Paper No.
5622

®

Design of a C. P. System Upgrade at Comanche Peak Nuclear Power Plant

Earl L. Kirkpatrick, P.E.
ELK Engineering Associates, Inc.
8950 Forum Way
Fort Worth, Texas 76140
USA

Jacob Smith
Luminant Generation Company LLC
6322 North FM 56
Comanche Peak Nuclear Power Plant
Glen Rose, Texas 76043
USA

ABSTRACT

The distributed anode impressed current C. P. system, installed during original plant construction, was at the end of its useful life. A total system replacement was required since the existing groundbeds could not be replaced with like kind due to interferences with in place structures. The lead author functioned as Subject Matter Expert and Engineer of Record working with plant engineering staff to develop a new ICCP system consisting of 20 rectifiers and 22 semi-deep anode groundbeds. The task was completed by early 2013. This resulted in 4.2 million dollar construction project completed in 2013.

Key words: CP, cathodic protection, logging anode, nuclear plant, semi-deep groundbed, test wells.

INTRODUCTION

CPNPP is a two unit nuclear plant nominally rated at 1,150 megawatts per reactor and is sited in Somervell County north of Glen Rose, Texas. Unit 1 went commercial in 1990 and Unit 2 in 1993. Squaw Creek Reservoir provides the primary and ultimate heat sinks. Surface condenser cooling is via lake water once through system employing a single dug tunnel run to and from each unit. Traveling screens are provided at the entrance to the circulating water intake structure (CWIS) wet wells. The service water intake structure (SWIS) is similarly configured with a pair of 30 inch coal tar coated and wrapped steel circulating water (CW) lines run to and from each of the two units.

Typical of most power plants, the underground metallic matrices at CPNPP consists of at least the following components:

1. Welded steel, dielectrically coated fire water (FW) lines and other liquid lines. The underground steel lines were provided with a mill applied, hot coal tar enamel external coating system. The prevalent industry standard at the time was TGF-3 which was a fiberglass reinforced 3/32" flood coat of hot enamel with a 15 # coal tar saturated felt outer wrap
2. Various control lines and electrical conduits.
3. Bar grilles, traveling screens and water pumps in the clear wells at the CWIS and the SWIS.
4. A bare tinned copper grounding grid system in the main plant area and in the commonly connected switchyard constructed of 4/0 through 500 MCM copper cables and a few driven copper clad ground rods. In addition, sheet piling is connected to the grid. There are many secondary grounding loops and grounding pigtails throughout the plant site.
5. Extensive structural steel embedded in concrete for building foundations, tank bottoms, and underground electrical duct banks.
6. Aboveground storage tank (AST) bottoms on concrete foundations.

Typical of most power plant construction, including both fossil fuel and nuclear plants, the electrical grounding grid is electrically common with all underground piping and indirectly with all reinforcing steel in concrete structures. Common bonding of all underground plant avoids potential differences between the grid and underground piping and provides maximum personnel safety under electrical fault conditions. [1, 2] This plant design significantly impacts cathodic protection current requirements. [3, 4, 5, 6, 7, 8]

ORIGINAL DESIGN

For initial plant construction, beginning with a "clean sheet of paper" design, it was most practical to design an impressed current cathodic protection (ICCP) system employing distributed anode groundbeds installed immediately adjacent to the piping systems that were intended to be protected. [9, 10, 11] Thus, the protected piping is in the gradient fields of the individual anodes. This groundbed configuration is the most efficient possible and has been employed in both nuclear and fossil fuel plants for decades. Disadvantages to this type of system include the extensive cabling that must be installed to connect the individual anodes to the transformer/rectifier unit that powers them and the high likelihood of damage to the system by future construction.

With the distributed anode configuration, the acceptance criterion traditionally has been -0.85 Volts with the current applied. [12, 13] Most of the "test Points" where structure contact was made for the pipe-to-soil (P/S) potential measurements were fire hydrants (FH) or post indicator valves (PIV) which provided less than reliable connections to the BPP. Thus, many of the reported low (unacceptable) P/S potential noted during previous surveys may have been in error.

The following components of the original cathodic protection (CP) system, installed with plant construction, were decommissioned as a part of this modification:

CPX-ECCPRT-01 was a 50 Volt, 50 Ampere rectifier installed in the turbine generator building (TGB) which powered a distributed anode groundbed that was installed under the floor slab of the TGB. The intent of this installation was to protect the circulation water (CW) piping underneath the Elevation 778 floor slab.

CPX-ECCPRT-02 was a 50 Volt, 250 Ampere rectifier installed on the north east side of the TGB. This unit powered a very large distributed anode groundbed on the north side and the west side of the TGB. This system was intended to protect underground yard piping, primarily the FW mains, but also Unit 2 diesel fuel oil (DFO) tanks and piping, also the circulating water (CW) system.

CPX-ECCPRT-03 was an 80 Volt, 160 Ampere rectifier at the southwest corner of the TGB. This unit powered a large distributed anode groundbed around the southwest corner of the TGB and was intended to protect underground yard piping, primarily the FW mains.

CPX-ECCPRT-04 was an 80 Volt, 160 Ampere rectifier next to the south portal of the TGB. This unit powered a large distributed anode groundbed around the southeast corner of the TGB and was intended to protect underground yard piping, primarily the CW lines and the FW mains.

CPX-ECCPRT-08 was an 80Volt, 80 Ampere rectifier at the CW discharge structure that powered a remote conventional anode groundbed along the shore line of the Squaw Creek Reservoir. This system was intended to provide supplemental protection to both yard piping and TGB under slab piping.

The remaining three systems were designed to provide protection to intake structure clear well traveling screens and pump bowls. These systems are still functioning adequately and were not included in the modification.

EXPERIMENTAL PROCEDURE

One of the critical design requirements was that the proposed semi-deep anode groundbeds (SDAG) must not penetrate the Twin Mountain Formation which is the principal aquifer in the region. The Twin Mountain underlies the essentially impervious Glen Rose Formation that was to contain the groundbeds. The decision was made that the bottom of each SDAG hole must remain a minimum of twenty feet above the aquifer. Earlier geophysical investigations approximated the depth to the Twin Mountain/Glen Rose horizon, but this was not deemed to be adequate enough to assure a minimum of twenty feet of undisturbed Glen Rose formation above the horizon for each proposed groundbed site. The top of the Glen Rose formation within the PA is unweathered due to leveling of the site prior to initial construction. The Glen Rose Formation consists primarily of claystone and argillaceous limestone.

A local geotechnical engineering firm, familiar with the site, was retained to provide a "Hydrologic and Geologic Summary for Proposed Cathodic Protection System Area" report [14] to cover the entire protected area (PA) of the plant. A total of four continuous cores from the surface to the Twin Mountain horizon were drilled. One hole was drilled approximately mid way along each side of the protected area (PA) of the plant and as close to the barricade wall as practicable. Accurate surface elevations for each hole were provided by plant engineering so that depth to the horizon from the PA surface elevation could be accurately determined. Each drilled hole was a nominal four in. (50 mm) diameter and was left full of drilling mud until electrically logged, then plugged.

The logging procedure employed a one in. (25 mm) diameter copper tube 5 ft. (1.524 m) long test anode using a truck battery connected to a reliable electrical safety grid (ESG) conductor. Resistance-to-remote earth was calculated at five ft. (1.524 m) intervals from the surface to total depth. An inversion of H. B. Dwight's equation for a single vertical anode then provided accurate five ft. layer electrical resistivities expressed in Ohm/centimeters. These data were then used to calculate ground bed resistance for each proposed SDAG.

Based upon these efforts, the limit for total depth (THD) was determined to be 180 ft. (54.9 m.) or 175 ft. (53.3 m.) depending on the area of the plant where the individual groundbed was sited. This required two groundbeds for the larger T/Rs in order to have a sufficient length for the working columns in the groundbeds.

BASIS OF DESIGN

Evaluation of the existing CP systems and preliminary system design took place in 2012 with the general approach defined by the end of the year. Formalization of the CP system modification (MOD) design took place in late 2012 and early 2013. [15] The original CP system was decommissioned on 23 May 2013 to allow several months for depolarization prior to measuring plant-wide "native" or "rest" P/S potentials. Construction of the MOD took place in the spring through early fall of 2013.

The design process began with a review of the original CP system documentation. [9,10,11,16] Seven hundred Amperes of capacity was provided with the original plant construction and provided effective protection up until the time that the groundbeds began to fail. Original construction employed high silicon iron (HiSi) anodes with high molecular weight polyethylene (HMWPE) insulated cables in metallurgical coal coke breeze backfill. The initial "first cut" design assumed a 10 percent multiplier to account for the less efficient current distribution from SDAGs when compared to distributed anodes and an additional twenty five percent safety factor. This exercise resulted in an initial design goal of 953 Amperes.

Current requirements calculations based upon surface areas exposed to the CP currents were performed next. Assumptions utilized in the calculations included: [12, 17, 18, 19, 20]

- Assume 20 percent coating failure at the end of the plant's projected 60 year commercial life
- Six milliamperes per square foot on all bare iron and steel exposed to soil or water
- One tenth milliamperes per square foot for exposed galvanized surfaces
- Six milliamperes per square foot for bare tinned copper grid conductor
- One hundred twenty milliamperes per square foot for bare copper
- Two tenths of a milliamperes per square foot for rebar or other bare steel in concrete

Results of these calculations showed the following minimum required Amperages:

Structure to be protected	Calculated Requirement (Amperes)	Percent of Total Requirement
Electrical Safety Grid	83	20.91
Buried Plant Piping	110	27.71
Under the TG Building	34	8.56
Building Foundation Steel	110	27.71
Cooling Water Tunnels	60	15.11
Total	397	100.00

The project requirement was a conservative forty year design life for the complete system which was adequate to carry the plant through the re-licensing process. This design life resulted in utilizing 14 in. Schedule 40 PVC casing with a 12 in. open hole below in order to have an adequate quantity of consumable conductive backfill.

The entire design process was thoroughly peer reviewed by an independent third party who had extensive nuclear CP design experience. [21] This peer review provided full validation of the design.

Materials choices

Given the proven track record at the site with the existing CP systems, the choice of anode material was easy. HiSi tubular anodes of Canadian manufacture were chosen. Providing a forty year life at an assumed 1.0 pounds (0.488 kg.) per ampere year resulted in rating 7 ft. (2.13 m.) long 128 pound (58kg.) anodes for 3.2 Amperes per anode.

Due to the difficulty in pumping metallurgical coal coke breeze, calcined petroleum coke with surfactants and lubricants were chosen.[17] Consumption rate for the carbonaceous backfill was calculated at four pounds (1.814 kg.) per Ampere per year.

Given the excellent track record with the existing CP systems, high molecular weight (HMWPE) polyethylene insulated cables were chosen. Ground water present in the parched aquifer (Glen Rose) is fresh with only traces of chlorides or other halogens. Therefore, there was little need to resort to more exotic and expensive cable sheaths.

Air cooled, galvanized steel, pad mounted rectifier cases were selected for all transformer/rectifier (T/R) units for minimal maintenance. All new T/R units were to be fed from a dedicated 25 kV power loop. Therefore, 480 Volt, three phase, 60 Hertz primary windings were selected for all units.

Final Configuration

Two more or less concentric rings of rectifiers and groundbeds were selected to provide the optimal current distributions to the plant piping of interest. The SDAGs in the inner ring were provided with forty feet of non metallic casing which placed the top of the working column at the elevation of the floor of the TG building. This was necessary in order to force sufficient current onto the CW piping under the building floor. The outer ring groundbeds were provided with twenty feet of non metallic casing with the objective or providing more uniform current distribution to the BPP in the plant yard.

The final choice called for a total of twenty transformer/rectifiers (T/R) powering a total of twenty two SDAGs [22] with an installed capacity of 940 Amperes. Individual T/R units were rated at 30, 40, or 60 Amperes. Thirty and forty ampere units were designed for a single SDAG while the sixty ampere units were designed for two groundbeds. Individual SDAGs were drilled to depths ranging from 110 ft. to 180 ft. The 40 Ampere groundbeds required 13 anodes spaced at 8 ft. (2.44 m.) on center. The 50 Ampere groundbeds required 16 anodes spaced at 8 ft. (2.44 m.) on center.
Due to the limiting depth to the Twin Mountain horizon, the 60 Ampere T/R units required two groundbeds. Each groundbed required 10 anodes spaced at 8 ft. (2.44 m.) on center.

During the design process lengthy discussions were held concerning various drilling techniques to be used for the SDAGs. The early sentiment for the plant staff and the drilling contractors was to use air rotary rather than mud rotary since faster penetration rates could be expected. Eventually the decision was made to drill a test hole in an open area of the plant well outside of the protected area (PA) of the power block. The test hole confirmed that the air rotary technique resulted in too much surface contamination to be acceptable. The decision was them made to use the mud rotary technique working from a construction footprint covered with a 20 mil polyethylene sheet. After construction started the decision was made to drill the 16 in. holes for the casing with an auger type foundation drilling rig in order to speed up the process.

Selection of groundbed holes was complicated by many variables and restrictions. Among these were:

- ✓ Minimum required separation from building foundations
- ✓ Minimum required separation distances of 5 ft. (1.53 m.) from BPP
- ✓ Minimum required separation distances of 50 ft. (15.24 m.) from the CW tunnels

- ✓ Overhead clearances (Limit of Approach)
- ✓ Tipping radius for the drill rig mast
- ✓ Minimum footprint required for construction
- ✓ Minimizing impact on normal plant operations

A complete remote monitoring system (RMS) with full interruption capability was built into the T/R units. The dedicated desktop computer was installed in the CP System Owner's office. This, we now have the capability to interrupt the rectifiers for annual CP surveys and other tasks or investigations. Now, any one of the currently accepted criteria for effective CP may be applied to the system.

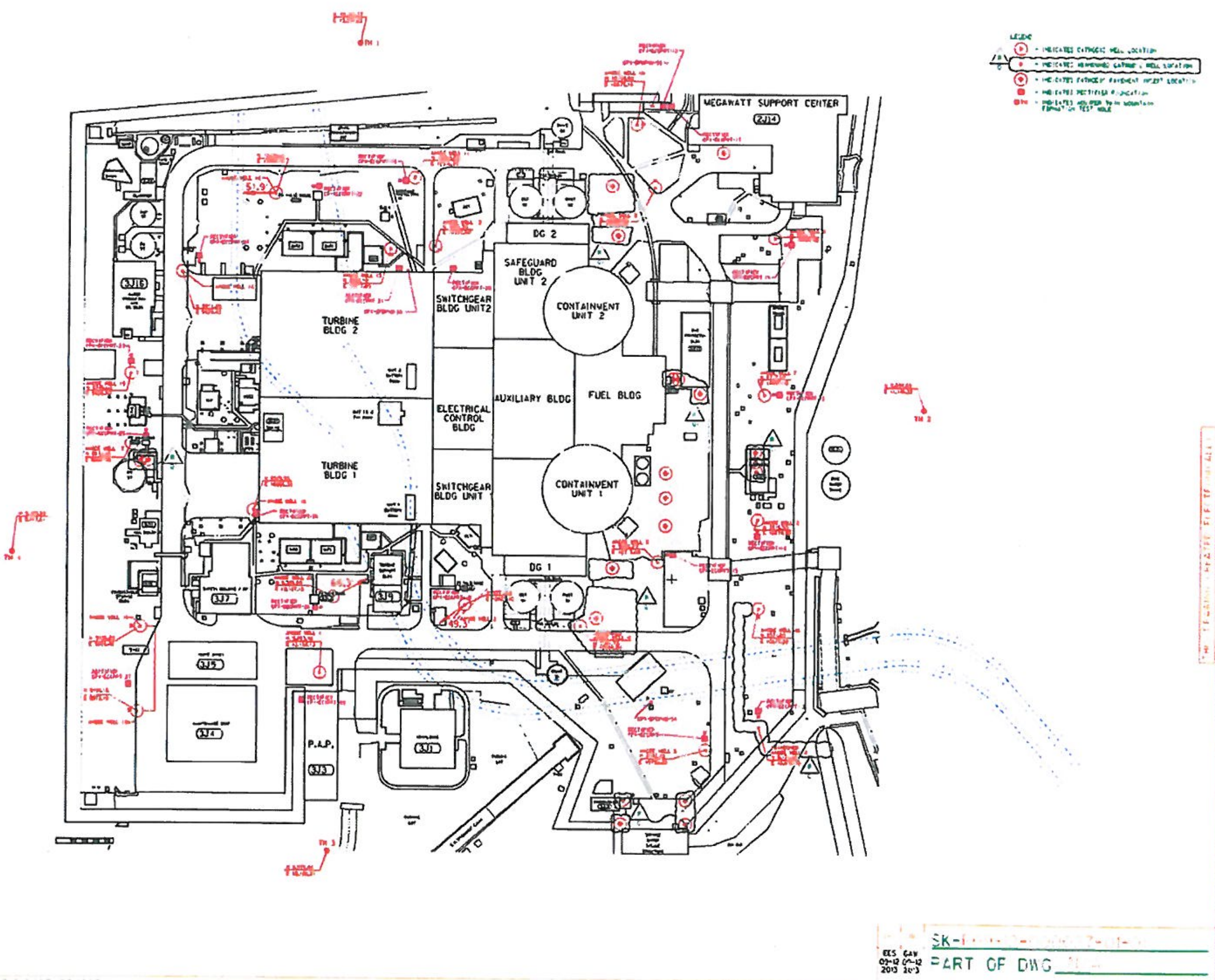

Figure 1 is a plot plan of the finally proposed system layout

Two new test stations were provided for the Unit 1 emergency diesel fuel storage tanks (DFO) and two more for the Unit 2 DFO tanks. Two inch Schedule forty PVC drop tubes were provided with each at grade test station. Two each small corrosion coupons were strapped to the outside of each PVC tube very close to the bottom. One coupon was bonded to a nearby grid conductor. The other one was allowed to freely corrode. Consequently we now have the capability to measure essentially IR drop error free on P/S potentials and native potentials at these locations. It is anticipated that additional test stations, of the same configuration, will be installed in the future. The Mod provided an inventory of flush to grade test lead boxes so that test leads could be installed at opportunity digs within the PA.

RESULTS

Normal construction difficulties when working in a nuclear facility were encountered and contributed to the length of time required to complete the project.

During construction of the groundbeds one of the thirty Ampere SDAG holes, closest to the Squaw Creek Reservoir, encountered highly fractured limestone close to grade resulting in lost circulation. All attempts to restore circulation were unsuccessful. A nearby alternate site was selected with the same results. Therefore the 60 Ampere T/R unit was de-rated to 30 Amperes, resulting in a total system capacity of 910 Amperes. This resulted in a 3.19 percent loss in system capacity. Unfortunately, the lost capacity was close to the SWIS structure where CP current demand is fairly high. Other than this one difficulty, the entire MOD was constructed as planned.

Revised CP System Procedures

On all future surveys, structure negative connections for P/S potential measurements will be made to a nearby grid conductor since the grid is electrically continuous with thee BPP plant wide. Reference will still be made in the field notes to the previously cited FH or PIV.

Drop Tubes and corrosion coupons will become standardized as preferred test points over time as facility staff has the opportunity to install them.

All future annual and special surveys will be conducted with all BPP rectifiers cycled by the RMS. The negative 0.85 Volts "instant OFF" criterion [12] will be employed for Safety Related or for Augmented Quality Non Safety Related BPP. The -0.85 Volt ON criterion will be utilized for the balance of the plant.

Passivation by concrete encasement will also be taken into consideration when evaluating the effectiveness of CP on specific piping segments, particularly on the CW piping underneath the TG building floor slab. For this environment, where little polarization will occur, application of the minus 100 millivolt criterion is a far more practical measure of protection. [23, 24, 25]

CONCLUSIONS

The CPNPP cathodic protection MOD has been successfully concluded essentially on time and on budget. The good results obtained will be the topic of a follow-up presentation by the same authors later in this symposium.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of and permission to publish by the management of Luminant Power. We also wish to acknowledge the professionalism and technical capabilities of plant staff without whose support the MOD would not have been completed.

REFERENCES

1. "C2-2007 National Electrical Safety Code," (New York, New York: Institute of Electrical and Electronic Engineers).

2. "NFPA 70, National Electrical Code," (Quincy, Massachusetts: National Fire Protection Association).

3. E.L. Kirkpatrick, "Effects Of Electrical Grounding On Corrosion," Corrosion/79, Paper Number 53 (Houston, TX: National Association of Corrosion Engineers, 1979).

4. E.L. Kirkpatrick with M. Shamim, "Copper Grounding Systems Have A Negative Effect On Cathodic Protection In Production Facilities," Eighth Middle East Corrosion Conference (Houston, TX: NACE International, 1998).

5. E.L. Kirkpatrick, "Copper Grounding Systems Have a Negative Effect on C.P. Facilities," Corrosion/2000, Paper Number 00743 (Houston, TX: NACE International, 2000).

6. E.L. Kirkpatrick, "The Conflict Between Copper Grounding Systems and Cathodic Protection Systems," second EPRI Corrosion and Degradation Conference (Charlotte, NC: Electric Power Research Institute, Dec. 2000).

7. E.L. Kirkpatrick, "Electrical Grounding and Cathodic Protection Issues in Large Generating Stations," *Materials Performance*, Vol. 40, No. 11, (2001).

8. E.L. Kirkpatrick, "Electrical Grounding Case Histories," Corrosion/2003, Paper Number 03701 (Houston, TX: NACE International, 2003).

9. 2323-X-1 (12-11-75), "Cathodic Protection – Underground Structures Remote Installation," (Gibbs & Hill).
10. 2323-X-6, (4-15-76), "Cathodic Protection - General Underground Structures," (Gibbs & Hill).

11. 2323-X-2, (12-9-76), "Turbine Building Piping Cathodic Protection," (Gibbs & Hill).

12. NACE International, "SP0169-2007 Control of Underground Corrosion on Submerged Metallic Piping Systems," (2007).

13. A.W. Peabody, *Control of Pipeline Corrosion,* Second Edition, Houston, Texas, NACE International, 2001.

14. E.F. Pastor, P.E. and W. F. Vienne, P.G., Pastor, "Hydrologic and Geologic Summary for Proposed Cathodic Protection System Area Comanche Peak Nuclear Power Plant, Glen Rose, Texas," (April 23, 2013): (Tab 3)

15. E.L. Kirkpatrick, P.E., "2722.02 CPNPP - CP Upgrade Design Calculations (Fort Worth, TX: ELK Engineering Associates, Inc., 15 October 2012).

16. *Electrical Engineering Cathodic Protection, UFC 3-570-02N,* Department of Defense, Washington, D.C., 2004.

17. 2323-X-4, (12-23-76), "Cathodic Protection – Anode Backfill," (Gibbs & Hill).

18. R. A. Gummow, "Cathodic Protection Current Requirements for Electrical Grounding Materials" (Houston, TX: NACE International).

19. R. Baboian, *NACE Corrosion Engineer's Reference Book*, Third Edition, Houston, Texas, NACE Press, NACE International, 2002.

20. *Balance of Plant Corrosion – The Underground Piping and Tank Reference Guide*, Revision 1, Palo Alto, California, Electric Power Research Institute, 2013.3002000682.

21. *Cathodic Protection Design Underground Piping Third Party Review*, (Norton Corrosion Limited, April 2013).

22. T.H. Lewis, Jr., *Deep Anode Systems, Design, Installation and Operation*, NACE Press, Houston, TX.

23. U. Bertocci and J. L. Mullen, "Laboratory Corrosion Studies on Tinned Copper Concentric Neutral Wires," *MP* 18, 6 (June, 1979).

24. D. A. Hausmann, "Three Myths About Corrosion of Steel in Concrete," *MP* 46, 8 (August, 2007).

25. D. A. Hausmann, "Steel Corrosion in Concrete", *MP* 6, 11 (November, 1967).