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Advantages of Silicon Iron as an Alternative to Copper Grounding Electrodes – Impact on Cathodic Protection Systems

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ABSTRACT

Copper grounding has a detrimental effect on cathodic protection (CP) of interconnected underground carbon steel piping. The copper can consume large amounts of protection current as well as introducing significant measurement errors when verifying the protection level of the piping.

This paper examines the interactions between copper grounding and pipeline systems as well as a cost effective solution to the problem. An actual case study is presented confirming that silicon iron can be used to replace copper electrodes resulting in effective electrical grounding with minimal impact on cathodic protection systems.

INTRODUCTION

As in most industrial plants, high pressure natural gas pumping stations routinely utilize a grounding system consisting of heavy gauge bare copper wire installed during construction. In lieu of detailed calculations, grounding systems are often based on the assumption that much more is always better.

The pumping station in this case study is located on a high resistivity shale formation. The copper grounding system was in a grid configuration with a spacing of approximately two metres throughout the plant. All plant piping and electrical equipment were bonded to this copper grounding system.

This met the objectives of the local Electrical Safety Authority by establishing an effective, long lasting and safe grounding system to guard against lightning strikes and electrical faults. The plant is located in the vicinity of a 230 kV and a 500 kV power transmission line which in part run parallel to the outgoing pipelines from the plant. Calculations indicated that the largest fault currents would be transmitted to the plant via the pipelines if the power transmission system faulted where the two systems share a common right of way. The grounding system also provides protection against step-touch potentials around the many above ground appurtenances.

EFFECTS OF COPPER ON CATHODIC PROTECTION SYSTEMS

This arrangement of electrical grounding creates a problem for cathodic protection systems intended to protect the underground piping.(1) As depicted in Figure 1, copper in aerated soils requires very large cathodic current densities to polarize to the potential required to protect carbon steel.(2)

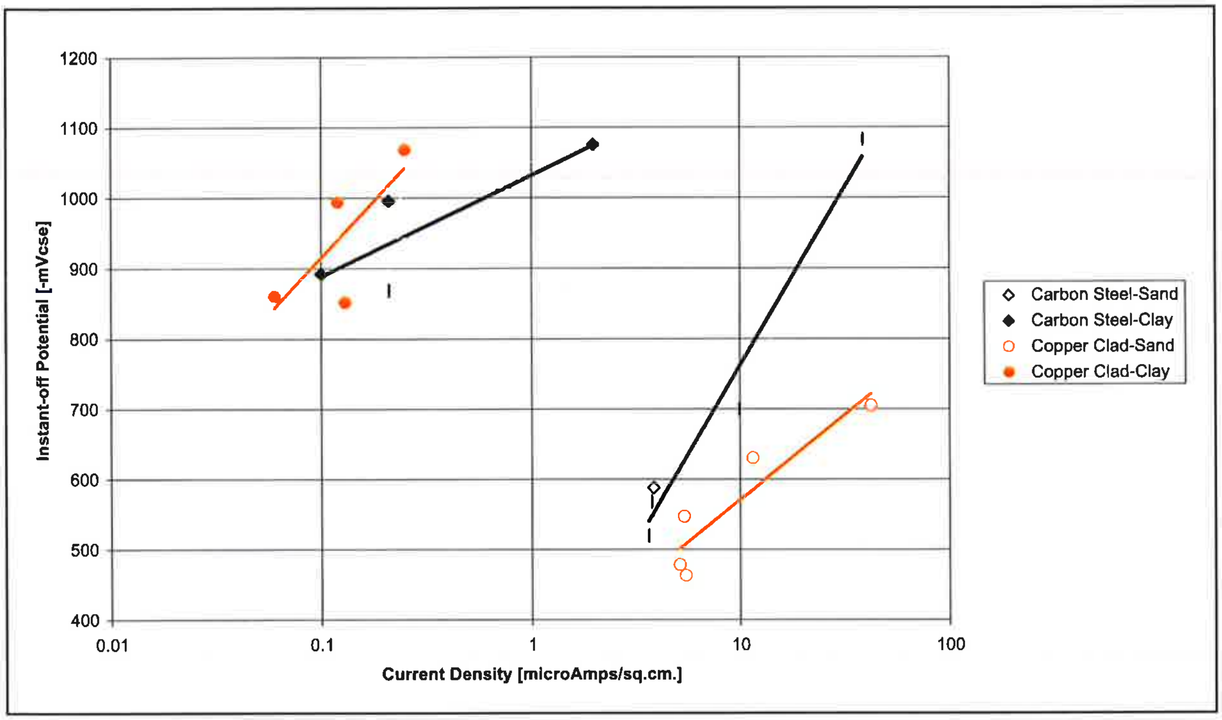

Figure 1 – Polarization Characteristics of Carbon Steel and Copper in Clay and Sand Soils (2)

In addition, the couple of copper to carbon steel precludes the use of the 100 mV depolarization criterion(3) due to the different electrochemical characteristics of copper and steel. As such, in order to ensure cathodic protection of underground piping coupled to copper grounding systems, the potential must be moved to a polarized value more negative than -850 mV ($Cu:CuSO_4$).

These factors result in wasted current and hence increased cost to protect the piping.

POSSIBLE SOLUTIONS

The most straightforward solution to eliminate the interaction between the copper and piping is to DC isolate and AC couple the dissimilar metals. This is accomplished by installing Electrolytic or Electronic Polarization Devices (EEPDs) rated for the fault current between the copper ground and carbon steel piping systems.[(4)]

Alternatively, the copper grounding electrodes can be replaced with a more galvanically compatible material. Figure 2 indicates the polarization characteristics of a number of possible grounding materials in comparison to carbon steel in aerated soil. Tinned copper and silicon iron are much more compatible with carbon steel than copper.

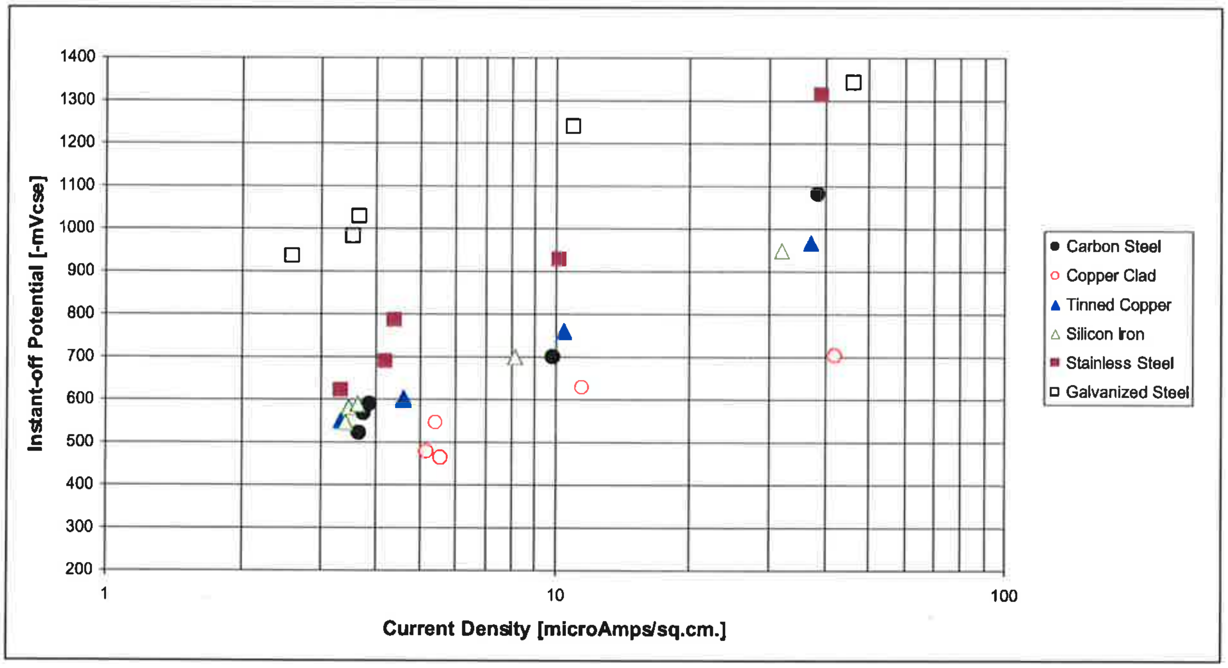

Figure 2 – Polarization Characteristics of Various Materials in Aerated Soils [(2)]

Silicon iron is the preferred material due to very low corrosion rates in virtually all soils. In addition, as the composition of the silicon iron electrodes is identical to that of impressed current anodes, it is the optimal material where pick up and discharge of cathodic protection currents may occur. It is imperative to realize that, unlike normal cathodic protection groundbed installations, the silicon iron grounding electrodes must not be backfilled with coke breeze. Backfill of this type will change the electrochemical behaviour of the silicon iron to that of carbon or graphite which is galvanically incompatible with carbon steel.

CASE STUDY

Several attempts were undertaken to electrically isolate a portion of the copper grounding system at the subject plant. All of the attempts were unsuccessful due to many intentional and unintentional interconnections.

A thorough review was conducted of alternative techniques.[5] After performing detailed step and touch potential calculations to ensure personnel safety in the event of a fault in the station as well as on the incoming pipelines, it was decided that the entire grounding system in one area of the plant would be removed. A new grounding system using silicon iron electrodes was designed and installed to achieve a satisfactorily low resistance to ground for fault protection and other safety considerations, as well as to improve the protection levels of the buried high pressure piping in the plant.

A cost analysis of various options was performed with and without the use of EEPDs. Table 1 outlines the relative material costs for the various options.

Table 1 – Relative Cost Comparison of Alternative Mitigation Techniques

OPTION	Description	Relative Cost – Materials ONLY
1	Bare copper installed in the same manner as the existing system, but properly isolated from the piping using EEPDs	3.11
2	Silicon Iron electrodes installed in place of the copper grounding and isolated from the piping using EEPDs	3.62
3	Silicon Iron electrodes installed in place of the bare copper grounding and connected directly to the plant and piping.	1.00
4	Zinc ribbon with backfill to replace existing copper grounding and isolated from the plant using EEPDs	5.40
5	Zinc ribbon with backfill to replace existing copper grounding and connected directly to the piping.	2.78

Alternative 3 was selected with the addition of bonding enclosures between the silicon iron grounding array and piping to install EEPDs if required.

IMPLEMENTATION

The first phase of the project consisted of the installation of approximately 146 silicon iron electrodes around the perimeter of the pumping station. These electrodes[6] were 152 cm (60 inches) long and nominally 3.8 cm (1.5 inches) in diameter, constructed with #2 AWG connection wires at both ends for redundancy. Only native material was used for backfill due to the previously mentioned problem with using coke breeze.

The anode tails were connected to a pair of #2 AWG green insulated header cables in an alternating fashion using a typical crimp sleeve tape wrapped anode groundbed splice. Bonding boxes were installed at nine locations around the perimeter to allow future installation of EEPDs if necessary, and to permit resistance measurements of a segment of the perimeter ground. Figure 3 shows the installation of the electrodes around the perimeter of the station.

Figure 3 – Installation of Station Perimeter Grounding System

A one metre wide layer of crushed stone was placed around the outside of the perimeter fence to limit step and touch potentials.

Several techniques were evaluated to remove the existing AWG 2/0 bare copper grounding grid. The north-south / east-west grid was installed at approximately two metre centres and a depth of 0.5 to 1 metre. Extreme caution was needed during this work as it was performed in close proximity to the high pressure gas lines. In addition, many control cables were installed above the grounding grid some of which would cause a complete plant shutdown if damaged! This prevented the use of usual mechanical excavation equipment.

Hydrovac excavation was used for some of the removal but the high cost, the need to dispose of the slurry, and purchase of replacement backfill limited use of this technique.

Ultimately, hand excavation proved to be the most cost effective method for removal of the old copper grid and re-installation of the new silicon iron electrode grounding system. Figure 4 shows a typical excavation required to locate and remove the copper grounding system.

Figure 4 – Removal of Copper Grounding System

As each section or area of the plant was cleared of the bare copper grounding, new silicon iron electrodes were installed in the existing excavation, if possible, or in new excavations. As was undertaken for the perimeter grounding, two runs of #2 AWG were used as a header and the electrode tails were spliced into alternate headers using typical crimp and tape wrap splices.

While the entire perimeter ground system was replaced, only a selected area of the plant interior system was removed in this phase. The area comprised approximately 1/3 of the plant area. Approximately 1,361 kg (3,000 lbs.) of bare 2/0 copper grounding wire was removed.

EVALUATION

Cathodic Protection Potential Survey

An interrupted potential survey of the entire pumping station is conducted on a regular basis. The results from the 2000 survey and the 2003 survey are presented as Figure 5.

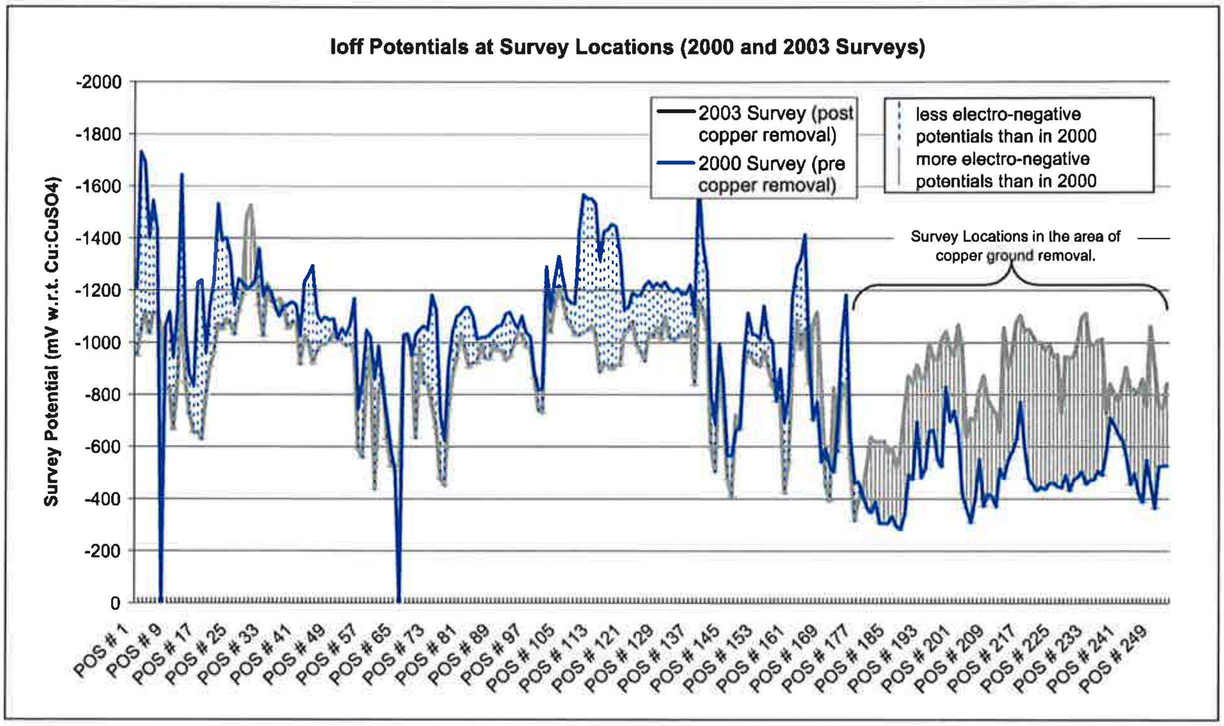

Figure 5 – Potential Shifts by Survey Location

The data from the surveys indicates a significant improvement in potentials after removal of the copper and installation of the silicon iron electrodes.

The surveys were conducted with all station rectifiers interrupted but other current sources (main line and foreign) remained in operation which impacted certain areas of the plant.

During the three years between surveys, many of the cathodic protection groundbeds in the plant were depleting which explains more electro-positive potentials in the balance of the plant where no copper removal was undertaken.

Testing is planned to determine if the 100 mV depolarization criterion can be utilized on underground carbon steel piping directly connected to silicon iron grounding arrays.

Plant Ground Resistance Measurements

The grounding resistance of the station was measured using, the 'fall of potential' method[7] to establish the resistance to remote earth.

One of the station cathodic protection rectifiers was used to power the test at a current of 3.7A. An auxiliary electrode consisting of seven grounding pins was installed at a distance of about 1 km from the plant perpendicular to the incoming and outgoing pipelines. The portable potential electrode was moved at 20 m intervals in order to locate the region of "null slope" (i.e. remote earth). The results of the measurement are shown in Figure 6.

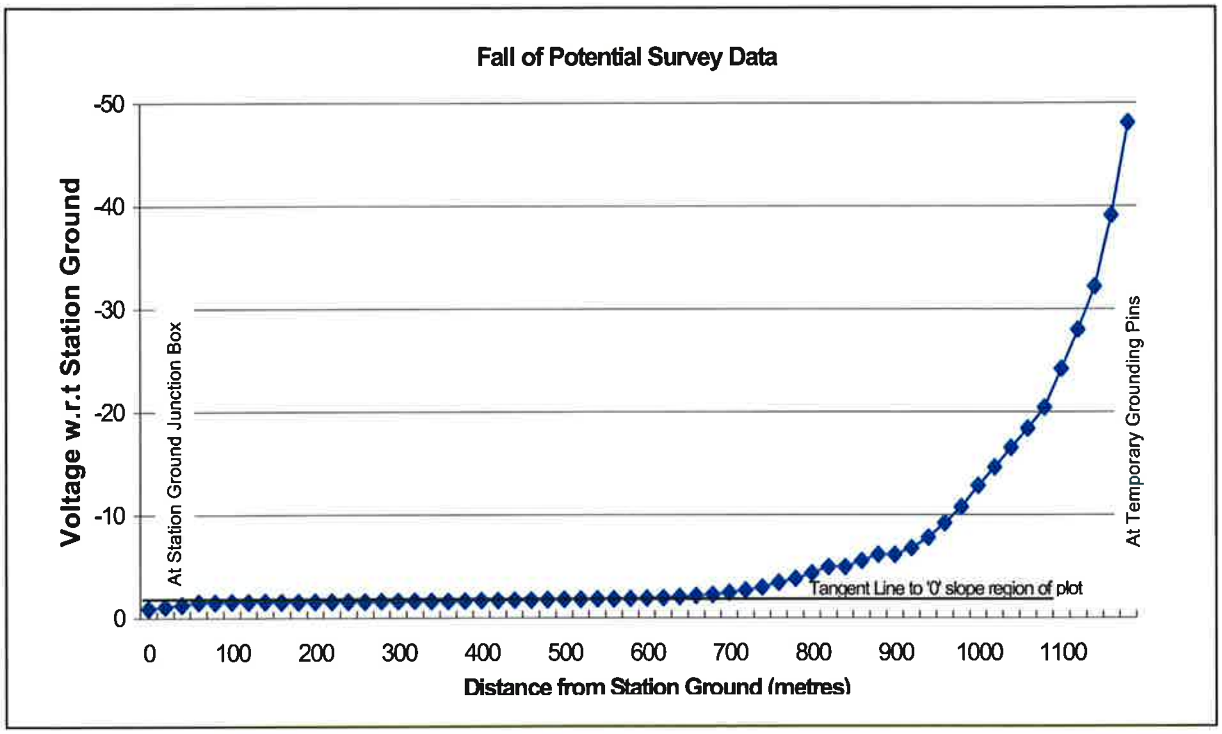

Figure 6 – Fall of Potential Survey

The graph area close to the station ground was expanded to show the I-R drop produced by the test current (i.e. 3.7A) at the station ground, as measured with respect to remote earth (i.e. the "null slope" region). The expanded graph and the calculations are shown in Figure 7.

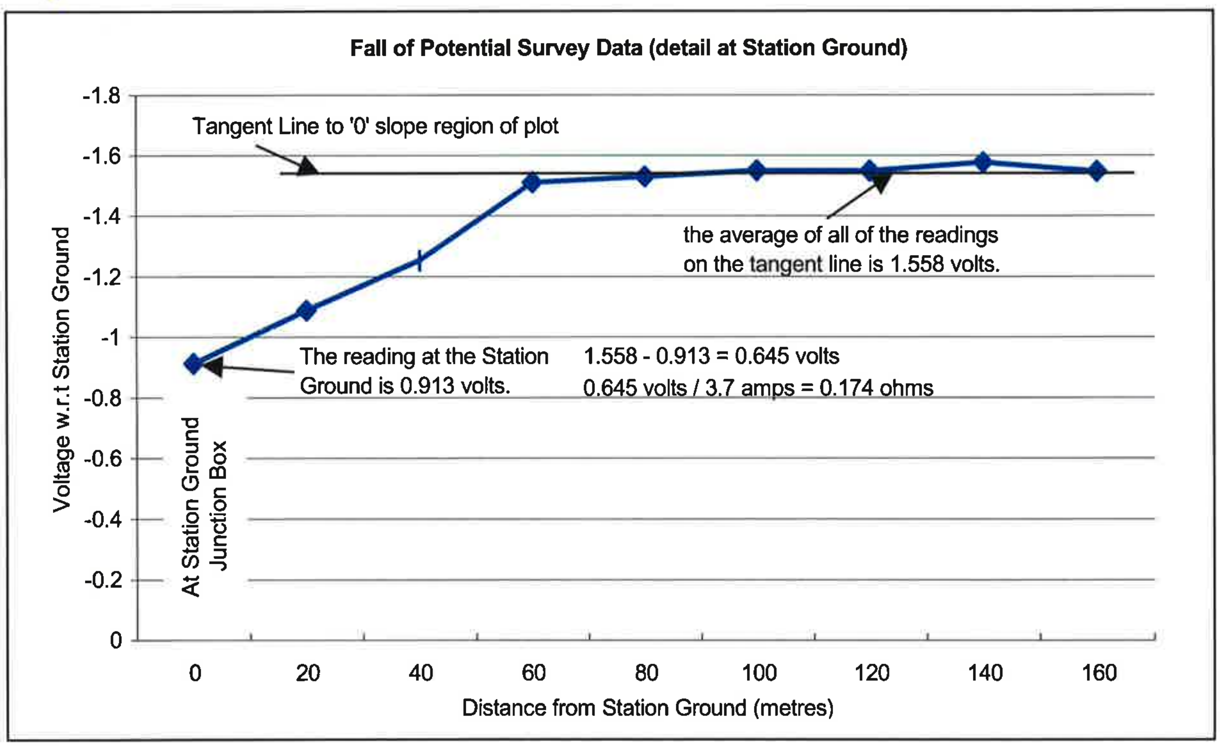

Figure 7 – Expanded Fall of Potential Data

The data indicates an overall plant resistance to remote earth of 0.174 ohms. This is somewhat lower than the originally calculated value and well within the limits of a satisfactory ground system.

CONCLUSIONS

The use of silicon iron electrodes to replace bare copper grounding systems can satisfy both the requirements of safe grounding as well as reducing the impact on the cathodic protection systems.

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