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Copper Grounding and Cathodic Protection In Nuclear Facilities

By
Earl L. Kirkpatrick, P.E.
ELK Engineering Associates, Inc.
8950 Forum Way
Fort Worth, Texas 76140
earlk@elkeng.com

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INTRODUCTION

Cathodic Protection (CP) and grounding conflicts are not unique to nuclear steam electric stations (NSES), but are also experienced throughout the fossil fueled fleet. The more conventional fossil fueled fleet operators have a long history with operation and maintenance of CP systems with varying degrees of success, ranging from excellent to dismal. The keys to successful implementation and maintenance of CP systems in power plants are: 1. commitment to monitoring and maintenance, 2. excellent record keeping, and 3. management commitment to funding needed repairs and replacements in a timely manner. We in the nuclear industry do have a clear advantage in the area of quality record keeping. The same may not always be said for the fossil fueled fleet. However, record keeping is only one piece of the puzzle.

As the NSES fleet continues to age, installed CP systems are nearing the ends of their useful lives. In some cases impressed current cathodic protection (ICCP) groundbeds and galvanic anode cathodic protection (GACP) system anodes have already failed due to anode consumption, or are now approaching failure. As many NSES facilities are now involved in the plant life extension process, this is an ideal time to assess the efficacy of existing CP systems, or to consider application of CP to buried plant piping (BPP) for those facilities that were not provided with CP at the time of construction.

TYPES OF CP SYSTEMS

There are two basic types of CP systems suitable for utilization on BPP in NSES facilities, each with multiple possible configurations. GACP systems are used on well coated, small piping segments while ICCP systems are more likely employed on large, complex systems. Tables I and II present the advantages and disadvantages of each system type.

TABLE I

GALVANIC ANODE CATHODIC PROTECTION

ADVANTAGES	DISADVANTAGES
▪ Simple, self regulating systems ▪ Easier to install ▪ Usually requires less equipment (backhoe) and materials (anodes, test stations, weld connections) ▪ Easier to maintain ▪ No external power requirements ▪ Ideal for use on a well coated, electrically isolated metallic structure in low resistivity soil conditions	▪ Not effective or practical in high resistivity soils ▪ Lower current outputs ▪ Limited design life ▪ Not suited for use on structures that have large overall bare surface areas or are poorly coated ▪ Not suited for electrically grounded structures ▪ Requires dielectric isolation at each end of each line ▪ Dielectric isolators must be provided with cathodic decoupling devices for electrical safety ▪ Effective electrical isolation may be difficult or impractical to achieve in a power plant environment

TABLE II

IMPRESSED CURRENT CATHODIC PROTECTION

ADVANTAGES	DISADVANTAGES
▪ Adequate for bare metallic structures or with large overall surface area. ▪ Will work in high to very high soil resistivity. ▪ Able to protect electrically grounded structure ▪ Can minimize excavations around structure due to decreased number of installations ▪ Longer design life	▪ Cathodic interference is a serious concern, requires very careful design ▪ Requires AC power or alternative power supplies for continuous operation ▪ Complex system, may require extensive ditching ▪ Requires constant monitoring checks on rectifiers ▪ Installation costs are greater per groundbed

CONFLICT BETWEEN COPPER GROUNDING AND CP SYSTEMS

Iron and steel piping surfaces buried in native soils or submerged in water polarize fairly readily upon the application of CP currents. A common design basis for CP is 1.0 to 3.0 milliamperes per square foot (10 to 30 milliamperes per m^2) of bare iron/steel exposed to the soil/water environment. Copper behaves far differently than steel and does not polarize readily, requiring up to 20 or more times the current per unit area to achieve an equivalent potential shift.(1) Given the massive copper grounding grids commonly employed in power plants, current demand on CP systems may approach or exceed ninety percent of each rectifier's output to protect copper with an integrated system that bonds BPP in common with the copper grid. (1,2,3,4,5,6) This approach is taken when employing ICCP systems in power plants in order to prevent stray current corrosion on grid conductors or rod beds. One benefit to this configuration is providing multiple negative return current paths back to the rectifiers. For instance, if there is a broken bond on a cast iron fire water main, the pipe on the far side of the discontinuity may still receive adequate CP current via alternate current paths supplied by grid conductors.(4) As a consequence, an ICCP system in a NSES will be large, complex and may require extensive excavations to install or to upgrade/replace. This can represent significant inconvenience to normal operation in an operating plant. There are three basic approaches to design of CP for BPP in a NSES:

1. Repair/Replacement of existing facilities in an operating plant
2. Clean sheet of paper design for a new facility
3. Design and installation in an operating plant not previously provided with CP

Repair /Replacement of Existing Facilities

Beginning with an operating CP system, it may be wise to consider replacing failed components (primarily anodes) with like kind. In making such an assessment, one should always consider more modern materials of construction for their impact on useful life of the system. This approach may significantly reduce engineering man hours required for the project. The process must begin with a careful review and assessment of all available records on the existing CP system. Should the review show many years of successful operation with adequate pipe-to-soil potentials (P/S) throughout the facility, then replacement with like kind makes good sense. Existing positive and negative header cables and transformer/rectifier (T/R) units should be retained in service. Additional facilities may be integrated into the existing design should a review of plant records show minor shortfalls. This approach will generally prove to be the most cost effective.

If, on the other hand, there are clearly documented shortfalls with the existing design, this must be addressed in the system upgrade. In this instance, a more detailed assessment of the existing system is warranted. Most commonly one may find that the CP system has done a commendable job of providing CP to BPP in open areas of the plant, but falls short where there is congested piping, massive grid conductors, and massive foundation rebar, such as close to the turbine generator building (T/G). Under these circumstances, it may be wise to consider installing point anodes in the trouble spots. These point anodes may be connected to an extension of an existing positive header cable. In many instances, it may be more economical to power one, or a small group of point anodes with a new dedicated T/R unit. Sizing, placement, and number of additional anodes must be determined by carefully conducted current requirement tests (CRT) performed in the low potential areas.

GACP systems, while far less complex than ICCP systems, will require extensive excavations for replacement. Some of these excavations may be in areas that are inconvenient towards normal plant operations, or quite costly on an individual basis. Again, a careful review of plant records and some testing is required before attempting to replace with like kind. It must be ascertained that the segment of BPP to be protected is still electrically isolated from all other underground structures in the plant. A GACP system will not work as intended if there is even one contact to another underground structure within the plant. In some instances, it may be impractical or too costly to re-establish effective electrical isolation on a specific segment of BPP. This certainly would not preclude installing GACP on other BPP segments within the plant. Should it not be practical or cost effective to re-isolate a segment of BPP, that particular segment can effectively be protected with a small dedicated ICCP system employing one or more point anodes. This certainly does not preclude utilizing GACP on the balance of the facility. Others(7) have proposed replacing massive ICCP systems in nuclear facilities with GACP systems on individual runs of BPP. Provided that the individual BPP segments can be economically electrically isolated from all other buried metallic elements within the facility, this may be a very viable and cost effective solution.

When installing electrical isolation for BPP within a generating station, one must always consider the implications of step and touch potentials imposed on such structures under power system fault conditions. Sufficient voltages and currents may occur during faults to arc across and short out insulating fittings. This has been an ongoing issue with older CP systems in the fossil fueled fleet. The bigger concern is the issue of personnel safety should a plant staff member be in contact with a test lead or other aboveground piping appurtenance at the moment of a fault. This could result in a fatality. Cathodic Decoupling Devices (CDD) in the form of wet polarization cells(8) or solid state decoupling devices are available to provide a reliable, low impedance path to the grid for fault currents while maintaining effective electrical isolation for CP currents. In addition to providing personnel safety, these devices also protect insulating elements from failure under fault conditions.

Clean Sheet of Paper Design for a New Facility

The designer for a new facility has much more latitude with CP and/or grounding design. This provides considerably more flexibility with design choices and cost control with both CP systems and grounding grids. Both ultimately impact the cost and complexity of the CP system.

GACP Systems

Design of a GACP system should consider at least the following parameters:

- Soil resistivities throughout the facility
- Grade changes across the facility
- Soil structures
- Water Table(s)
- Diameter & Length of pipe runs
- Location and number of CP monitoring test stations
- Coating systems
- Location & maintainability of insulating fittings
- Planned replacement of anodes

- Pipe surface temperatures
- Provision for a CDD at one or at both ends of each piping run.

Recognizing that most galvanic anodes are limited to a maximum 15 to 20 year life, under ideal conditions, planned replacements must be a part of the initial design. Avoid constructing anodes under major foundations, such as the T/G building. It will not be possible to avoid placing some of the anodes under permanent pavement. In these instances, at-grade access boxes should be places directly over each anode. This can assure much lower future replacement costs utilizing the air lance/vacuum excavation method which avoids pavement breakout and replacement. These costs must be factored into the annualized cost of a CP program. With a limited amount of underground plant piping, this can be the most cost effective method for application of CP. Again, it will be necessary to provide a CDD on at least one end of each isolated piping run.

ICCP Systems

The choice of an ICCP system affords the engineer considerably more flexibility in design choices. Installation of an ICCP system is particularly advantageous when faced with difficult site conditions or requirements such as:

- High to very high soil resistivities
- Solid rock at or close to grade
- Arid soil conditions, particularly with a deep water table
- Congested BPP runs
- Extensive BPP within the facility
- Required design life greater that 15 to 20 years before anode replacement

Once an ICCP system's basic anode configurations have been chosen, unlike a GACP system, it is a simple matter to increase design life of the system. In the case of a GACP, it would be necessary to double the number of anodes in order to double the design life. This may be possible if protecting BPP with zinc anodes in very low soil resistivity soils, but not when designing with magnesium anodes. Maximum practical anode life is 15 to 20 years since magnesium is such an active metal. For the case of an ICCP system, the number of anodes remains the same, providing adequate current distribution to the underground plant. One must only double the weight of the carbonaceous backfill surrounding each anode in order to double useful life. Carbonaceous backfill is one of the least expensive components of an ICCP system.

In a high resistivity soil/rock environment, the designer has multiple choices in order to achieve adequate current output from the system. Some of these design choices may include:

- Increasing T/R output voltage
- Increasing the number of anodes in a groundbed
- Increasing anode spacings
- Anode configurations, some of which may include :
  - Conventional Remote
  - Distributed
  - Semi-Deep
  - Deep
- Increasing the number of T/R's and groundbeds

Finally, the CP designer has the opportunity to interface with the Electrical Safety Grid (ESG) designer on materials choices and, to some extent, the grid configuration. There is no requirement that the grid be constructed with copper or copper clad materials. The requirements for an ESG include [9]:

- Low enough Resistance-to-Remote Earth to assure adequate relaying and an acceptable Grid Potential Rise (GPR) under system fault conditions
- Adequate conductor cross sectional area to safely conduct any grid currents under both steady state and fault conditions (resist fusing)
- Conformance with IEEE standards such as Std 80
- Assurance of safe step and touch potentials in any area of the plant that may be occupied by humans
- Long term permanence for the life of the plant
- Conductors must be mechanically reliable and rugged to a high degree
- Be able to maintain its function even when exposed to corrosion or physical abuse.

Therefore, materials of construction other than bare copper or copper clad steel may be utilized, particularly if supplemented with CP. Some of these materials choices may include :[2]

- Insulated copper conductor-particularly with a green jacket.
- Iron or steel structural shapes
- Galvanized Iron
- Ufer[1] grounds utilizing foundation rebar
- Zinc extrusions and/or cast zinc anode shapes
- Stainless steel

By utilizing any of the above materials of construction, current demand from the grid on the CP system may be reduced by and order of magnitude, or more. This results in great economies. However, this does require close coordination between both disciplines.

Design and Installation in an Operating Plant not previously provided with CP

Many NSES were originally designed, constructed, and placed into operation without benefit of CP for BPP. As these facilities go through the life extension and relicensing process, the application of CP to preserve or extend life for existing or replacement BPP must be assessed. Certainly one option would be to replace existing BPP with new aboveground piping. This may be a cost effective option for some but not all of the yard piping, but probably not for BPP entering the T/G building through floor slabs or basement walls. When considering aboveground piping runs, one must carefully assess overhead clearances and ongoing future maintenance painting costs.

Protecting existing coated BPP with GACP is only practical if each individual piping run can be properly electrically isolated from ground or from foundation rebar at each end, and if all underground contacts with grid conductors, etc. can be avoided. All insulating flanges must be

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[1] Herb Ufer, working as a consultant for the U.S. Army during World War II, developed the technique of utilizing rebar in concrete foundations as an effective grounding electrode in desert soil conditions. Today, the NEC (10) recognizes a Ufer ground as a viable grounding element.

installed aboveground or inside of a building. It is not acceptable to install an insulating fitting underground before making a wall penetration in order to avoid contact with rebar. Provided that individual pipe runs can meet this criterion and that the pipe has been provided with some form of dielectric coating, then that pipe run could be effectively protected with a GACP system. It must be realized up front that some of the BPP will not be able to be effectively isolated. Uncoated BPP can best be protected with ICCP. This implies that at least some of the BPP will require an ICCP system or must be a candidate for replacement. It is particularly true for circulating water piping to and from the surface condensers. Thus, when providing adequate protection to existing piping in an older facility, very likely all three solutions discussed above may be required. The objective is to assure life extension in a cost effective manner and in a form that causes the least impact toward ongoing operation of the facility. When considering all of these options and designing individual CP systems. It may be far more cost effective to employ the services of an outside CP consultant who is knowledgeable of nuclear power facilities.

SUMMARY

Types of CP Systems

There are two basic types of CP systems suitable for utilization on BPP in NSES facilities, each with multiple possible configurations. Advantages and disadvantages of GACP and ICCP systems are discussed. Copper grounding commonly employed in power plants represents a tremendous load on ICCP systems, required up to 90 percent or more of each rectifier's current output. One offsetting benefit to this configuration is providing multiple negative current return paths back to the rectifiers. As a consequence, an ICCP system in a NSES will be large, complex and may require extensive excavations to install or to upgrade/replace.

Three basic approaches to design of CP for BPP in a NSES are discussed.

Repair/Replacement of Existing Facilities in an Operating Plant

Beginning with an operating system, it may be wise to replace failed components (primarily anodes) with like kind using more modern materials where practical. The process must begin with a review and assessment or available records on the existing CP system. Existing positive and negative header cables and transformer/rectifier units should be retained in service. Additional facilities may be integrated into the existing design should a review of records show minor shortfalls. On the other hand, if there are clearly documented shortfalls, this may be addressed in the system upgrade. Most commonly one may find that the CP system has done a commendable job of providing CP to BPP in open areas of the plant, but falls short where there is congested piping, etc. such as close to the T/G building. Under these circumstances, point anodes may be installed in the trouble spots. Point anodes may be connected to existing positive header cables or may be powered with a new dedicated T/R unit. Sizing, placement, and number of additional anodes must be carefully determined.

GACP systems will require extensive excavations for replacement. Some excavations may be inconvenient towards normal plant operations or quite costly. Adequate electrical isolation must be ascertained on each BPP segment to be protected. GACP will not work without adequate isolation. In some instances it may be impractical or too costly to re-isolate a segment of BPP. That particular segment can be protected with a small dedicated ICCP system while the balance of the BPP is protected with GACP systems. When installing electrical isolation on BPP in a Generating station, one must always consider the implications of step and touch potentials imposed on such structures under power system fault conditions. CDDs in the form of wet polarization cells or solid state decoupling devices are available to provide a reliable, low impedance path to the grid for fault currents while maintaining effective electrical isolation for CP currents.

Clean sheet of Paper Design for a New Facility

The designer for a new facility has much more latitude with CP and/or grounding design, providing more flexibility with design choices and cost control with CP and with grounding. Installation of GACP systems is constrained by multiple factors including: soil resistivity & structures, BPP diameter & length of pipe runs, coating systems, insulation fittings, and planned replacement of anodes. Planned anode replacements must be part of the initial design. The air lance/vacuum excavation method working through at grade access boxes avoids pavement breakout and replacement.

An ICCP system affords the engineer considerably more flexibility in design choices. This is particularly advantageous when faced with difficult site conditions such as: high soil resistivities, solid rock, arid conditions, extensive BPP, or design life greater than 15 to 20 years. All of these conditions may be overcome with ICCP system design.

Finally, the CP designer has the opportunity to interface with the ESG designer on material choices and to some extent the grid configuration. Choices other than copper exist for grid materials of construction when the ESG is provided with ICCP.

Design and Installation in an Operating Plant not previously provided with CP

Many NSES were originally designed, constructed, and placed into operation without benefit of CP for BPP. As these facilities go through the life extension and relicensing process, the application of CP to BPP must be assessed. Replacing BPP with aboveground piping is an option. This may be cost effective for some but not all of the yard piping, but probably not for BPP close to the T/G building. Protecting existing coated BPP with GACP is only practical if each individual piping run can be properly electrically isolated. All insulating flanges must be installed aboveground. Uncoated BPP can best be protected with ICCP. It is particularly true for circulating water piping to and from the surface condensers. Very likely all three solutions discussed above may be required.

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