A Review of Cathodic Protection Criteria

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One of the primary methods of corrosion control for buried or submerged metal structures is the application of cathodic protection. A direct current is applied through the soil or water from a source outside of the structure to the structure. One fundamental question arises as to how much direct current is required to control corrosion. Another related question involves measuring the effectiveness of a cathodic protection installation. The National Association of Corrosion Engineers (NACE) recognized the need to answer these questions and incorporated various criteria to evaluate cathodic protection installations in their Recommended Practice RP-01-69, "Control of External Corrosion on Underground or Submerged Metallic Piping Systems."

The original version of RP-01-69 has had periodic revisions (most recently the 1983 revision) since its adoption in 1969. The criteria have not been affected in subsequent revisions, until the present time, (1986). Some criteria changes may be incorporated in the next revision of RP-01-69 in order to clarify the original version and to improve the technical nature of the criteria. As these proposal revisions have yet to be reviewed, amended, and approved by the technical committee within NACE, the reader should note that any reference to these revisions are for general information and that the revision adopted may be different than discussed in this paper.

The original version of RP-01-69 listed five basic criterion for ferrous materials, two for aluminum, and one for copper. The purpose of this paper is to review the original criteria in order to point out the engineering considerations associated with each criterion. The revisions presently under review will be discussed as they relate to these engineering considerations.

The criterion are summarized as follows:

For steel and cast iron structures:

1. A cathodic voltage of -0.85 volts to a $Cu\text{-}CuSO_4$ reference cell with current applied.
2. A minimum cathodic voltage shift of 300 mV produced by the application of protective currents.
3. A minimum cathodic polarization shift of 100 millivolts. The voltage shift is determined by measuring the polarization decay.
4. A voltage at least as cathodic as the beginning of the Tafel Segment of the E-log-I curve.
5. A net protective current flow from the electrolyte into the structure as determined by an earth current technique.

For aluminum structures:

1. A minimum cathodic voltage shift of 150 mV produced by the application of protective current.
2. A minimum cathodic polarization voltage shift of 100 mV.

For copper structures:

1. A minimum cathodic polarization voltage shift of 100 mV.

In addition to the specific criterion, RP-01-69 includes general requirements applicable to each specific criterion. These general requirements are:

1. Measurements made with the reference electrode as close as practical to the pipeline.
2. Consideration to voltage drops other than those at the structure electrolyte boundary.
3. Consideration of dissimilar metals.
4. Consideration of other structures.
5. Consideration of stray currents.
6. Consideration of abnormal conditions

   a) elevated temperatures
   b) disbanded coating
   c) shielding

d) bacterial attack
e) electrolyte contamination

-0.85 V (Steel and Cast Iron)

The use of a simple voltage criterion has a great appeal for several reasons:

1. Minimal interpretation
2. Ease of record keeping
3. Ease of Measurement

The -0.85 volt criterion is a technically correct method of evaluating cathodic protection effectiveness. The -0.85 volt value has both theoretically electrochemical and field use support.

A major consideration in using the -0.85 volt criterion is the IR drop factor. As stated in RP-01-69, the measurement is to be made with the protective current applied. Inherent in the measurements are metal IR drops and electrolyte IR drops which are extraneous to the actual structure to reference cell voltage. The present version of RP-01-69 does not **stress** correction for these IR drops and makes it difficult to determine the relative magnitude of the correction required. The present form requires that the protective current be applied during the measurement. IR drops are to be considered, but guidelines for considering them are not included. In actual practice, a great many corrosion control engineers and technicians consider them to be beneficial.

The proposed revision to the criteria stresses that the IR drop portion must be removed from the measured potential for comparison to a criterion. Methods suggested for determining IR drop involve one or more of the following:

1. Contacting the pipe close to the point of measurement to reduce metal IR drop.

2. Placing the reference cell close to the pipe surface to reduce electrolyte IR drop.

3. Interrupt the protective current to eliminate IR drop.

4. Calculate IR drop from a step-wise current reduction or increase.

5. Estimate IR drops as a function of distance from the pipeline and extrapolate.

The removal of IR drop from the measurements requires additional time and precision, but the -0.85 criterion has a greater reliability and scientific basis with the proper corrections.

-300 mV Voltage Shift (Steel and Cast Iron)

The interpretation of the -300 mV shift has been confusing. The origins of this criterion are based upon experience of the late 1940's and early 1950's. There is no scientific basis to the use of this type of criterion. One of the interpretative questions revolves around the consideration of IR drops. The application of protective current produces an instantaneous IR drop which shifts the potential in the negative direction. Traditionally this shift has been used by many corrosion control personnel as the potential shift of the criterion. However, when the IR drops are eliminated, these shifts are removed from the potential value and resultant is a native or steady state potential.

Another view of the -300 mV shift is to consider it a shift after IR drops have been removed. In this instance, the -300 mV is a measure of the potential increase caused by cathodic polarization. In most cases, this interpretation is technically correct in that corrosion is substantially reduced or halted, but significantly greater than the 100 mV polarization shift provided in a separate criterion.

Because of the difficulty in finding a basis for the -300 mV criterion, of the vague manner in which it is presented, and of the confusion of interpretation, the proposed revision to RP-01-69 eliminates this criterion.

100 Millivolt Polarization Shift (Steel and Cast Iron)

The cathodic protection currents react with the electrolyte around the pipe and the resultant products produce a shift in the negative direction of the structure to electrolyte potential. A minimum value of 100 millivolts is a positive indication that the pipeline is reacting as a cathode and that corrosion is substantially reduced or eliminated.

The present form of RP-01-69 determines the amount polarization by interrupting an operating cathodic protection source and measuring the decay in potential over time. The criterion does not indicate the time frame over which to obtain the data The proposed revision permits the measurement of either polarization formation or decay. Provided that IR drops are removed for the calculation of polarization formation, the inclusion this means will be a great benefit in evaluating cathodic protection installations on previously unprotected structures.

Tafel Segment of E-Log-I Curve (Steel and Cast Iron)

This criterion is one of the more difficult to use because of the extensive measurement techniques required to obtain an E-log-I Plot. The theoretical foundation of this criterion is based upon the work of the early 20th century electrochemist John Tafel. As current is incrementally applied to a structure, oxidizing (corrosion) reactions and reduction (cathodic) reactions occur on the pipe surface. When the reduction reactions dominate, a plot of the applied current vs polarized structure potentials on a semi-log graph produces a straight line. This line is the Tafel Segment of the E-log-I Plot. The polarized potential at the beginning of the Tafel Segment is the value which indicates adequate cathodic protection.

The use of the initial Tafel Segment potential as as criterion on a complex structure may require extensive measurements and result in a separate criterion value for each key location. In practice, Tafel Segment measurements are performed when the cost of cathodic protection is great enough to warrant the expense of the testing. The Tafel Segment criterion is often used for uncoated pipelines and for complex piping arrangements.

The proposed revision to RP-01-69 adds to the Tafel Segment criterion the requirement that the Tafel Segment should extend over two decades (i.e., from 10 units to 1000 units) of current. The extension of a Tafel Segment over two decades insures that the plot is linear and that a true Tafel Segment is defined.

Net Protective Current (Steel and Cast Iron),

The net current flow criterion is based upon the theory that net currents flow in one direction. With current flow from the electrolyte to the structure, anodic currents away from the structure are canceled. Correctly applied, this criterion involves continuous measurements around the circumference of the pipeline. This method of measurement is tedious and requires extensive excavation of the structure. Short-cut methods of measurement involving surface measurements of the potential drop from the pipeline to the adjacent earth and along the pipeline are commonly used to determine net current flows.

The use of these short-cut methods does not permit the detection of localized corrosion cells such as oxygen concentration differences between the top and bottom of a pipeline. Adjacent buried structures, soil resistivity, stray currents, and depth of a pipe cover also make the use of a net protective current criterion uncertain.

The original criterion is technically limited to the use of net protective current to bare or ineffectively coated pipelines where long line corrosion cells are of the primary concern. This criterion is ineffective in multiple rights of way, high resistivity surface soil, deep burial, and stray current areas. The revision stresses that this criterion does not assure the elimination of local action corrosion cells. The net protective current criterion will be eliminated from the criteria presented by NACE.

-150 mV Shift (Aluminum)

Aluminum may undergo corrosion under high pH conditions. The cathodic protection reaction produces an increase of pH value around the protected structure. The maximum potential with IR drop compensation for aluminum is -1.20 volts. The -150 mV shift is similar to the -300 mV shift for steel and is mostly IR drop. This criterion is based upon maintaining values lower than -1.20 volts. There is no proposed revision to this criterion.

100 Polarization Shift (Aluminum and Copper)

As with the related criterion for steel, this is a polarization decay measurement. The basis is that at 100 mV of polarization the reduction reactions dominate. Corrosion is substantially reduced or eliminated. There is no proposed revisions to these criteria.

Summarv

Roth the original and the proposed revision of RP-01-69 indicate that the specific criterion are not the only means of verifying cathodic protection installations. The original version states that the persons responsible not be limited to these criteria if it can be demonstrated by other means that the control of corrosion has been achieved. This statement is very broad in that it sets no technical qualification on either the person or on the other means.

The proposed revision defines the qualifications of the person making the confirmation of alternative criterion. This definition essentially states that the person be directly experienced in corrosion control of buried or submerged piping and have a knowledge of the sciences related to cathodic protection. The proposed revision does not set a standard on which to judge any alternative criterion. It should proceed further and prescribe a series of theoretical, laboratory, and field parameters which must be met before an alternate criterion is recognized. The revision in general does state that the effectiveness of corrosion control can be affirmed by visual observation or by measurement of wall thickness. This general guide could be used as the foundation for the acceptance of any alternate criteria. Without a precise method to evaluate and recognize alternate criterion, the corrosion control industry could be beset by many “snake oil” approaches to cathodic protection.

The industry needs to set stringent control over alternate criteria or face the possibility that the Recommended Practice RP-01-69 will be diluted by multiple alternate approaches with little scientific foundation.

The preceding discussion was intended to cover the basic criterion for cathodic protection. A review of the technical considerations for each and some proposed revisions were presented. The information presented is based upon publications of the NACE and its technical committees. While the statements contained in this article are believed to be accurate, they are presented with the statement that the reader is responsible for his own interpretation of the documents.