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From the desk of G. A. Aaker, Jr., PE.

The following is a sample calculation to determine the requirements for an Impressed Current Cathodic Protection System

Assume the following pipelines require CP

10 inch x 2100 m long	**Pipeline A**
10 inch x 3100 m long	**Pipeline B**
10 inch x 2500 m long	**Pipeline C**
10 inch x 100 m long	**Pipeline D**
10 inch x 1900 m long	**Pipeline E**
10 inch x 8000 m long	**Pipeline F**

DESIGN PARAMETERS

The following design parameters were utilized in the design of the impressed current cathodic protection system:

Soil Resistivity	**50,000 ohm-cm (estimated)**
Current Density	**20 mA/sq.m**
Coating Deficiency	**0.05**
Electrical Isolation	**electrically isolated @ each end**
Test Stations	**Installed at 2 km intervals maximum**
Design Life	**20 years**
Anode Material	**High Silicon Cast Iron**
Anode Dimensions	**67mm x 2133 mm long (28.6 kg)**
Consumption Rate Cast Iron	**0.50 kg/amp-yr**
Utilization of Cast Iron	**0.75**

The current density and coating deficiency selected are based on previous experience on similar pipelines and are within industry standards. The soil resistivity value selected is an approximate value for sandy clay at the deep well depth. (Geological information from water well drilling reports).

CALCULATIONS

Pipelines Considered:

10 inch x 2100 m long **PIPELINE A**

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10 inch x 3100 m long	**PIPELINE B**
10 inch x 2500 m long	**PIPELINE C**
10 inch x 100 m long	**PIPELINE D**
10 inch x 1900 m long	**PIPELINE E**
10 inch x 8000 m long	**PIPELINE F**

EXTERNAL SURFACE AREA OF EACH PIPELINE TO BE PROTECTED

For underground pipelines, the external **surface area (SA)** is calculated as follows:

$$SA = 3.142\ dl$$

Where:

SA = external surface area (sq m)
D = diameter of pipeline = 0.273 m
L = length of pipeline

Substituting:

SA =	**1801 sq m**	**PIPELINE A**
	2659 sq m	**PIPELINE B**
	2144 sq m	**PIPELINE C**
	86 sq m	**PIPELINE D**
	1630 sq m	**PIPELINE E**
	6862 sq m	**PIPELINE F**

ESTIMATED CATHODIC PROTECTION CURRENT REQUIRED

Using the calculated surface area and the assumed coating deficiency and current density, the current requirements can be calculated as follows:

$$I = (SA)(CD)(H)$$

Where:

I = current required (amps)

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SA = external surface area (sqm)
CD = current density (20 mA/sqm)
H = coating deficiency (0.05)

Substituting:

I =	**1.8 amps**	**PIPELINE A**
	2.7 amps	**PIPELINE B**
	2.1 amps	**PIPELINE C**
	0.09 amps	**PIPELINE D**
	1.6 amps	**PIPELINE E**
	6.9 amps	**PIPELINE F**

GROUND BED RESISTANCE TO EARTH

Using Dwight's equation the resistance to earth of the deep ground beds can be calculated as follows:

$$Rv = 0.0016x\ \rho[\ \ln(8L/D)-1]/\ L$$

Where:

Rv = resistance to earth of vertical anode (ohms)
ρ = resistivity of soil (50,000 ohm-cm)
L = anode column length including backfill (34m)
D = anode column diameter including backfill (0.254m)

Substituting:

Rv = 14 ohms

RECTIFIER SIZING

Rectifier voltage output is calculated using Ohm's Law (V = IR) as follows:

PIPELINE A Voltage = IxR + backvoltage
= 1.8 x 14 + 2
= 27 volts

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PIPELINE B Voltage = IxR + backvoltage
= 2.7 x 14 + 2
= 40 volts

PIPELINE C Voltage = IxR + backvoltage
= 2.1 x 14 + 2
= 32 volts

PIPELINE D Voltage = IxR + backvoltage
= 0.9 x 14 + 2
= 3 volts

PIPELINE E Voltage = IxR + backvoltage
= 1.6 x 14 + 2
= 25 volts

Therefore for the above pipelines A to E above, the total voltage required is 130 volts.

Hence a 130 Volt/ 10 amp DC output, 380 Volt/50 Hz/ 3 phase AC rectifier is selected.

PIPELINE F Voltage = IxR + backvoltage
= 6.9 x 14 + 2
= 99 volts

Hence a 100 Volt/ 10 amp DC output, 380 Volt/50 Hz/ 3 phase AC rectifier is selected for the 8.0 km flowline from pipeline F.

DESIGN LIFE

Assuming the current output from each deep well (one per each rectifier) is evenly distributed between the six anodes, the current output for each anode in the deep well is as follows:

$$A = I/N$$

Where:

A = current output per anode (amps)
I = total current per ground bed (9.1 amps) & (6.9 amps)
N = number of anodes per ground bed (6)

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Substituting,

- **each anode will discharge, 1.5 amps (ground `bed 1) and,**
- **1.2 amps (ground bed 2).**

The design life of the individual anodes can be calculated as follows:

L = (W)(C)(U) /A

Where:

L = life (years)
W = weight of anode (28.6 kg)
C = capacity of cast iron in coke breeze (2 amp-yr/kg)
U = utilization factor of cast iron in coke breeze (0.75)
A = Current discharge per anode

Substituting:

Design Life =

- **28 years for ground bed 1 and,**
- **35 years for ground bed 2.**

COMMENTS

The anode manufacturer recommends limiting the current output of the cast iron anodes to 9.5 amps per square meter of anode surface, which correlates to a current output of 2 amps for the selected anodes. The anode design current of 1.5 and 1.2 amps is less than the maximum recommended by the manufacturer and therefore acceptable.

Industry Practice recommends that the maximum current discharge from the surface of the coke breeze column be limited to 1.6 amps per square meter of coke breeze column surface. The external coke breeze surface area is 27.1 square meters (SA = πdl). Design current is 6.9 – 9.1 amps which is equivalent to a maximum current density of 0.34 amps per square meter of coke breeze. This is less than that recommended in Industry Practice and is therefore acceptable.

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VOLTAGE ATTENUATION

In a conductive medium, such as soil, attenuation may be a factor in the design of a cathodic protection system. The following estimates the attenuation of the subject pipeline.

LINEAR RESISTANCE OF PIPE

The linear resistance of 1 meter of pipe is calculated as follows:

$$R = \rho L/A$$

Where:

ρ = resistivity of steel (2.06 x 10^{-5} ohm-cm)
L = length of pipe (100 cm)
A = area of pipe wall (197 sq cm)

Substituting:

R = 1.05 x 10^{-5} ohms.

CALCULATION OF CONDUCTANCE

Assuming a good quality coating with a leakage conductance of 2.5 x 10^{-4} Siemen/sq m in a 1,000 ohm-cm soil, conductivity in 50,000 ohm-cm soil is 5.0 x 10^{-6} Siemens/sq m.

The unit conductance can be calculated as follows:

$$G = (A)(S)$$

Where:

g = unit conductance of pipe to environment (Siemens)
S = conductance (5.0 x 10^{-6} Siemens/sq m)
A = external surface area per meter of pipe (0.86 sq m/m)

Substituting:

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g = 4.3 x 10^{-6} Siemens

CALCULATION OF THE ATTENUATION CONSTANT AND CHARACTERISTIC RESISTANCE

The attenuation constant and the characteristic resistance can be calculated as follows:

$$\alpha = (rg)^{0.5}$$

$$R_G = (r/g)^{0.5}$$

Where:

α = attenuation constant
R_G = characteristic resistance (ohms)
R = unit linear resistance of the pipe (1.05 x 10^{-5} ohms, assuming 1" WT)
g = unit conductance of pipe to environment (4.3 x 10^{-6} Siemens)

Substituting:

α = 6.7 x 10^{-6}

R_G = 1.56 ohms

CALCULATION OF ATTENUATION FROM GROUNDBED IN ONE DIRECTION

Calculating the resistance in one direction from the deep well ground bed is as follows:

$$R_{SO} = R_G \coth(x\alpha)$$

Where:

R_{SO} = resistance in one direction from the ground bed (ohms)
R_G = characteristic resistance per meter (1.56 ohms)
α = attenuation constant (6.7 x 10^{-6})
x = the distance between the ground bed and the far end of the pipe (11,100 M from the CPF to the end of HBNSE GDM)

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Substituting:

R_{SO} = 21 ohms

Current from the ground bed to produce a 1 volt shift in potential at the groundbed:

$$I_s = E_s / R_{SO}$$

Where:

E_s = voltage at the source (1.0 volts)
R_{SO} = resistance in one direction from the ground bed (21ohms)

Substituting:

I_s = 0.048 amps

The voltage shift at the far end of the pipeline for a 1.0 volt shift in potential at the source is as follows:

$$E = E_s \cosh(\alpha x) + R_G I_s \sinh(\alpha x)$$

Where:

E_s = voltage shift at the source (1.0 volts)
α = attenuation factor (6.7×10^{-6})
x = the distance between the ground bed and the far end of the pipe
R_G = characteristic resistance per meter (1.56 ohms)
I_s= current at source (0.048 amps)

Substituting:

E = 1.0 volts for all cases

CONCLUSIONS-There is little to no voltage attenuation ($E=E_s$) along the pipelines and a single ground bed for each rectifier can protect the whole pipeline system without overprotecting the area near the ground bed. If the coating quality is less than expected, the attenuation could be considerably higher.

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Sample Bill of Materials for the Base Case

ITEM NUMBER	QUANTITY	UNIT	DESCRIPTION
1	6	Ea.	ANODES, HIGH SILICON CAST IRON, 67mm X 2133 mm WITH 10 SQ. MM DOUBLE JACKET CABLES, OUTER INSULATION HWPE AND INNER INSULATION OF POLYVINYLIDENE FLUORIDE, (BY VENDOR)
2	2,300	KG	COKE BREEZE, LORESCO SC-2 (BY VENDOR)
3	35,000	mm	LORESCO ALLVENT 1" DIAMETER. (BY VENDOR)
4	3,000	mm	PVC PIPE, SHEDULE 40, 10"DIAMETER WITH BELLED END, (BY VENDOR)
5	1	Ea.	PVC CAP, 10" DIAMETER, (BY VENDOR)
6	30,000	mm	PVC CONDUIT SCHEDULE 40, 1" DIAMETER WITH BELLED ENDS, (BY VENDOR)
7	2	Ea.	PVC CONDUIT ELBOW, 90^{O} STANDARD RADIUS, SCHEDULE 40, 1".
8	AS REQD		GRAVEL OR CRUSHED STONE.
9	10	M	CONDUIT, 2" DIAMETER, RIGID, HOT DIPPED GALVANIZED.
10	2	Ea.	GROUNDING BUSHING 2"DIAMETER MALLEABLE IRON
11	1	Ea.	INSULATING CONDUIT BUSHING 2" DIA.
12	10	M	CABLE 25 SQ. mm SINGLE CONDUCTOR COPPER WITH HMWPE INSULATION. (BY VENDOR)
13	1	Ea.	"LL", 2", FERALOY, W/COVER & GASKET
14	1269	mm	CHANNEL, 6" X 8.2, HOT GALVANIZED
15	1	Ea.	ANODE JUNCTION BOX, STAINLESS STEEL, IECIP44, 6 TERMINAL. (BY VENDOR)
16	610	mm	FRAMING CHANNEL, HOT DIP GALVANIZED, 41 mm x41 mm UNISTRUT, #P 1000-HG OR EQUAL
17	1	Ea.	STEEL PLATE, 203 mm X 203 mm X 12 mm THICK, HOT DIP GALVANZIED.
18	4	Ea.	SQ. PLATE 41 mm 41mm HOT DIP GALVANIZED 7/16 DIA. HOLE, UNISTRUT #1063-HG OR EQUAL
19	4	Ea.	HEX HEAD BOLT, HOT DIP GALVANIZED 3/8"-16 x 3 "

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			LONG.
20	4	Ea.	SPRING NUT HOT DIP GALVANIZED 3/8"-16, UNISTRUT #1008-hg OR EQUAL.
21	4	Ea.	LOCK WASHER, HOT DIP GALVANIZED, 3/8"
22	4	Ea.	EXPANSION ANCHOR, SINGLE ACTION MASONARY 1/2"-13 X 63mm
23	4	Ea.	HEX HEAD BOLT, HOT DIP GALVANIZED 1/2"
24	4	Ea.	FLAT WASHER, HOT DIP GALVANIZED, 1/2"
25	4	Ea.	LOCK WASHER, HOT DIP GALVANIZED, 1/2"
26	1	Ea.	RECTIFER, OIL COOLED, 130 VOLT/10 AMP DC OUTPUT, 380 VOLT/50 Hz/3 PHASE AC RECTIFIER
27	1	Ea.	2 1/2"-2" REDUCER RE, FERALOY.
28	1	Ea.	GROUNDING BUSHING 2 1/2".
29	1	Ea.	CONDUIT HUB 2 1/2".
30	2	Ea.	2" LB, FERALOY W/COVER & GASKET
31	2	Ea.	2" CONDUIT HUB.
32	1	Ea.	2" "T", FERALOY W/COVER & GASKET
33	10	M	PVC CONDUIT, SCHEDULE 80, 2"
34	1	Ea.	RIGID CONDUIT TO PVC CONDUIT TRANSITION COUPLING, 2"
35	7	Ea.	STEEL PIPE, 4" DIAMETER X 1900mm LONG, SCHEDULE 40

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Bill of Materials for Test Stations

1	29	Ea.	TEST STATION, "BIG FINK' OR EQUIVALENT
2	40	M	CONDUIT, 3 " DIAMETER GALVANIZED
3	58	Ea.	PLASTIC SUPPORT
4	90	m	4mm^2 (NO. 12 AWG) SOLID COPPER CABLE WITH THIN INSULATION, WHITE
5	58	Ea.	RUBBER OR PVC BUSHING
6	29	Ea.	ADJUSTABLE BAND
7	29	Ea.	NAMEPLATE, 2" X 3", STAINLESS STEEL
8	58	Ea.	15 GRAM THERMIT WELD CHARGE/ MOLD

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