# DIAGNOSIS OF CORROSION PROBLEMS IN UNDERGROUND ELECTRICITY DISTRIBUTION EQUIPMENT

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# DIAGNÓZA KORÓZNYCH PROBLÉMOV V ZARIADENIACH PODZEMNEJ DISTRIBÚCIE ELEKTRICKEJ ENERGIE

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## Abstrakt

Presná diagnóza korózneho poškodenia podzemných a nízkokvalitných kovových častí zariadení na distribúciu elektrickej energie je dôležitá pre spoľahlivosť zariadení, investícií do bezpečnostných opatrení a zníženie nákladov na výmenu poškodených častí. Bol vyvinutý expertný systém ktorý asistuje pomocnému personálu počas inšpekcie zariadení a/alebo analýze porúch za účelom rozpoznania, identifikácie a zhodnotenia korózneho poškodenia. Program vedie užívateľa procesom analýzy stavu zariadenia kladením jednoduchých otázok pričom odpovede na ne je možné získať určením typu zariadenia, jeho umiestnením, súčasného prevádzkového stavu, materiálového zloženia a rôznych parametrov ktoré môžu byť merané za účelom detekcie korózie a určenia jej rozsahu. Báza vedomostí použitá v tomto expertnom systéme obsahuje všetky potrebné informácie k určeniu a vyhodnoteniu korózie zariadenia systému distribúcie energie ako aj k návrhu potrebného opatrenia.

## ABSTRACT

Correct diagnosis of corrosion damage of buried and below-grade metal equipment belonging to electric power distribution utilities is essential to maintain reliability, safeguard investment and avoid equipment replacement costs. An expert system package was developed to assist utility personnel during equipment inspection and/or failure investigation to recognize, identify and assess corrosion damage. The program guides the user through the equipment investigation process by asking simple questions, answers to which can be obtained by determining the equipment type, location, current service status, material of construction, and various parameters which can be measured to detect corrosion and establish its extent. The knowledge base used in this expert system contains all pertinent information to detect and evaluate power distribution system equipment corrosion, and suggest a corrective action.

**Key words:** underground corrosion diagnosis/protection, electricity distribution, buried equipment, expert system

## INTRODUCTION

The reasons for attention to underground corrosion on any electric system with distribution lines that are partly or wholly underground are strong and compelling. The amounts invested and the costs of equipment replacement are to great to risk the premature failure and possible need for replacement.

Although there is a considerable body of knowledge available about the causes and prevention of corrosion of buried metal equipment and structures, the control of underground corrosion is largely a science of experience.

Furthermore, most of this knowledge is inapplicable to power distribution systems because of different metals (copper vs. steel) are used, special grounding requirements, physical dispersion of the equipment, etc. However, significant advances have been made in the past such that reliable and economical methods exist to effectively control underground corrosion of below-grade power distribution systems.

These systems typically involve guy anchors, grounding systems, tower footings, submersible transformers, copper concentric neutral cables, buried aluminum and lead sheathed cables. All of these equipment are susceptible to corrosion and thus must be protected, surveyed and maintained to ensure safe and reliable operation. Because of the complexity of the system and the corrosion problems, these are not trivial tasks. One of the main obstacles which the utility personnel, responsible for corrosion controls, must overcome when solving equipment problems related to corrosion is accessibility to up-to-date, complete and evaluated expertise.

Recent developments in the information technology (both hardware and software) make possible to overcome the problem of expertise accessibility through use of powerful computers and intelligent software. Necessary tools exist today to build programs, which enable the user to retrieve information efficiently, and interpret and apply it more effectively than ever before. These programs, called expert systems or knowledge-based systems, are effective tools for the transfer of knowledge, accumulated in guidelines, summaries, private communications, etc. and personal experience, into a computer- accessible and user-friendly format.

To aid utility personnel to control underground corrosion of power distribution systems, an expert system called CORUND was developed. This computer program is intended to act as guide in diagnosis and amelioration of corrosion related problems. Due to diversity of detailed designs in use by different utilities, the program was assembled to provide advise on how to apply the principles of good corrosion control practice to a variety of situations encountered in utility practice. This generic information can be, if necessary, supplemented to incorporate local practices, regulations, heuristics, etc. In other words, the expert system can be easily customized to suit local utility requirements. Furthermore, it can be updated as frequently as necessary to include new practices and reflect changes in local regulations.

## SOURCE OF KNOWLEDCE FOR EXPERT SYSTEM "CORUND"

The acceptance of an expert system undoubtedly depends on the credibility of its knowledge base. In the conceptual design of this expert system, two criteria were adopted for selecting the main sources for the factual portion of the knowledge base. The facts should have been: ( i ) published in public domain so that their reliability could be judged; and ( ii ) accepted by the practicing experts in the area of corrosion control of electric power distribution systems.

Out of numerous publications on this subject in open literature, two publications where chosen: "Underground Corrosion Control - Guide for Rural Electric Systems" [1] prepared for the National Rural Electric Cooperative Association in 1982 and "Power System Corrosion" [2] prepared for the Canadian Electrical Association in 1983. These two publications met both acceptance criteria and formed the factual framework for this expert system.

Based on facts extracted from these two publications and heuristic components contributed by the developer of this expert system, a knowledge base was constructed which contains all pertinent information to detect and evaluate power distribution system equipment corrosion and suggest a corrective action. A brief summary of this knowledge is given in the following Section.

## CORROSION AND PROTECTION OF BURIED METAL

Corrosion of buried metal in aqueous environment such as soil is an electrochemical process. Typically a corrosion cell is composed of an anode, a cathode, an electrolyte in which both the anode and cathode are situated and an external electrical path between the anode and cathode. In this cell the anode corrodes. In this process, metal is ionized (oxidized) and positively charged ions leave the surface of the metal and enter the soil. Various metals have different tendencies to corrode, the most active are those with the most negative electrochemical potential. The anode corrosion causes electric current flow in the electrolyte toward the cathode, returning through the external electrical path to anode. The rate of metal weight loss from the anode is proportional to the corrosion cell current.

Corrosion cells develop when two different metals are in electrical contact, same metal is exposed to two different environments and due to externally induced stray currents.

The fact that corrosion cells exist does not necessarily mean serious damage will occur. Several factors can limit the corrosion process. Specifically, high soil resistivities tend to reduce currents and damage as does the involvement of anodes and cathodes between which there are only modest electrical potential differences. Furthermore, galvanic cells in which the anode area is large in comparison to the cathode area will result in less damage than if the reverse were true.

Corrosion prevention is thus based on methods which make the corrosion cell less active or prevent its operation. These are:

materials selection

environmental control

protective coating

cathodic protection

Noble metals or special alloys such as stainless steel are frequently used to reduce corrosion of buried equipment. However, selection of compatible materials such that there is not a mixture of different metals electrically interconnected and buried is probably of greater significance. When more than one metal must be used, corrosion problems will be minimized if the surface area of the anodic (least noble) metal far exceeds the cathode area.

Environmental control to prevent corrosion is usually restricted to draining away corrosive ground water from underground equipment vaults. The use of special high resistivity backfill material is also an option if it is not too expensive or rendered ineffective due to the influence of the surrounding indigenous soil.

Protective coatings are effective in preventing corrosion but should never be assumed to achieve 100% coverage. Coatings should be used only on cathodic areas, equipment where rapid localized corrosion will not present a service problem, and in conjunction with cathodic protection.

Cathodic protection is an electrical method of reversing a corrosion cell that works by polarizing the structure to be protected negative (i.e., making it a cathode) such that metal cannot ionize and enter the surrounding soil. The cathodic polarization can be achieved by use of a sacrificial anode (a more active material such as zinc or magnesium) or by applying direct current from an external source.

The mitigation of corrosion caused by stray currents can be tackled in several ways: eliminating the source, providing a low resistance bond to divert stray current from a relatively high resistance path through the soil, applying protective coatings in areas of current pick-up, inserting insulators and installing cathodic protection systems.

## Guy Rods

Guy rods usually corrode in a non-uniform manner called penciling. Penciling corrosion results from corrosion cell formation due to different oxygen levels in the soil along the length of the rod, interconnection with dissimilar metals (typically a copper grounding system), or stray current corrosion such as from a transit system or a cathodic protection rectifier installation. In addition, corrosion can occur in the vicinity of the wood (e.g., wooden slug anchors) under many soil and moisture conditions. Uniform corrosion of guy rods is seldom seen and is not as serious as penciling since for a given corrosion severity, the mechanical strength of the rod does not deteriorate as rapidly.

Differential aeration and localized uniform galvanic corrosion cannot be detected by electrical measurements. Both galvanic and stray current corrosion, however, can be detected by measuring the current in the guy wire. This is most practically accomplished using a clamp-on milliammeter. Current readings can be converted into metal wastage to determine whether anchor rod replacement is required.

Electrical isolation of the guy anchors is frequently effective in eliminating the guy rod corrosion problems. However, this may be forbidden in some jurisdictions. Epoxy or other high quality coatings applied to rods can be effective, but care must be taken to not damage the coating upon installation since the damage will hasten failure. Cathodic protection of individual anchors by small prepackaged zinc or magnesium anodes is also effective.

**Ground Rods**

The corrosion of ground rods results basically in the same type of metal wastage as with anchor rods (eg., penciling). Similarly, the corrosion causes are practically the same being either galvanic or stray current origin.

The extent of corrosion can be assessed by various non-destructive testing methods which include resistance measurements, ultrasonic pulse-echo testing, ac and dc ground rod-to-earth potential measurements, and ac and dc current flow measurements.

Since copper clad steel rods are usually cathodes in underground corrosion cells and hence have a longer service life than bare steel, which is anodic to copper and reinforcing steel in concrete. Under stray current corrosion conditions, there is no relative advantage to either copper or steel.

As a general rule, grounding systems consisting of dissimilar metals should be avoided to minimize galvanic corrosion attack. Copper is the preferred choice for grounding systems provided that supplementary cathodic protection is applied when feasible.

**Tower Footings**

The expected service life of tower footings is between 20 to 30 years before significant corrosion occurs. Therefore, corrosion is not considered a serious problem. Although the practice of supporting galvanized tower footings above grade on reinforced concrete has eliminated many corrosion problems, there are isolated cases of accelerated corrosion. For example, inadvertent flooding around galvanized tower legs caused by grade changes or beaver dams can result in a serious corrosion problem, even on newly built transmission lines. Fortunately, these problems can be identified by visual inspection. Another serious corrosion problem can arise from stray currents due to neighboring cathodic protection systems. Investigation should be performed using potential and current measurements. Effective mitigation of this problem can be as simple as isolating the tower from the sky-wire in both the stray current pick-up and discharge zones.

The options for general corrosion prevention include galvanic cathodic protection, proper materials selection and environmental control.

**Copper Concentric Neutral (CCN) Cables**

Copper concentric neutral cables are susceptible to both general and pitting corrosion. This corrosion is caused by formation of concentration cells: differential aeration and copper ion concentration type. The extent of corrosion is therefore governed by the degree of soil aeration and solubility of copper corrosion product. Thus, the corrosion rate in coarse soils or backfills, and in soils containing high concentration of chloride and ammonia ions can be significant.

The corrosion problem of CCN cables buried bare can be overcome very effectively by application of cathodic protection. Long lengths of cable can be protected easily with either sacrificial or impressed current systems. This is so, because -300 mV polarization can be achieved with current densities of fraction of a milliampere per square foot.

The CCN cables inside ducts can be successfully protected by cathodic protection only when the duct is continuously flooded. If not, measures must be taken to seal the ducts to eliminate alternating moist and dry conditions.

To avoid corrosion problems and the need to install cathodic protection, new installations should be jacketed with an insulating material.

**Submersible Transformers**

Transformers which are directly buried or placed in vault enclosures are exposed moist soil or vault water. Under these conditions the steel transformer tank is susceptible to galvanic corrosion because of interconnected dissimilar metals. The rate of metal wastage is dependent on the cathode-to-anode surface ratio and the electrolyte resistivity. Since most transformer tanks are coated, the cathode-to-anode surface ratio in a galvanic cell is large.

Replacement of coated carbon steel by stainless steel or use of a better coating are not very good corrosion prevention measures. Firstly, stainless steel is vulnerable to chloride induced pitting corrosion. Secondly, it is practically impossible to obtain a perfect coating at a reasonable price.

The best way to protect directly buried transformers is to apply a good quality coating and install cathodic protection.

Transformers enclosed in vaults are best protected by draining the vault. Drained vaults should be inspected periodically to ensure that they are free of debris and that the transformer is not exposed to ground water flooding. If draining is not feasible, a good quality coating in conjunction with the cathodic protection should be used.

For new or replacement installations, the benefits of placing transformers in above ground enclosures should be considered whenever physically possible.

**Aluminum**

Components made of aluminum are usually subject to corrosion attack in the form of pitting. This is due to the fact that aluminum is almost always anodic in soil to other metals such as copper.

Aluminum is subject to rapid corrosion under dc stray corrosion and ac leakage currents, since it is subject, under certain conditions, to both cathodic as well as anodic corrosion.

To prevent aluminum attack, the components should be jacketed with insulating material or protected by cathodic protection. Polarized potentials more negative than -1200mV with respect to a $Cu/CuSO_4$ electrode must be avoided to eliminate possibility of alkali attack.

**Lead Sheathed Cables**

Electric utilities have been using lead sheathed cables successfully for many years in both direct burial or duct service. This performance record is largely due to excellent corrosion resistance in neutral aqueous environments containing sulfates, silicates, etc. Due to its amphoteric nature, lead corrodes rapidly in strong acids and alkalies. The vulnerability to attack by alkalies makes this metal susceptible to stray current corrosion. The attack occurs when the current is interrupted or varies with time. The alkaline layer, which forms on the surface of the cathode at the current pick-up location becomes corrosive when the protective potential is interrupted. In addition, lead is attacked at the stray current discharge location (anode).

Mitigation techniques involve various types of electrical bonding techniques, electrical insulation of stray current source grounding systems, jacketing and cathodic protection (minimum polarization potential -700 mV with respect to a $Cu/CuS0_4$ electrode). Care must be taken not to exceed polarized potential of -1500 mV.

## "CORUND" EXPERT SYSTEM PACKAGE

### Expert System Development Package

EXSYS [3] is a generalized expert system development package. Expert system is a type of artificial intelligence program that emulates the interaction a user might have with a human expert on a subject area. Expert systems developed with this package will ask user questions relevant to a subject. The user answers by selecting one or more answers from a list by entering a numeric value. The computer will continue to ask questions until it has reached a conclusion. The conclusion may be the selection of a single solution or a list of possible solutions arranged in order of likelihood. The computer can explain, in English, how it arrived at its conclusion and why.

Expert systems can be developed with this package for any problem that involves a selection from among a definable group of choices where the decision is based on logical rules. The rules can involve relative probabilities of a choice being correct. Any area where there is a person or group of persons that have special expertise needed by others is a possible area for EXSYS. Anything from identification of biological specimens, to automating complex regulations, to aiding customers in selecting from among a group of products, to automated user assistance is possible.

Expert systems deal with knowledge rather than data and the files they use are often referred to as knowledge bases. The rules that the program uses are IF/THEN type rules. A rule is made up of a list of IF conditions (normal English sentences or algebraic expressions) and a list of THEN conditions (more sentences) or statements about the probability of a particular choice being the appropriate solution to the problem. If the problem determines that all of the IF conditions in a rule are true it adds the rule's THEN conditions to what it knows to be true. The program determines what additional information it needs and how best to get this information. If possible, the program will derive information from other rules rather than asking the user. This ability to derive information allows the program to combine many small pieces of knowledge to arrive at logical conclusions about complex problems. The rule editor allows the rules to be easily modified, added or deleted.

The final goal of an expert system is to select the most appropriate solution to a problem based on the data input by the user. If more than one solution is possible the program will provide a list of the possible solutions arranged in order of probability.

### Knowledge Organization and Utilization

This expert system was developed as a guide to diagnosing corrosion problems of buried or below-grade metal equipment for electric power distribution. It is intended to assist the utility personnel responsible for corrosion control to become informed, select and assess results of field tests and provide advice on need and type of ameliorative measures.

The first step in representing the knowledge was the creation of a decision tree structure incorporating the facts from the two publications [1,2] and heuristic components contributed by the developer of this expert system. Then the facts were expressed in the form of production rules using an expert system development package.

The process begins with establishing the type of equipment under investigation:

guy wire anchor rods

ground rods

tower footings

copper concentric neutral cables

submersible transformers

aluminum components

lead sheathed cable

Some equipment may not be buried bare and be located in vault enclosures or ducts. Frequently, it is necessary to drain flooded enclosures or remove debris before corrosion survey can proceed.

Next the program requests information on location and current service status of the equipment.

The service status of the equipment makes significant difference in the type of further action which is taken. If failed, type of equipment, material and measures to prevent future corrosion problems are recommended.

If the equipment is in service it is important to know the material of construction, since the results of corrosion survey tests can be properly interpreted only when this information is available.

The type of tests which are performed during the corrosion survey depend on the type of equipment, the availability of instruments, cost/benefit ratio of the tests and need to know. The program is built such that it guides the user to apply first least expensive and less technically demanding methods to detect the corrosion and then proceed to more sophisticated tests. These are:

current measurement (ac,dc)

voltage measurement

resistance of equipment components

soil resistivity

ultrasonic pulse echo type integrity evaluation, and

structure-to-earth corrosion and polarization

potential measurement

To support these tests the following analyses are frequently required:

water (pH, chloride concentration and electrical conductivity), and

soil (determine constituents which affect corrosion).

If the corrosion survey using the above tests is inconclusive and corrosion attack and its extent must be established, excavation is necessary. Assessment of excavated equipment, with results of corrosion survey tests usually leads to definite determination of corrosion cause and extent.

Determining the correct cause of corrosion attack is important for the prevention of future failures. Proper corrective measures can be undertaken to alleviate future problems only when the cause is correctly identified.

Lastly, the program provides advice on the need and type of ameliorative measures if the equipment is not considered suitable for continued service.

Although, this expert system is designed to guard against misinterpretation, the conclusions should be treated like any advice of a single expert. A second opinion is recommended if an incorrect conclusion entails great risks.

The user is assumed to be aware of local rules and regulations, which apply to the design, construction, surveillance and maintenance of the buried or below-grade power distribution equipment. Furthermore, it is anticipated that the user will seek advice and/or have sufficient experience and expertise to make decisions when the program is asking for instructions as to the need for further investigation, feasibility of protective equipment installation, etc.

To greatly reduce these risks and make the expert system more useful, it is recommended that it is customized to take into account local utility conditions. That is, rules and regulations, rules of thumb, experience, unique equipment use and mode of operation. Also, it is recommended that it is frequently updated to incorporate new procedures and regulations.

**EXAMPLE OF DIAGNOSTIC SESSION WITH "CORUND"**

This expert system is extremely simple to use because it asks a series of questions whose answers are given in a menu (multiple choice) format. Answers are chosen by use of only two keys (numerical and ENTER). Depending on the answer, the program determines the next question and so on. The end of the session is when enough information is entered into the computer to make a diagnosis.

For the purpose of this demonstration, an investigation of a carbon steel ground rod was chosen. This ground rod is functioning and it is necessary to know whether it is corroding. The only equipment which is available is a potentiometer and $Cu/CuSO_4$ reference electrode. The measurements of structure-to-earth corrosion potential indicate negative -800 mV. An example of diagnostic session is presented in the following.

First, the expert system requests information on the type of equipment. The user is asked to choose from seven different equipment shown on the first screen.

The equipment is ground rod, so the user enters 2. Then the system requests information on the service status of the ground rod.

The ground rod is in operation, so the user enters 2.

Since the equipment is still in service, the system asks if it is necessary to confirm its integrity.

It is suspected that the ground rod is corroding, therefore, confirmation of its integrity is required, the user enters 1.

Next the system tries to ascertain the availability of field survey instrumentation.

This instrumentation is not available, so the user enters 2.

This instrument is not available, so the user enters 2.

This measurement instrument is available, so the user enters 2.

In order to interpret results of ground rod-to-earth potential measurements it is necessary to know the ground rod material.

Ground rod material is carbon steel, so the user enters 2.

Next, the system asks which of the five categories the result of the potential measurement is in.

Since the measured potential (-800 mV) is more negative than the most negative value of typical corrosion potential of carbon steel in soil, user chooses 3.

Based on the provided information, the system performs diagnosis, selects recommendations and displays a summary on the screen.

The user, if interested, can obtain background information from the Appendices and Reference Section of the expert system package manual.

## SUMMARY

The CORUND expert system package was developed as a guide to diagnosing corrosion of buried and below-grade metal equipment belonging to electric power distribution utilities. It is intended to assist utility personnel during equipment inspection and/or failure investigation to recognize, identify and assess corrosion damage. The program guides the user through the equipment investigation process by asking simple questions, answers to which can be obtained by determining the equipment type, location, current service status, material of construction and various parameters which can be measured to detect corrosion and establish its extent. In a matter of seconds one can diagnose a problem with the same confidence as the best corrosion control specialists. The CORUND is based on a reliable information published in the public domain and accepted by the practicing experts in the area of corrosion mitigation.

The developed expert system is designed for ease of use, and no previous computer experience or computer programming knowledge is required. One simply follows the directions on the screen and refers to the manual if necessary.

## Literature


[1] Zastrow, O.W.: "Underground Corrosion Control - Guide for Rural Electric Systems," prepared for National Rural Electric Cooperative Association, NRECA Research Project 81-7, August 1982

[2] Gumnow, R.A. and Carr, J.: "Power System Corrosion," prepared for Canadian Electrical Association, Research and Development Project 091 D188, August 1983.

[3] EXSYS is an Expert System Development Package, available from EXSYS Inc., P.O. Box 75158, Contr. Sta. 14, Albuquerque, NM 87194, USA.