CORROSION EVALUATION METHODS FOR POWER TRANSMISSION LINES

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METÓDY VYHODNOCOVANIA KORÓZIE ENERGETICKÝCH SIETÍ

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Abstrakt

Prevádzkovanie a udržiavanie elektrických sietí vyžaduje presné znalosti o stave komponent siete, aby bolo možné vyvinúť cenovo efektívne programy na predĺženie ich životnosti. Tento článok popisuje testovacie a vyhodnocovacie metódy používané na zhodnotenie stavu komponent siete. Pretože korózia je primárnou príčinou degradácie siete, dôraz je kladený na detailnú diskusiu o najčastejšie používaných metódach koróznych testov v praxi.

Abstract

Maintenance and refurbishment of in-service electric power transmission lines require accurate knowledge of components condition in order to develop cost effective programs to extend their useful life. This paper describes testing and evaluation methods that are used to assess the line components. Since corrosion is the primary cause of in-service line deterioration, the focus is on detailed discussion of corrosion testing methods that are most frequently used in current practice.

1. INTRODUCTION

Corrosion of electric power transmission lines is a primary cause of in-service equipment degradation. An integral part of the effort to mitigate corrosion processes is the use of standard and non-standard testing methods for corrosion prevention, correct recognition and damage extent determination. Corrosion testing is also used in equipment design, manufacture, and service life extension.

In the following, discussion will be directed principally to those corrosion testing methods that are used most frequently in current practice.

Power transmission is a mature technology, which has evolved into an optimised system with a very high reliability based on utilisation of traditional low cost materials and maintenance procedures with a predictable performance. Thus, the most frequently employed corrosion protection measures are those used for quality control tests during manufacture, performance maintenance, and service life extension.

2. MATERIALS OF FABRICATION AND ENVIRONMENT

The power transmission system in North America consists of equipment, which has been built up since the turn of the century. Although, the design of individual components has changed, the materials of construction remained virtually the same: steel and cast iron (bare, painted or galvanised), aluminium alloys and copper alloys, porcelain, glass and wood. To enhance the corrosion resistance of these materials various treatments, coatings and inhibitors are applied.

The continued integrity and soundness of the power system components depend mainly on the control of corrosion. The severity of this metal wastage and ageing process is governed by the aggressivity of the environment.

Traditionally, the atmospheric environment is classified as industrial, marine, urban, or rural. Recently, efforts have been made to classify the atmospheric corrosivity based on atmospheric data (estimated) or standard panel testing (measured). The atmospheric corrosivity categories range from benign to severely corrosive. This classification is practical for design, scheduling of maintenance and refurbishment planning.

Table 1 Main causes of line components deterioration and typical estimates of service life

Component	Cause of Deterioration	Life to Failure (yrs)	Typical Asset Life (yrs)
Conductor (ACSR)	Corrosion, Creep Mechanical Fatigue	60-80	50
Overhead Ground Wire -Galvanised Steel	Corrosion Mechanical Fatigue	30-40	45
Structures - Steel - Wood Pole	Corrosion, Rot, Woodpeckers, Ants	100+ 30-40	 55
Foundations			
- Grillage	Corrosion	100+	
- Concrete	Spalling	100+	55
-Insulators	Cracking Cement Growth Lightning Vandalism Corrosion	40-80	55
Hardware	Corrosion Mechanical Fatigue	40-80	40

Corrosion of buried power line components is governed by diffusion of dissolved oxygen in the water entrapped in the soil resulting in the average corrosion rate of zinc and steel being about the same. Copper and lead, which form corrosion barrier films, show lower corrosion rates. In marshy and swampy areas, anaerobic sulphate-reducing bacteria (SRB) enhance the corrosion rate of steel significantly. Soils are classified into five classes, which have been found to correlate with soil resistivity as measured by the Wenner 4-pin method. These classes range from very low corrosivity (Resistivity >10,000 Ωcm) to very high corrosivity (Resistivity <1000 Ωcm).

3. CORROSION PROBLEMS

Numerous studies have shown that corrosion is the main cause of power line deterioration, and that it affects all components. The Table 1 gives main causes of line components deterioration and typical estimates of service life.

There are ten broad classes of significant corrosion damage, which lead to loss of component function and/or integrity if not remedied. These are:

- General Corrosion
- Pitting Corrosion
- Crevice Corrosion
- Exfoliation Corrosion
- Stress Corrosion
- Corrosion Fatigue
- Hydrogen Embrittlement
- Galvanic Corrosion (dissimilar metal, differential aeration)
- Stray-Current Corrosion
- Coating Damage and Deterioration
- Microbial Induced Corrosion
- Rotting of Wood

4. CORROSION EVALUATION

In recent years, the emphasis of power line operators has been on predictive/preventive maintenance to ensure reliable and safe operation. Breakdown maintenance is becoming a thing of the past. Crucial elements of this approach are consistent application of the most up-to-date technological know-how and systematic surveillance of the condition of power lines.

Corrosion tests are an integral part of a wide variety of methods (techniques and tools) employed to establish the condition of overhead lines so as to devise the most suitable approach for maintenance and refurbishment. Although the information needs for maintenance are different from those for refurbishment, investigation and surveillance methodologies are practically identical. To establish the overall condition of the line for a refurbishment program a detailed "snapshot in time" is needed. In comparison, a limited periodic survey continuing across the whole system over an extended duration is needed to determine maintenance requirements.

The most common method of power line inspection is visual assessment, performed from the ground by foot-patrol or from the air during routine helicopter surveillance. This is a very efficient method, but must be used in conjunction with instrumental, chemical, biological, electrical and electrochemical methods followed by laboratory failure analysis to obtain a true picture of future maintenance or refurbishment work required.

Foundations

Degradation of foundations enclosed in concrete or grillage-type can be best assessed by excavation. This is the most rigorous method since it allows determination of the extent and type of corrosion attack, including possible involvement of microbial induced corrosion. To minimise excavation at every footing, tests to indicate the presence of stray current and/or galvanic corrosion can be used. Stray current and galvanic corrosion can be identified by potential surveys of the footings with a $Cu/CuSO_4$ half-cell reference electrode.

New galvanised steel footings, when buried will exhibit a potential of -0.85 to -1.1 V. After the galvanising is lost, the newly exposed bare steel surface will have a potential between -0.5 V and -0.7 V. Corroded steel with a heavy scale will have a potential between -0.3 V and -0.5 V. In addition to the potential survey, an electrochemical polarisation technique was developed to determine the rate of galvanic corrosion [1]. The device operates by passing a small current between the tower footing and a probe inserted into the ground nearby. These currents perturb the electrochemical processes at any active corrosion site and the resulting changes in potential are measured with reference to a $Cu/CuSo_4$ half cell in contact with the ground close to the footing. The level of current required to displace the corrosion potential indicates the severity of the corrosion process in progress. This instrument provides results, which are a useful guide to the relative condition of the footings, but not an absolute measure of the metal wastage [2]. For concrete footings, the scale of potential readings is greatly affected by the high resistance of the concrete. Great care is required to interpret the readings.

Towers and Tower Steel

Determining correctly the type and extent of power line tower component damage is essential for making proper assessments of the structure condition and for recommending the specific place of action to ensure safe and reliable operation. Component damage is defined as degradation leading to loss of load bearing capacity, which would, if not remedied, lead to tower failure.

The type and extent of the component damage caused by corrosion is determined during field inspection from [3]:

Detailed visual inspection,

Measuring loss of cross-section and physical shape deformation,

Measuring protective (galvanising and/or paired) coating loss, and

Measuring contamination on surfaces.

During visual inspection, the type of corrosion damage is established at locations where the protective coating was lost. The extent of the corrosion damage must be accurately determined to: assess structure's fitness for service, estimate the remaining service life and recommend maintenance, refurbishment or replacement of the line. The techniques and methods used to gauge the corrosion attack are standard and excellent instruments for field and/or laboratory use are readily available.

Breakdown of the protective coating occurs usually by a combination of erosion and physical damage. The extent of erosion (loss of thickness) of an intact coating can be measured by a variety of methods. These include destructive (scribing), magnetic pull-off, magnetic flux, eddy current, ultrasonic, etc. gages.

The extent of protective paint physical damage can be determined utilising standard methods for evaluating the degree of rusting on steel surfaces [4,5] and paint coating degradation [6,7,8,9].

Change in colour is an indication of the galvanised coating condition. As galvanizing weathers, it loses its brightness and turns dull grey and becomes progressively darker grey as it gradually corrodes. The appearance of yellow and reddish-brown colour indicates that the pure zinc coating has been lost and corrosion has reddened the zinc-iron amalgam layer. This is the optimal time to paint the structure [10]. When the coating is lost, the surface of the bare steel becomes covered with dark-brown corrosion scale.

The contamination of tower surfaces with aggressive chemicals can lead to enhanced corrosion and deterioration of protective coatings. Although, the methods of detection and determination are not standardised, several test methods [11] are accepted by the industry. Surface contamination analysis kits are available [12] to measure pH, chlorides (detection limit 40 ppm) and soluble ferrous ions (detection limit approximately 3 ppm). In most cases these detection limits are sufficient to establish the aggressivity of the operating environment and surface cleanliness before painting.

Wood Structures

Wood pole condition has traditionally been assessed by the sound of an impact on the pole or the condition of a cored sample of the wood. Recent developments include non-destructive test procedures, which offer more refined assessment of wood pole condition. A device based on the measurement of the passage of ultrasound through the wood has been developed [13]. The condition of the pole can be assessed, provided there is an adequate database to calibrate the signal delay time against the measured strength of the particular wood species. The device can only indicate the condition at and above the ground line.

Hardware

Corrosion is a contributing factor to wear damage to hardware caused by aeolian vibration. This damage is very difficult to detect from the ground [14]. Initially, x-ray equipment was taken to the field to enable detection of internal cracks or conductor strand breaks within clamps. This was a cumbersome, slow and costly procedure, and had to be done with the line deenergized. More recently, a live line technique using a gamma ray source on hot sticks, has been developed which permits detection of the internal damage in a practical manner.

In highly corrosive environments, such as marine environment, the effect of atmospheric corrosion on hardware materials using a series of 'CLIMAT' devices [15] can be established. These devices consist of aluminium wires wound tightly around threaded plastic rods. The weight loss during a 90 day period is measured to indicate the level of corrosion activity and allows mapping of the area in terms of air aggressivity index (Atmospheric Corrosivity Index). These data are valuable to schedule maintenance and evaluate new materials.

Insulators

In marine and highly polluted environments, the steel components of insulators corrode at an accelerated rate. Galvanising protection is lost early and the remaining steel forms voluminous oxide scales. The growth of these scales induces large stresses in the ceramic parts leading to cracking, spalling and failures [1]. This type of ceramic insulator cracking can be detected by any electrical resistance testing.

Overhead Ground Wires

Galvanised steel overhead ground wires age during service and corrosion is a major contributing factor to this process. A standard torsional ductility test [16] is used to determine the remaining life. Based on experience, wire which would break in less than six turns is considered to be at the end of service life.

Conductors

The service life of power lines is limited by deterioration of the most vulnerable component: the conductor. The deterioration processes include creep, mechanical fatigue and corrosion. Both traditionally used materials in conductor construction (aluminium alloy and galvanised steel) are prone to corrosion. It was shown [17] that the aluminium alloys suffer from accelerated corrosion in coastal areas, while inland in industrial areas; corrosion attack of the galvanised steel core is more prevalent.

Helicopter borne infrared sensors are employed [18] to inspect power lines for aluminium corrosion. This method is suitable for detection of severe corrosion with many strands distorted and bulging. Early corrosion damage can not be effectively detected.

The condition of the steel core is a key indicator of the remaining useful life of the conductor. The first step in this assessment is the use of a galvanised steel corrosion detector on in-service lines. Two similar detectors have been developed, tested and used: one based on an eddy current technique [19] and the second one utilising an electromagnetic induction [20, 21] principle. The second assessment step is the same as used for overhead ground wires [16], a standard torsion test. Unfortunately, neither of these test methods is adequate to provide sufficient information on which refurbishment decisions can be made. Alternate methods are being developed and evaluated at Ontario Hydro Technologies.

To prioritise maintenance and refurbishment, and select the most suitable materials of construction, the aggressivity of the environment must also be established. Passive corrosion tests are the most economical way of mapping large areas accurately. The CLIMAT test [15] and a test [17] comprising of zinc cans and aluminium wire twisted around steel bolts are used most frequently.

5. CONCLUSIONS

Most of the corrosion problems in power transmission can be reliably detected and assessed using conventional and well established corrosion testing instruments, practices and methods. Data, from both field and laboratory, are essential for the implementation of ameliorative measures, and must be interpreted in conjunction with a quantitative understanding of ageing processes before information can be provided for effective decision making. Corrosion control technology available today can, in a cost-effective way, improve reliability, performance and safety of transmission lines.

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