RESTORING EFFECTIVE CATHODIC PROTECTION TO BPP IN A LARGE COAL FIRED POWER PLANT

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A. HISTORY

The Limestone Steam Electric Station (LSES) was designed by the New York office of Ebasco Services, Inc. (ESI) in the late 1970s for Houston Lighting and Power Company (HL&P). The presenting author conducted a peer review of the LSES buried plant piping (BPP) cathodic protection (CP) systems during the design. The plant was constructed by the Houston, Texas office of ESI. The HL&P generation fleet was renamed to CenterPoint Energy, Inc. (CEI) in October 2002. Following deregulation of the Texas electrical market, CenterPoint's regulated generating assets were renamed TexasGenco which was subsequently sold to NRG Energy Inc. (NRG) in February 2006.

ELK Engineering Associates, Inc. (ELK) was contracted by CEI in 2005 to conduct an annual CP system survey and to formulate a plan of action for system repairs. The 2005 report presented a three phase repair/refurbishment plan for the facility.

After purchase of the TexasGenco fleet by NRG, they became proactive with repairs to the CP system. ELK prepared plans and specifications for replacement of five groundbeds, three with conventional distributed anodes, and two with deep anodes. Construction was completed in 2008 but a commissioning survey was not conducted at that time.

B. DESCRIPTION OF THE FACILITY

"Limestone Electric Generating Station is located on a 3,800 acre site 120 miles north/northwest of Houston near the junction of the Limestone, Freestone and Leon County lines. There are two steam units with a net generating capacity of 1,689 MW. Unit 1, uprated in 2001, is an 831 MW drum-type reheat unit and was placed in commercial service on December 1, 1985. Unit 2, uprated in 2006, is a similar unit with a net capacity of 858 MW and was placed in commercial operation on December 1, 1986. Cooling water for the main condenser is circulated through a mechanical draft cooling tower with makeup from existing Lake Limestone. Service water is pumped from Lake Limestone and is clarified to supply service water loads and auxiliary cooling water. Auxiliary cooling water provides cooling water for generator hydrogen gas, turbine lubrication oil and auxiliary equipment coolers. Auxiliary water is also cooled by a mechanical draft cooling tower. Plant fresh water is supplied by three deep wells. The units have electrostatic precipitators for particulate control and flue gas desulphurization systems for SO_2 removal."

The underground metallic matrices at Limestone S.E.S. consist of at least the following components:

1. Welded steel, dielectrically coated diesel fuel lines.
2. Welded steel, dielectrically coated compressed air lines.
3. Cast iron pipe (CI), fire water lines.

4. Various control lines and electrical conduits.
5. A concrete cylinder water line from Lake Limestone to the plant.
6. Driven steel sheet piling at the Bottom Ash Slurry Ponds.
7. Prestressed concrete cylinder pipe (PCCP) circulating water lines consisting of an inlet pipe and a discharge pipe to each of the units.
8. A bare copper grounding grid system in the main plant area constructed of copper cable and driven copper clad ground rods. In addition, driven piles are connected to the grid.
9. Structural steel embedded in concrete for building foundations and underground electrical duct banks.
10. Above ground storage tank (AST) bottoms in soil contact.

C. ORIGINAL CATHODIC PROTECTION SYSTEM

Given that the plant is situated in marine colloidal clays of low to moderate resistivity and that all BPP was to be commonly bonded to a massive bare copper electrical safety grid (ESG), an impressed current cathodic protection (ICCP) system was chosen for the facility. Cathodic protection rectifiers (CPR) were powered from 480 VAC motor control centers (MCC). All but the smallest units were supplied with 3-phase power. Given the large amount of prestressed concrete cylinder pipe (PCCP) within the facility, distributed vertical anodes were placed on both sides of each PCCP run. This was deemed necessary to provide adequate levels of CP to the pipe without exceeding the hydrogen overvoltage potential at local areas on the prestressing wires. BPP in the balance of the plant was protected by ICCP systems employing conventional remote anode groundbeds. A few deep anode groundbeds were installed in congested areas of the plant where there was insufficient room for conventional vertical anode groundbeds. Original system design was adequate to assure a minimum twenty year useful life.

Up until the 2005 survey, rectifier inspections and some annual surveys had been performed but very little archivable data was available. There were no records of repairs and/or upgrades to the system.

D. CRITERIA

The latest edition of SP0169 $_{(1)}$ recognizes three numerical criteria for CP of buried or submerged ferrous piping systems. Quoting from SP0169:

> *6.2.2.1.1 A negative (cathodic) potential of at least 850 mV with the CP applied. This potential is measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte. Voltage drops other than those across the structure-to-electrolyte boundary must be considered for valid interpretation of this voltage measurement.*
>
> *NOTE: Consideration is understood to mean the application of sound engineering practice in determining the significance of voltage drops by methods such as:*
>
> *6.2.2.1.1.1 Measuring or calculating the voltage drop(s);*
>
> *6.2.2.1.1.2 Reviewing the historical performance of the CP system;*
>
> *6.2.2.1.1.3 Evaluating the physical and electrical characteristics of the pipe and its environment; and*
>
> *6.2.2.1.1.4 Determining whether or not there is physical evidence of corrosion.*
>
> *6.2.2.1.2 A negative polarized potential (see definition in Section 2) of at least 850 mV relative to a saturated copper/copper sulfate reference electrode.*
>
> *6.2.2.1.3 A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion*

The second criterion, -850 millivolts instant off would assure excessive over protection of most BPP and could be quite problematic for PCCP, possibly resulting in reinforcing wire breakage due to hydrogen embrittlement.

The third criterion, 100 millivolts polarization, can be very useful in a power plant environment provided that there is sufficient "native" pipe-to-soil (P/S) potential data to provide a baseline from which future immediate off measurements may be compared. That data does not exist for LSES. It is considered to be impractical and detrimental to the health of the BPP within the facility to leave all CPRs in the plant off for three months in order to obtain representative native P/S potentials. Therefore, we are left with only the first criterion of -850 millivolts to copper-copper sulfate reference electrode (CRE) for use at LSES. This criterion requires that the corrosion engineer take into account IR drops in the soil associated with application of CP current to the BPP. Given the relatively low soil resistivities encountered in this facility, the effects of IR drops in the soil environment may be disregarded, provided that the CRE is placed directly over the structure to be measured.

Meaningful application of these criteria requires direct soil contact by the CRE at each point of measurement. Again, CRE contact must be made directly over the structure of interest. There often may be obstacles in the way of direct soil contact. Under these circumstances, one may be tempted to place the CRE at a fixed lateral offset distance. Given the complex underground plant, including extensive ESG conductor and massive reinforced concrete foundations, such readings are questionable at best and usually are meaningless. Readings taken over asphalt or concrete pavement are highly suspect, even if taken at cracks in the pavement. Asphalt is an electrical insulator, resulting in excessively high surface contact resistance to the CRE. While concrete is an electrolyte with only moderate volume resistivity, rebar in the concrete will be much closer to the CRE than the segment of BPP that is being measured. The result is an indeterminate bias voltage, rendering the measurement meaningless.

The only practical and meaningful method for taking P/S measurements on BPP beneath pavement is to bore a hole through the pavement. These may be temporary holes for one-time measurements which may be later plugged. Or, they can become permanent test points by providing some form of non-metallic pavement insert to close the opening. This assures repeatable measurements.

E. PLAN OF ACTION

The following language is taken from the 2005 survey report (2):

Phase I Groundbed Repairs

CPR-5 - Locate and repair/replace damaged header cable to groundbed "C".

CPR-12 - Replace failed semi-deep groundbed with an improved design.

CPR-18 - Trace out and as-built groundbed.

CPR-19 - Trace out and as-built groundbed.

Commissioning Survey – increase rectifier outputs, conduct an uninterrupted, close P/S only commissioning survey. Provide written report with drawings.

Install Pavement Inserts

A number of pavement inserts are required at what will become permanent CP test points.

The following systems were proposed as candidates for replacement groundbeds under Phase II:

Rectifier Designation	Probable Groundbed Configuration
CPR- 6	Distributed
CPR- 9	Semi-deep
CPR- 10	Semi-deep
CPR- 13	Distributed
CPR-19	Deep or multiple semi-deep

The following systems were proposed as candidates for replacement groundbeds, as Phase III work:

Rectifier Designation	Probable Groundbed Configuration
CPR- 5	Multiple deep or semi-deep
CPR- 11	Semi-deep
CPR- 14	Deep or multiple semi-deep
CPR- 16	Deep or multiple semi-deep

F. CURRENT STATUS OF CP SYSTEM

BPP in open "yard" areas of the plant is always the easiest to adequately protect. Congested BPP in and under the power block is the most difficult to adequately protect due to a phenomenon known as "cathodic shielding." Under these circumstances, BPP close to the perimeter of the power block is easily protected. BPP within the middle of the power block tends to be shielded from receiving adequate CP current density. This is because of excessive current demand by foundation rebar and by close spaced ESG conductors. Current demand by bare copper is orders of magnitude greater than coated ferrous plant piping on a unit area basis. (3, 4, 5, 6, 7)

G. THE WAY FORWARD

Because of the phased approach of providing the most cost effective groundbed replacements first, the BPP in the open yard areas of the plant are currently well protected. While we have demonstrated improvements in P/S potentials on BPP in the power block, it is not fully protected as of this writing. The following excerpt from the 2010 Annual Cathodic Protection Survey Report shows the current status of BPP across the plant site (8):

STATUS OF UNDERGROUND RECTIFIERS AND GROUNDBEDS					
Unit No.	Rated Amps	Est. Year Groundbed Installed	Pre-Cleaning Output (Amps)	Post-Cleaning Output (Amps)	Groundbed Status
1	50	1983	35.2	41.4	Groundbed ageing, but still functional.
2	70	1983	29.4	42.6	Groundbed ageing, but still functional.
3	60	1983	53.6	56.2	OK.
4	60	1983	32.9	37.8	Part of groundbed lost - still functioning.
4A	35	2009	27.3	27.3	OK - new rectifier and groundbed.
5	120	2000	0.2	97.2	Groundbed ageing, but still functional.
6	120	2009	0.0	0.0	Rectifier out of service.
7	120	2008	104.7	105.9	OK, new groundbed.
8	140	2008	79.2	87.6	Groundbed failing.
9	40	2008	34.9	35.4	Groundbed failing.
10	40	1983	5.7	6.9	Defective ammeter. Groundbed OK.
11	40	1983	11.7	16.0	Groundbed OK.
12	40	2005	11.1	12.1	Groundbed OK, replaced.
13	140	2009	0.0	126.0	OK, new groundbed & neg. hdr.
14	70	2008	31.4	32.4	OK, groundbed beginning to age.
15	70	1986	26.6	35.9	Groundbed OK.
16	70	2008	0.0	57.6	Groundbed OK. New neg. hdr.
17	70	Pre 2007	61.8	65.1	Groundbed OK.
17A	200	2009	171.2	171.2	OK - new rectifier & groundbed
18	30	1991	23.7	24.8	Groundbed OK.
19	30	2008	26.9	27.4	Groundbed failing.
	1,615		765.5	1,106.8	Totals

After completion of the survey, the following rectifiers and groundbeds were added to the system to address the remaining low P/S potentials in the power block:

Unit No.	Rated Amps	Est. Year Groundbed Installed	Pre-Cleaning Output (Amps)	Post-Cleaning Output (Amps)	Groundbed Status
20	100	2010	N/A	94.3	OK.
21	100	2010	N/A	94.9	OK.
22	100	2010	N/A	95.0	OK.

In the fourth quarter of 2010 we designed and installed three new 100 ampere rectifiers and conventional remote anode groundbeds on the north side of the power block. These systems were energized on 20 December 2010. Due to the very slow polarization characteristics of bare copper and of rebar in concrete, the commissioning survey is scheduled for March 2011.

H. CONCLUSIONS

As has been demonstrated by our efforts at LSES refurbishing ICCP systems in large central generating stations is not an easy one-time fix. In order to refurbish such a system in a timely and cost effective manner requires all of the following:

- Careful assessments of existing systems
- Buy-in by senior management
- Adequate budgeting of finances and manpower
- A careful phased construction program

Unfortunately, this is a multi-year process if the refurbishment is to be constructed in the most cost effective manner. The process is:

1. Detailed plant wide survey
2. Engineering assessment
3. Design repairs
4. Construction
5. Repeat the process, as required.

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