During 2005, sacrificial anodes were installed on another important transmission line to solely protect the steel stays, as the towers placed on concrete above ground level do not require protection. The photo on page 65 shows Sweden's first line built for 800 kV but, due to political reasons, now used for a 400-kV twin-conductor transmission line, which will have cathodic protection.

OLD PAINTED TOWERS

In the 1930s, many towers were painted with lead-based paint covered with alkyd, and the foundations were covered by tar. After more than 70 years in direct contact with the soil, these foundations are almost intact. The tower sections above ground level have been repainted at least once, but the tower legs can be subject to severe corrosion at the intersection between ground and air. By careful measurement of the remaining section in these positions and compared with a computer analysis, it is possible to determine the mechanical strength of these sections. The results can then be used to determine which alternative solution to adopt, namely by strengthening the tower legs, installing cathodic protection or leaving the tower untreated. In this way, each tower is treated individually and the most cost-effective remedial maintenance is selected.

RESEARCH CONTINUES

There are several solutions available for the remedial maintenance of corroded overhead line steel towers, but research and development work on this particular problem is vital and continues. In Sweden, the development work and pilot projects increase the knowledge database but it still remains difficult to predict the increased life span that the various protection methods offer.

Tower corrosion is caused by an electrochemical process normally studied by metallurgists; therefore, it is difficult to train utility staff on how to select the most appropriate form of protection to use in each location. Hence, in the absence of specialist knowledge, decisions are often made to replace the tower rather than install a more economic solution such as cathodic protection. Also, it is often considered easier to do nothing because the problem seems so complex, but utilities that overcome this problem by establishing a comprehensive tower maintenance program will reap considerable economic benefits.

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