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Cathodic Protection for Multiple Well Casings in Existing Gas Processing Plants

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ABSTRACT

Designing of cathodic protection (CP) systems for bare well casing in existing gas processing plants is a challenging task, particularly for effective current distribution between wells, piping and other infrastructure. The cathodic protection design for well casings must be integrated with existing plant CP systems to avoid interference and to have proper current distribution over the structures intended for protection. Consideration must be given to the affecting factors such as - well casing resistance to remote earth, back EMF, flow line and trunk line resistances and negative cable resistance.

This paper presents various scenarios of multiple well casing CP system design.

- Gathering required information & existing systems testing.
- Detection of any suspected interference problems.
- Establish current requirement for well casings.
- Design and current distributions.
- Commissioning findings & rectifications.

1. INTRODUCTION

The RasGas has five wastewater injection (WWI) wells and two acid gas injection (AGI) wells installed inside the operating plant facility. These wells dispose-off plant wastewater and acid gas into the ground to a depth of 6,000 feet (approx.).

The RasGas initiated a project to protect these well casings by cathodic protection. Since the injection wells were already in place and in operation, electrically isolating a specific well was not practical because CP current demand increased drastically since the casings drew huge CP current from nearby structures causing imbalance.

The main project scope was to survey, design, supply, install and commission the CP system.

2. STRUCTURES TO BE PROTECTED

This project consisted of five wastewater injection (WWI) wells (Well 1,2,11 and 15) and two acid gas injection (AGI) wells (Well 3 and 4). These wells are located within the company's operating facility and are near to seashore. Each well consists of multiple sizes of casings. The dimensions of casings for each well are described below in Table-1:

Well Nos.	Casing-1		Casing-2		Casing-3		Casing-4		Casing-5	
	Dia. (m)	Ln. (m)	Dia. (m)	Ln. (m)	Dia. (m)	Ln. (m)	Dia. (m)	Ln. (m)	Dia. (m)	Ln. (m)
Well-1	0.18	314.55	0.25	934.82	0.34	420.02	0.47	122.22	0.76	25.91
Well-2	0.18	277.06	0.25	681.23	0.34	528.52	0.47	36.58	-	-
Well-3	0.18	348.08	0.25	935.74	0.34	526.99	0.47	38.41	-	-
Well-4	0.18	351.13	0.25	937.26	0.34	530.35	0.47	33.53	-	-
Well-11	0.14	975.67	0.25	880.56	0.34	543.16	0.47	42.67	-	-
Well-12	0.14	956.77	0.25	1028.09	0.34	545.90	0.47	42.67	-	-
Well-15	0.14	2171.00	0.25	1040.10	0.34	551.66	0.47	42.67	-	-

Table-1: Structure Details

3. CP SYSTEMS DESIGN

The cathodic protection system design for these well casings complied with the British Standard BS EN 15112 and NACE SP0186. The system was designed to meet the current demand for protection that would maintain all designated structures within the required protection criteria limit.

3.1. CP System Design for WWI Wells

The CP system for the protection of all WWI well casings consisted of one transformer rectifier (TR) with four deep well ground beds (GBs) segregated at two selected locations. The proposed TR was oil cooled constant voltage (manual control type) with DC output of 250A – 100V. It was to be used as a power source to feed CP current to the four GBs with the maximum current capacity of 80A for each GB, hence the total current capacity of the whole system was designed for 80A x 4GBs = 320A. Each GB was provided with a separate anode junction box (AJB) to monitor the individual anode performance. Each AJB was connected to the positive terminal of TR through a main positive junction box (PJB).

Similarly, each WWI well casing was connected to the negative terminal of TR through a main negative junction box (NJB), which was provided with resistors and shunts to control and monitor the current consumptions of the individual well casings.

There was one existing LPG pipeline, passing near to two GBs. Project requirements included the mitigation of all possible interferences that might be caused due to this pipeline. Therefore, a common bonding station with current control resistors and current measuring shunts was installed between all designated structures and the interfered pipeline.

3.2. CP System Design for AGI Wells

The CP system of AGI wells casings consisted of one TR with two deep well GBs in selected locations. The proposed TR was oil cooled, constant voltage (manual control type), with DC output of 100A – 50V. It was used as power source to feed CP current to two GBs with the maximum current capacity of 80A, hence the total current capacity of the whole system was designed for 80A x 2GBs = 160A. Each GB was provided with a separate AJB to monitor the individual anode performance. Each AJB was connected to the positive terminal of the TR through the main PJB.

Similarly, each AGI well casing was connected to the negative terminal of the TR through the main NJB, which was provided with resistors and shunts to control and monitor the individual well casings current consumptions.

4. DESIGN BASIS AND CONSIDERATIONS

4.1 Interference testing

There were many existing CP systems in the plant which were found connected to well casings through structural continuity and which caused interference with the designated structure. Therefore, a complete survey to identify the interfered CP systems had to be done first, which indicated the following results:

Existing CP System Status	Well Casing Stray Current Status (A)							Remarks
	Well-1	Well-2	Well-3	Well-4	Well-11	Well-12	Well-15	
All CP Systems ON	4.79	2.21	-	-	Isolated	2.91	-	Well casings interfered by existing CP systems
All CP Systems ON	4.55	1.73	-	-	Isolated	2.44	-	Well casings interfered by existing CP systems
6 CP Systems Nearby WWI Wells OFF	3.92	1.10	1.29	2.61	Isolated	1.85	-	Well casings interfered by existing CP systems
Interruption Testing of AGI Wells	-	-	Receive Interruption	Receive Interruption	-	-	-	27 CP systems found causing Interference

Table-2: Interference Survey Results

Following to these indications, all those CP systems that were found to be causing interference to well casings were switched off during the time of the pre-design survey.

4.2 Soil Resistivity Testing

The main aim of the soil resistivity survey was to collect sufficient data and information and to take the necessary measurements to finalize the design of the CP system in accordance to the mandatory standards requirements. Accordingly, the soil resistivity testing was carried out at three proposed GB locations by using a Geonics EM-31 and an EM-34. Following are the soil resistivity values, used for the engineering design calculation:

Well Ref.	GB Ref.	Depths	Average Resistivity Value
WWI	GB-1	26m to 60m	334 ohm-cm
WWI	GB-2	26m to 60m	317 ohm-cm
AGI	GB-3	22m to 56m	411 ohm-cm

Table-3: Average Resistivity Values

4.3 Comparison of Soil Resistivity Testing Results with Resistivity Logs

All the measured soil resistivity values at different depths were compared and verified with company formation resistivity logs. The measured values were found within the range of ±10% of formation resistivity logs.

4.4 Design Current Density based on E Log I Testing

The E log I survey is a method employed to gather information regarding the current requirements of the structure. The results are affected by various variable parameters such as resistance, polarization and time. The obtained values are not accurate but do provide a conservative figure for design considerations.

The idea behind conducting the E log I testing was to determine the potential shift between cathode structure and surrounding electrolyte. Based on current magnitude and time dependent polarization, the potential was measured by placing and shifting the reference electrode until the remote earth is reached. The potential shift for a given current level depends on the following factors:

- The length of time the current is applied.
- Current density which is affected by factors such as well depth, casing sizes, and cement.
- Properties of the electrolyte.

As impressed current is increased in steps, polarization begins on the surface of the casing. The measured potentials are plotted against the log value of the impressed current to select the polarization beginning point.

The testing was done on four selected well casings, i.e. Well-11, Well-15, Well-1 and Well-12. Survey requirement is to perform the E log I test up to current output of 50A, a temporary ground bed established at selected locations by inserting 10 copper rods (20mm Ø x 1.5m long) into the ground. Following are the measured resistance of copper rods with ground.

a) One (1) rod resistance to ground = 5 ohms
b) Ten (10) rods resistance to ground connected parallel = 0.77 ohms

The testing was done in increments of 1A feeding current with the duration of 3min polarization. After the polarization, the current was interrupted to measure the polarized potentials. The complete potential profile was recorded in a data logger. The E log I survey chart was developed by computing the measured values manually in excel graphs. Using the plotted graph, the design current requirements were interpreted through the polarization curve as shown in Figure-1.

BS EN 15112 states that, once the polarization curve is established, the tangents of two linear parts are used to determine the design current requirement for adequate protection of well casings. However NACE SP0186 states that, the first point lying on polarization curve is the design current requirement of well casings. Hence the E log I test design current requirement was established by taking the average of both values, interpreted through two above stated standards. The values are shown in below Table-3;

Well Nos.	Well Casing Surface Area (m^2)	Potentials Before Interfering System OFF (mV_{CSE})	Potentials After Interfering System ON (mV_{CSE})	De-Polarized Potentials After Well Isolation (mV_{CSE})	Current Req. By E log I Survey (A)			Casing to Earth Resistance (ohm)
					By NACE Standard	By BS Standard	Average	
Well-1	1,603.05	-1,007	-966	-827	20.00	26.00	23.00	0.035
Well-2	1,310.26	-1,015	-974	-	-	-	-	-
Well-3	1,551.38	-1,053	-943	-	-	-	-	-
Well-4	1,550.68	-1,051	-939	-	-	-	-	-
Well-11	1,763.89	-1,002	-945	-865	19.00	23.00	21.00	0.035
Well-12	1,874.37	-1,005	-982	-884	20.00	27.00	23.50	0.034
Well-15	2,424.00	-790	-790	-782	17.00	23.00	20.00	0.031

Table-3: E log I Test Results

The E log I test current density requirements were established by taking the highest value calculated by dividing test current with surface area of well casings, i.e. 12.48mA/m^2. (Following NACE standard)

4.5 Design Current Density based on NACE Literature

The reference was made from NACE Corrosion Engineer's Reference Book, Section # 162 (Approximate Current Requirement for Cathodic Protection of Steel).

According to this, the current density ranges from 20mA/m2 to 30mA/m2 for steel immersed in seawater in stagnant condition. Since the well casings are uncoated, embedded in concrete filling and located on ground near to seashore area, therefore the considered value was 20mA/m2 for engineering design calculations.

4.6 Well Casings Attenuation Calculation

The well casing attenuation calculation was done to determine the current attenuated in casings, and to establish minimum level of protective potential over the entire length of structure. These calculations are based on method described in European Standard EN 15112:2006 (External Cathodic Protection of Well Casings). This calculation done based on following assumptions;

- The lineal resistance of structure referenced from NACE Corrosion Engineer's Reference Handbook.
- Based on BS EN 15112, the leakage resistance of structure is considered as negligible. This assumption has been taken since the casing pipes are encased in cement.
- The potential shift for structure polarization is considered -250mVCSE, hence the attenuation current is based on the specified potential shift.

4.7 Design Current for Protection

The current requirement for the protection of well casings was taken into consideration in three different ways, i.e. E log I test method, NACE literature basis and current attenuation basis, as specified above. The results with comparison are shown in below Table-4.

Well Nos.	Well Casing Surface Area (m^2)	Design Current (A)			Casing to Earth Resistance (ohm)
		Based on Max. E log I CD	Based on NACE CD	Based on Attenuation Calculation	
Well-1	1,603.05	20.01	**32.06**	44.67	0.035
Well-2	1,310.26	16.35	**26.21**	26.01	-
Well-3	1,551.38	19.36	**31.03**	26.55	-
Well-4	1,550.68	19.35	**31.01**	26.49	-
Well-11	1,763.89	22.01	**35.28**	25.16	0.035
Well-12	1,874.37	23.39	**37.49**	25.17	0.034
Well-15	2,424.00	30.25	**48.48**	25.18	0.031

Table-4: Current Requirement for Protection

With comparison of these results and considering worst case scenario, the design current has been chosen on the basis of NACE literature value i.e. 20mA/m2 current density.

4.8 Protection Criteria

Reference to NACE standard # NACE SP 0186, Section # 4.2.1:

"The cathodic protection applied to the well casing shall be considered adequate when measurements indicate that a net flow of current to the casing has eliminated all anodic areas."

Based on E log I survey results of Well-1, Well-11, Well-12 & Well-15, it was found that the average current requirement for protection of wells range from 20A to 23A (from Table-3). Hence the commissioning current for all well casings considered as 23A.

4.9 System Design Life

According to project specifications, the design life of the CP system was required to be 25 years. This was calculated and verified through design calculations as well as the manufacturers graph for anode life, based on the relationship between anode current output and time in years.

4.10 Simulated Current Distribution

The simulated current distribution is one of the ways to verify the design of the CP system to get verified about the designed CP system. This can only be authenticated if the measured, or calculated, CP circuit resistance is as accurate as possible. Here, electrical software has been used to simulate the current distribution as shown in Figure-2.

5. COMMISSIONING FINDINGS AND RECTIFICATIONS

Initial pre-commissioning survey was completed and major adjustments and measurements were done during this testing. The commissioning survey for both WWI and AGI well casing consisted of following tests;

a) TR testing to measure the operating conditions.
b) Well casings testing to measure the current distribution and potentials.
c) AJB testing to measure the individual anode current outputs.
d) Interference testing on nearby structures.

5.1 Survey Findings and Rectifications

- Both TR operating conditions were satisfactory. The TR of WWI wells was operating at 49.68% current output from its rated current output and the TR of AGI wells was operating at 60.75% current output from its rated current output.
- The operating CP circuit resistances of both locations were also lower than the designed CP circuit resistance.
- The measured potentials inside cellar (concrete casing around well casing) showed low readings due to the area being shielded with concrete walls, however the potential outside showed protective polarized potentials.
- The measured potentials at remote earth location showed protective polarized potentials.
- The pickup current measured on all well casings were uniform and within the range or slightly above of 23A (commissioning current).
- The total current picked up by all WWI well casings was 113.31A, the total current picked by inter-connected flow lines was 9.14A and the current picked up by LPG pipeline was 1.2A. The total of all 113.31A+9.14A+1.2A = 123.65A was close to operating current output of TR, hence distribution was balanced.
- Similarly, the total current picked up by both AGI well casings was 51.27A and the total current picked by inter-connected flow lines was 9.33A. The total of all 51.27A+9.33A = 60.6A was almost the same to operating current output of TR, hence distribution was balanced.
- The reverse current direction was recorded at one location i.e. 2.06A from flow line to Well-1 well casing. This indicates after switching ON the dedicated CP system, the well casings receiving total 2.06A current from other plant CP systems instead of 13.53A recorded during OFF condition. Hence the interference is mitigated to the acceptable level.
- All nearby structures in the vicinity of 200m around GB, were checked for Interference effect. The result shows current pickup causing electronegative shift on structures within the range of 1.5V to 1.2V. No current discharge was observed in tested locations, hence interference effect was mitigated effectively by dedicated CP system
- Current discharge from LPG pipeline caused by interference from anode GBs (GB-1 & GB-2) of WWI well casing CP system. This interference was mitigated after bonding the pipeline with WWI wells through a Bonding Station directly connected to main NJB.

6. CONCLUSION

This paper presents the methodology of designing a cathodic protection system for multiple existing well casings inside process plants. The design method used is almost the same as common practice in normal well casings CP protection projects, but the unique things are the environments, conditions and variables affected on design, which are discussed in detail in this paper. It has been assumed that the information provided in this paper will help the readers to understand the concept used for designing, the tools used for designing and the factors involved in designing.

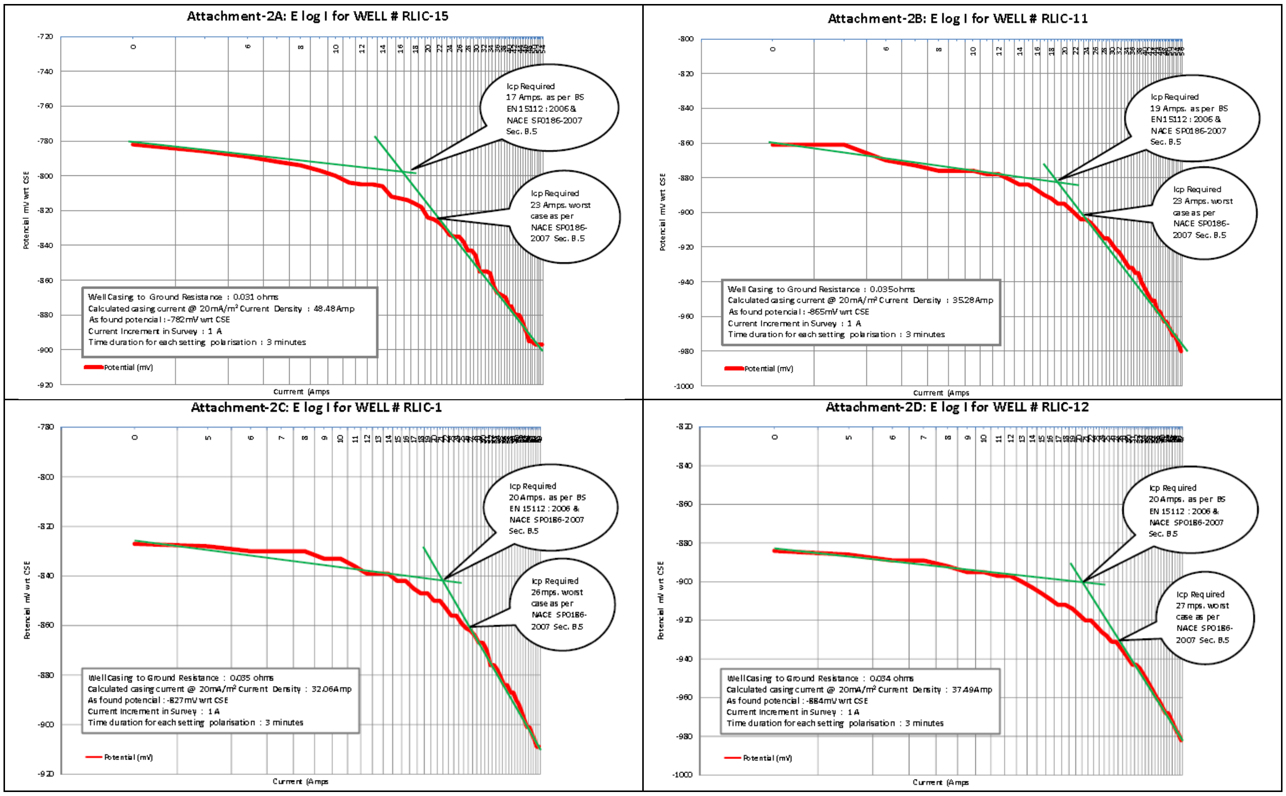
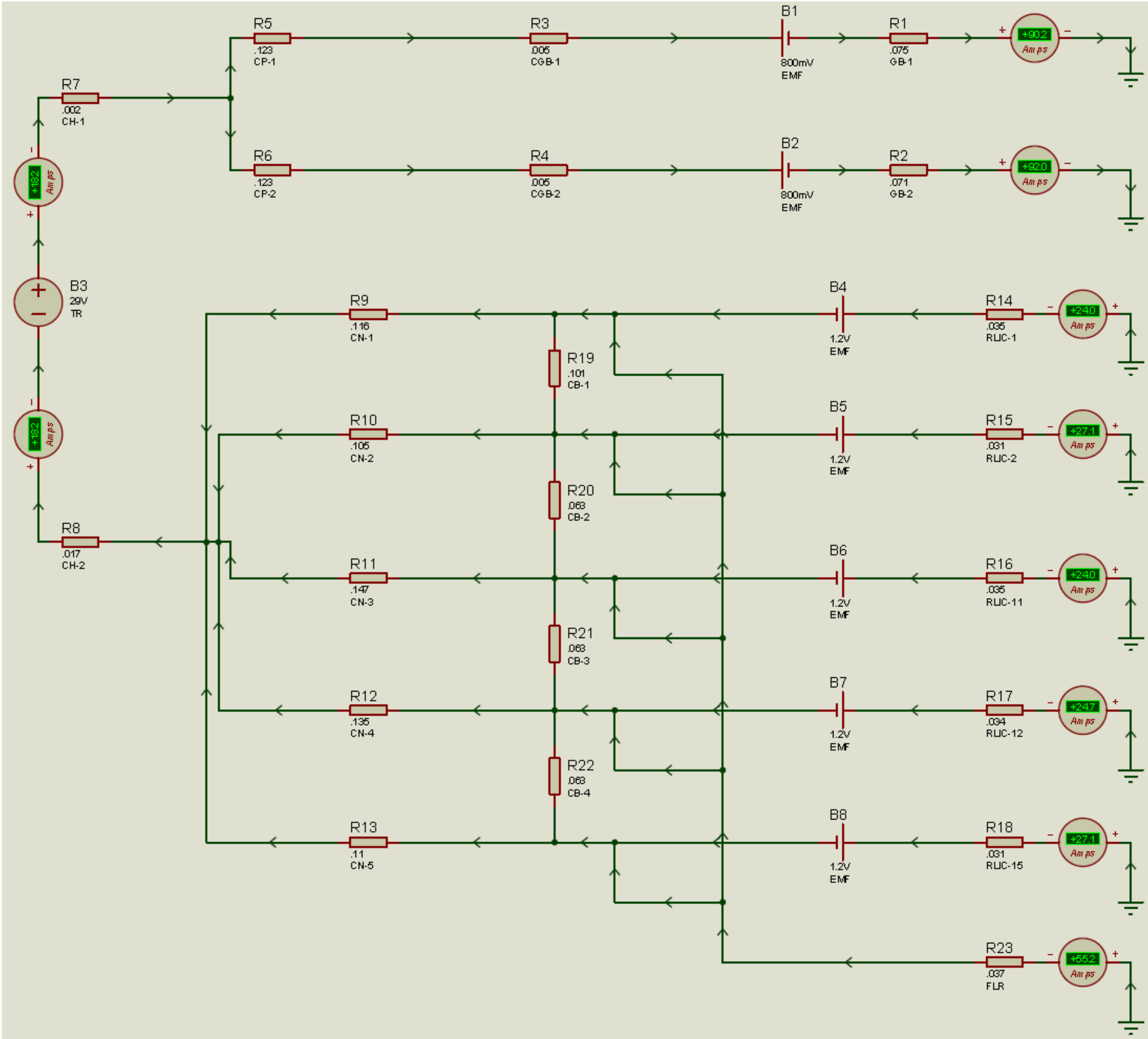


Figure-1: E log I Survey Graph



LEGEND:

CH	=	CABLE HEADER	CGB	=	CABLE GROUNDBED
CP	=	CABLE POSITIVE	CB	=	CABLE BOND
CN	=	CABLE NEGATIVE	FLR	=	FLOW LINE RESISTANCE
GB	=	GROUNDBED			

Figure-2: Simulated Current Distribution