Functional relationship between cathodic protection current/potential and duration of system deployment in desert conditions

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Abstract

This paper analyzes the attenuation of cathodic protection (CP) current/potential in pre-stressed concrete cylinder pipes while using galvanic anodes during system employment. The focus in this paper is on the functional relationship between CP current/potential and the duration of system employment in desert conditions. The purpose of this paper is to reach an approximate formula for the functional relationship current/potential following a deployment of a CP system. Consequently, costly field measurements of said PCCP current/potential can be avoided, thus rendering a more efficient operation of the CP system. These measurements have been taken in desert conditions in sections with very high and low soil resistivity during 22 months. Field measurements confirm that there is a substantial reduction of CP current magnitude following initial CP system deployment. Field data confirm the existence of the correlation between CP current and the time of system exploitation, until the point where full system polarization occurs. For both values of soil resistivity, based on measured current values over time, the paper presents a regression model that is a determined two-term exponential equation.
Keywords: cathodic protection, correlation model, cylinder pipes, protection current, measurements, desert conditions.

1 Introduction

In this paper we analyze the attenuation of cathodic protection (CP) current/potential in conditions of high and low soil resistivity that are typical for

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desert oasis environments. Our study focuses on cases where CP has been applied to pre-stressed concrete cylinder pipes (PCCP) while using galvanic anodes. We present a functional dependency between CP current/potential and the duration of system deployment for cases of high and low soil resistivity. We conclude that total polarization occurs after approximately six months of system deployment, which is the time needed for polarization of bare steel structures in the electrolyte with low soil resistivity. The results have both technical and commercial value, since they make long-term field measurements no longer necessary. The derived dependency between CP current/potential and the duration of system deployment enables a more accurate computation of current/potential parameters in CP systems.

The attenuation of the protection current, until the point of full PCCP polarization in the CP system, is caused by [1–5]:

- polarization of the PCCP;
- partial wear of the cast zinc anode as a result of CP system operation;
- increase of anode resistance R_A during system operation.

Purpose of this paper is reaching an approximate formula for the polarization current/potential following a deployment of a CP system. Consequently, costly field measurements of said PCCP current/potential can be avoided, thus rendering a more efficient operation of the CP system.

2 Experimental basis and functional correlation

A computerized statistical method that calculates current/potential as functional correlation of duration based on measurement data for CP system is introduced. The method uses the regression and correlation analysis of measurements of current and potentials of the piping network in desert environment. This approach ensures during the time installation of more CP capacity with distributed anodes around the piping network and examination of the protection potentials without need for new expensive measurements. This procedure is recommended for the improvement of the existing and new CP system.

Based on this approach, developed program determines the relationship between two or more variables from a group of known values from such variables using regression and correlation analysis. The main objective of the program is, with a set of data and based in a curve as a model, to use the regression analysis to obtain the coefficients of the curve to fit the best correlation (minimal standard deviation) between the mathematical model and the set of known data.

2.2 The measured values and functional relationship for high soil resistivity

For high soil resistivity we have measured values of the grounded current over time as presented in Table 1. Measured values are given for several points. Also, in Table 2 are given measured values changes of polarization potential over time. Graphical illustration of the change in current over time is presented in Figure 1.

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Table 1: The change in the grounded current over time [6,7].

section	st 224+240	st 224+850	st 225+420	st 226+020	st 228+950
t [days]	I [A]	I [A]	I [A]	I [A]	I [A]
10	1,36	1,26	1,08	1,06	1,08
70	1,23	1,06	1,00	1,00	1,00
160	1,18	0,96	0,94	0,94	0,96
250	1,06	0,84	0,86	0,82	0,82
340	0,95	0,70	0,78	0,70	0,68
410	0,84	0,54	0,68	0,62	0,60
530	0,74	0,44	0,58	0,54	0,52
620	0,70	0,40	0,52	0,46	0,48
710	0,68	0,40	0,50	0,45	0,47
ρ [Ωm]	860	875	1030	1170	970

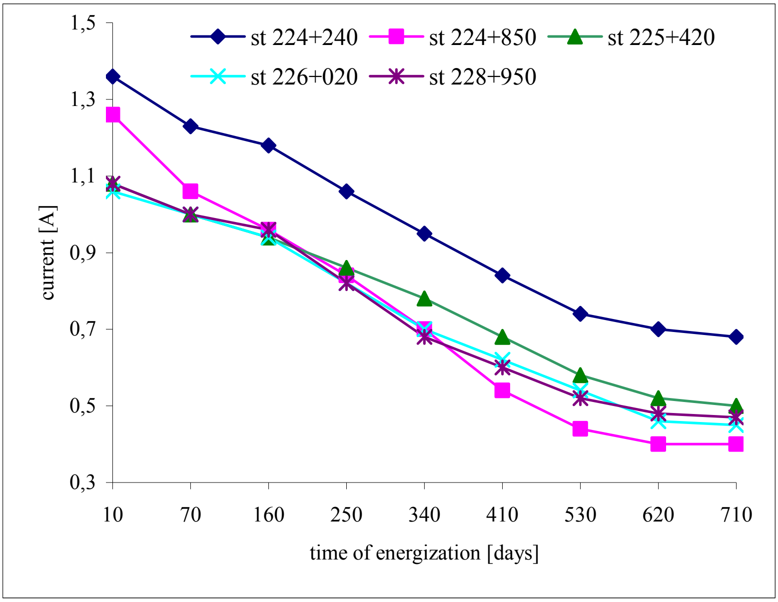

Figure 1: The change in current over time.

On the basis of the measured values of current over time, presented in Table 1, a sample correlation of the results was conducted so as to obtain the functional relationship of the current change over time. To express correlation, we select an exponential regression line:

Table 2: Changes of polarization potential over time [6,7].

section	st 224+240	st 224+850	st 225+420	st 226+020	st 228+950
$V_{natural}$	-23 [mV]	-47 [mV]	-32 [mV]	-42 [mV]	-15 [mV]
t [days]	– V [mV]	– V [mV]	– V [mV]	– V [mV]	– V [mV]
10	429	302	380	228	612
70	442	295	365	242	618
160	491	332	375	298	602
250	430	265	341	284	476
340	328	196	286	268	370
ρ [Ωm]	860	875	1030	1170	970

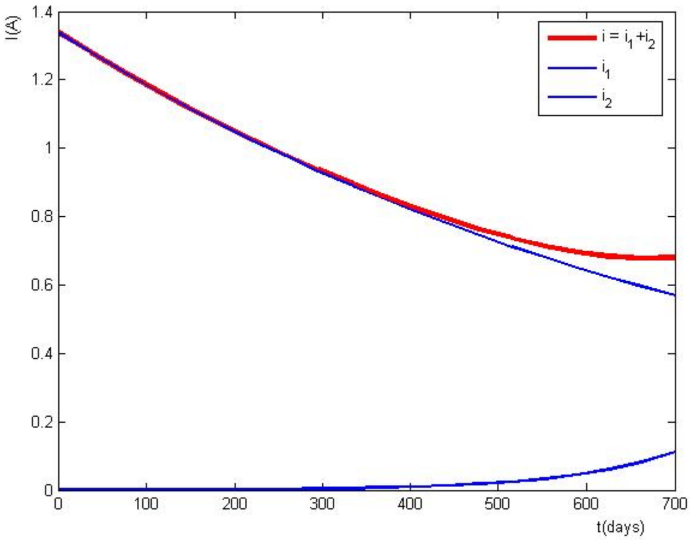

Figure 2: Regression curve for st 224+240.

$$I = I_{01}e^{-at} + I_{02}e^{bt}$$

An example of the regression curve for st 224+240 (ρ = 860 [Ωm]) is given in Figure 2.

For this section, the functional relationship is:

$$I = 1,374972e^{-0,001150t} + 0,000124e^{0,008793t}$$

In the case of nonlinear regression, following formula is used to determine the correlation coefficient:

$$k = \sqrt{1 - \frac{s_y^2}{\sigma_y^2}} = \sqrt{1 - \frac{\sum (y_m - y_r)^2}{\sum (y_m - \overline{y})^2}}$$

where:

- y_m – the measured values of the current at given points;
- y_r – the values of current at given points, calculated with regression curve;
- $\overline{y} = \frac{1}{n} \sum_{i=1}^{n} y_{im}$ – the sample mean of the measured values of current at given points.

Values of the correlation coefficient k that are close to 1 indicate that the selected regression curve is in close proximity to the measured data. In that case, we say that there is high stochastic nonlinear relationship between the varying values.

Another factor that can determine the quality of the stochastic correlation of results is the standard deviation s of the random error component of the measurement results. This is calculated as follows:

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (y_r - \overline{y})^2}$$

The values of the standard deviation that are close to 0 indicate that the chosen model has a small random error component and that the regression was done properly. In case st 224+240, these factors are k = 0,995124 and

Table 3: Coefficients for the correlation function for given sections.

section	I_{01}	I_{02}	a	b	k	s
st 224+240	1,374972	0,000124	0,001150	0,008793	0,995124	0,024634
st 224+850	1,193506	0,075234	0,002043	0,000042	0,991874	0,040072
st 225+420	1,399827	-0,306529	0,000744	0,000194	0,995527	0,020199
st 226+020	1,165009	-0,107443	0,001445	-0,015353	0,996517	0,019431
st 228+950	1,121880	0,000002	0,001416	0,014730	0,991647	0,030585

s = 0,024634, which suggests that the functional relationship between protection current and time of polarization is almost complete. Table 3 gives the coefficients for the correlation function for specific sections.

Table 4: The change in the grounded current over time [6,7].

section	st 261+660	st 262+270	st 262+870	st 263+340	st 263+960
t [days]	I [A]	I [A]	I [A]	I [A]	I [A]
10	4,18	4,72	3,82	4,00	3,98
70	2,50	3,10	2,30	2,55	2,10
160	1,75	2,44	1,78	1,95	1,55
250	1,40	2,20	1,50	1,65	1,35
340	1,14	2,00	1,25	1,44	1,18
410	1,00	1,85	1,12	1,30	1,02
530	0,92	1,75	1,11	1,22	0,91
620	0,90	1,73	1,10	1,21	0,85
710	0,89	1,72	1,10	1,20	0,84
ρ [Ωm]	35	30	25	35	40

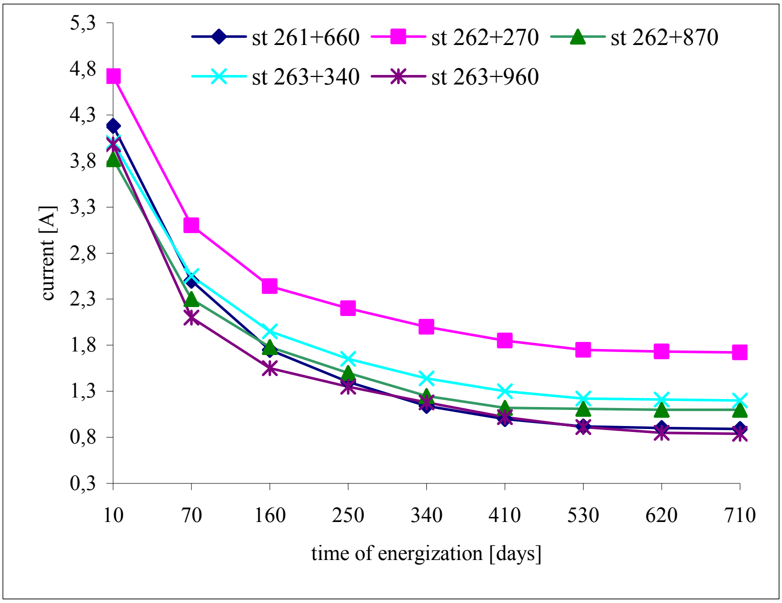

Figure 3: The change in current over time.

Table 5: Changes of polarization potential over time [6,7].

section	st 261+660	st 262+270	st 262+870	st 263+340	st 263+960
$V_{natural}$	-8 [mV]	-10 [mV]	-13 [mV]	-7 [mV]	-10 [mV]
t [days]	– V [mV]	– V [mV]	– V [mV]	– V [mV]	– V [mV]
0	560	615	624	540	552
20	570	585	565	529	523
80	480	545	435	454	440
250	387	430	352	389	370
340	327	354	283	314	306
ρ [Ωm]	35	30	25	35	40

The contribution of the second factor of regression equation during the first year of operation of the CP system does not surpass the value of 2% of total protection current. Thus, we can ignore the second factor in the regression equation during the first year of operation, without any significant effect on the accuracy of results. If we analyze the data in Table 3 we see that the I_{02} and b coefficients in regression function are becoming more significant when the values of protection potential fall below the allowed protection level. This coefficient becomes important only when we have low resistivity of surrounding soil or a prolonged period of operation of the CP system.

This computerized method can be run on a personal computer and can provide timely design support and aids the professional designer in predicting, with a greater degree of certainty, the performance of CP systems.

2.2 The measured values and functional relationship for low soil resistivity

For low soil resistivity we have measured values of the grounded current over time as presented in Table 4. Measured values are given for several points. Also, in Table 5 are given measured values changes of polarization potential over time. Graphical illustration of the change in current over time is presented in Figure 3.

Table 6 gives the coefficients of correlation function for specific sections. If we analyze the data in Table 6, we can see that the I_{01} and *a* coefficients in regression function are becoming more significant when the values of protection potential fall below the allowed protection level. This coefficient becomes important only when we have a low soil resistivity or a prolonged period of operation of the CP system. On the basis of the measured values of current over time, presented in Table 4, a sample correlation of the results was conducted so as to obtain the functional relationship of the current change over time. To express correlation, we select an exponential regression line:

$$I = I_{01}e^{-at} + I_{02}e^{bt}$$

Table 6: Coefficients for the correlation function for given sections.

section	I_{01}	I_{02}	a	b	k	s
st 261+660	2,973364	1,614316	0,014779	-0,000966	0,998193	0,065652
st 262+270	2,748315	2,417513	0,017469	-0,000544	0,998371	0,056016
st 262+870	2,555295	1,648338	0,016530	-0,000682	0,995738	0,083149
st 263+340	2,515544	1,841271	0,015385	-0,000693	0,997693	0,062871
st 263+960	1,777417	2,875912	0,001187	-0,025777	0,999124	0,042028

The conclusions we have made about changes in protection current values can be used effectively in the periodical recording of CP parameters in similar facilities, which cannot be considered as being isolated by means of a proper passive isolation. This is a simpler and more efficient way to reach valuable and realistic conclusions, especially in difficult climates, about:

- a realistic calculation of CP system lifetimes (seeing as the protection current decreases, as does the driving voltage),
- a realistic calculation of anode grounded configuration from the viewpoint of anode/solution resistance, considering that there is a decrease of total protection current,
- an estimation of the length of protective zone (a decrease of protection current and PCCP potential),
- the elimination of costly and long measurements, CIPS recording, as the values of protection current can be determinate at any moment during the time of exploitation of the CP system

Naturally, the defining of approximate analytical equations to express the functional relationship of changes in potential and in protection current values during the time of exploitation, are followed by appropriate recordings on the concrete object installed in desert ambient [6–9].

3 Conclusion

Extensive and cost – intensive field measurements confirm that there is a substantial reduction of CP current magnitude following initial CP system deployment. Thus, there exists a need for repetitive field measurements in order to establish and confirm the scope of CP protection for the object of interest [10,11]. Field data shown in this paper confirm the existence of the correlation between CP current and duration of system deployment, until the point where full system polarization occurs. Specifically, the case of extreme desert conditions necessitates a high soil resistivity, where the CP current decays exponentially with the duration of deployment. The same conclusion can be applied in case low soil resistivity, but with other functional relationship. This paper provides a set of parameters which enables a computation of CP current at any point of system deployment thus enabling CP system architects to estimate the CP current without making expensive filed measurements.

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