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100mv Cathodic Protection Criterion-Using Of "Instant-on" Potential in ICCP of New Structures

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ABSTRACT

Nowadays, application of 100mV criterion is more desirable than other criteria especially for buried structure in high resistivity soils where corrosion potentials may be low. Also, since this criterion can be readily evaluated by comparison of two potentials (Normally, Instant-off potential and free corroding potential), some errors by monitoring equipments include half cell and potentiometer can be avoidable.

According to all relevant NACE standards, for assessment of 100mV formation or decay criterion, measuring and recording of instant-off potential is a necessity. For new structure immediately after synchronized energizing an "instant-on" potential can be read. Reasonably the difference between this potential and free corrosion potential refers to IR drop, as well as, the difference between "instant-on" and steady on potential is the "net polarization". This paper compares the results by Instant-off method and Instant-on method for buried piping in a big plant. At the same time, evaluation of laboratory results is another major subject of this paper.

Keywords: Instant on potential, Buried piping, Cathodic Protection criteria

INTRODUCTION

For cathodic protection of buried carbon steel structures, formation or decay of 100 mV polarizations is an accepted criterion as the "soundest fundamental basis"[1]. The origin of this criterion is from 1951 by Ewing[2] and now it is an accepted criterion by most of the standards. The -850 mV polarized potential may seem like the more reliable than other criteria, but there is growing interest in use of the 100 mV polarization criterion. In other words, although, the -850 mV polarized potential is an absolute criterion for cathodic protection but normally it is not a cost effective criteria because its more current demand.[3] In the case of AC interference, more current may be the cause of AC corrosion due to more alkalization.[4] In high resistivity soils more DC voltage should be apply to supply sufficient current for -850 mV criterion and sometimes it may be a safety threat (Step Potential).Additionally, attempting to reach a -850 mV polarized potential may result to hydrogen damages and SCC especially for high strength steel.[5]

On the other hand, the 100 mV polarization criterion is more desirable especially for congested plant where any electrical leak can be an electrical interference threat for other electrical and instrumentation devices.[6] as with other criteria, the 100mV cathodic polarization criterion is not considered valid when elevated temperature or sulfate reducing bacteria are present. Since formation or decay of 100 mV polarization should be evaluated by comparative method, normally it isn't affected by some unwanted parameter such as temperature effects on CSE (Copper/Copper Sulfate reference electrode). However, when the large amounts of metals, for example above ground piping are interconnected to the protected structures and electrical leaks, through damaged insulation joints, is considerable, the 100mV polarization is the only one that is practicable. A minimum of 100mV is a positive indication that the structure is reacting as a cathode and corrosion is substantially reduced.

Both methods need to instant-off measuring by synchronizing interruption or any suitable method[7, 8], so the structures on which the 100 mV criterion is used are usually protected by impressed current systems. Using of this criterion depend on "Base" or "Free corrosion potential" of buried steel structures (with respect to $Cu/CuSO_4$ reference electrode). From the point of view of base potential, all buried structure can be divided to three categories as below:

- Structure to soil potential less (more positive) than -450 mV: it may be due to high resistivity soil/coating or connection to other metals e.g. copper grounding system (Mixed metal potential).In these conditions, the 100mV criterion should not used because the test results are difficult to interpret.

- Structure to soil potential from -450 to -700 mV: they are expected potentials for ineffectively coated pipe in high or moderate soil resistivity. The 100 mV criterion is useful for these conditions.

- Structure to soil potential more(less positive) than -750 mV: it may be due to a soil with high conductivity. Achieving the -850 mV polarized potential criterion is easier than 100 mV criterion and may need to less current.

The 100mV criterion can be evaluated by comparing the instant-off potential to native or free corrosion potential (formation, Test method 3b -NACE)[7] or allowing polarization decay to meet minimum 100 mV (Decay, Test method 3a -NACE)[7]. Usually, depolarization may take a long time, so the formation of polarization is more practicable to measure than its decay. Knowing the free corrosion potentials and reading in the exact location are two main parameters for using the 100 mV formation test method. This study was conducted to compare the polarization amounts measured by two "Instant-on" and "Instant-off" methods.

BASIC RELATIONSHIPS

Assessing cathodic protection effectiveness, an instant-off potential should measure for both -850 mV polarized potential and 100 mV polarization criteria. An instant off potential may result by synchronized interruption of all current sources. In other words, the IR drop is the unwanted portion of potential and it should be eliminated. When the potential of underground structure is measured against a copper/copper sulfate electrode, during the passage current, a voltage drop is always included in the measured value. Figure 1 shows the buried structure to soil potential versus time, upon application of cathodic protection.

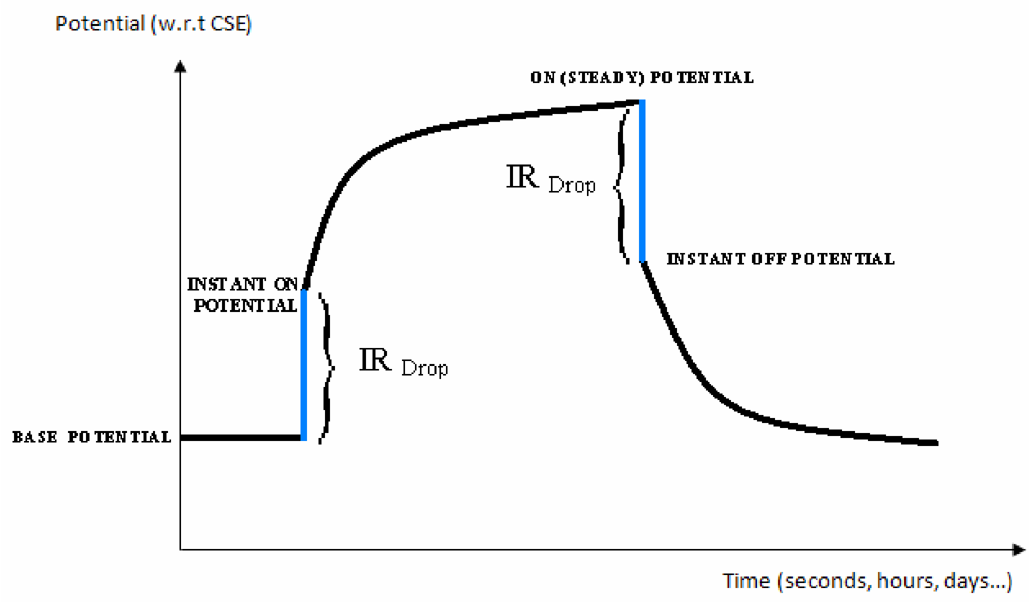

Figure 1: Potential changes by CP system energizing and de-energizing

Regardless to other affecting factors such as ripple, interference effects and long line currents, Figure 1 shows a simplified curve of metal potential changes by cathodic protection system energizing and deenergizing.[9]

As seen, for calculation of the net polarization potential (IR_{Drop} free), measuring the instant off potential should be done according to NACE relevant standard[7], the polarization potential can be calculated by following equations:

Polarization potential = Instant-off potential – Base potential (Formation) (1)

Or

Polarization potential = Instant-off potential –Completely depolarized potential (decay) (2)

To minimize measuring errors, all potentials readings should be performed at the same location and preferably by the same devices (half cell and potentiometer)

With respect to Figure 1, a 100 mV polarization can be also measured by following equation:

$$\text{Polarization potential} = \text{On (Steady) potential} - \text{Instant-on potential} \quad (3)$$

Getting the IR $_{Drop}$ free potential, an instant-on potential value can be subtracted from on-potential value in steady conditions. For the new structure, an instant-on potential can be measured while system energizing. A spike free measurement may be another benefit of polarization assessment by instant-on method. Spikes are fast, short duration electrical transients in voltage in an electrical circuit. Current interruption for instant-off measuring may cause of voltage spike and sometime, depends on magnitude and duration, a negative or positive spike can be a source of error.[10] Although, the present of the spike while an instant-on procedure is the subject needs to more investigation. The present work pertains to assessment of 100 mV criterion measured by above mentioned (Instant-on) method.

FIELD STUDY

The results to be discussed were obtained from a petrochemical plant located in south of Iran. A big Olefin unit located in mentioned plant, comprise vast network of underground structure include about 30000 square meters piping system coated by poor applied bitumen. Soil investigations state a 3000-5000 Ohm-cm resistivity and no evidence of SRB was observed. Impress current cathodic protection system has been installed by four deep well ground beds include sufficient number of MMO anodes and some shallow ground bed to more current distribution. Field assessment has indicated leak problem for some insulating flanges and DC current attributed to cathodic protection was detected on above ground piping system. The unit floor was covered with pavement reinforced by steel bar. Although these steel bars were unprotected but cathodic interference was clearly detected through the DC sources synchronized interruption.

In the mentioned conditions, a 100 mV criterion was more desired than other criteria through following reasons:

1. Applying sufficient current to meet the -850 mV criterion can be a big threat for aboveground electrical and instrumentation devices. Where the leaks via damaged insulation flanges were detected; an electrical interference was unavoidable.

2. Unwanted current can be distributed to other neighbor units via the steel net placed in pavements as an electrical interference.

3. In a congested petrochemical site, applying the more current; can be the cause of electrochemical interference.

Since the mentioned unit was under operation, repairing of damaged insulating flanges was impossible before CP system energizing (only on scheduled overhaul time), so, the contractor had to connect negative cable (CP current drain point) as far as possible from the damaged insulating joints.
Table 1 shows the results of the 100 mV criterion and compares the measurements obtained from two methods: first instant-on potential method and second instant-off (polarization formation) method. Because of concrete pavement, all measurements have been carried out with a portable Copper/Copper Sulfate reference electrode (CSE) located

within a soil-access PVC plastic tube. Based on the suitable location and minimum likelihood of interference, 19 test points were selected.

Table 1: Base, Instant-On, On, Instant-off potentials measured in site

Test point	Base potential	Instant On-potential	Steady On-potential	Instant Off-potential
T/P1	-0.492	-1.200	-1.515	-0.773
T/P2	-0.505	-0.813	-0.959	-0.616
T/P3	-0.475	-1.110	-1.279	-0.618
T/P4	-0.413	-0.745	-0.817	-0.466
T/P5	-0.406	-0.702	-0.818	-0.519
T/P6	-0.531	-1.050	-1.141	-0.565
T/P7	-0.452	-0.777	-0.889	-0.556
T/P8	-0.464	-0.812	-0.928	-0.548
T/P9	-0.554	-0.853	-0.871	-0.595
T/P10	-0.508	-0.740	-0.989	-0.709
T/P11	-0.521	-0.971	-1.238	-0.738
T/P12	-0.536	-0.836	-1.004	-0.675
T/P13	-0.531	-0.977	-1.147	-0.706
T/P14	-0.607	-1.040	-1.141	-0.708
T/P15	-0.609	-1.220	-1.367	-0.751
T/P16	-0.508	-1.020	-1.079	-0.573
T/P17	-0.589	-1.121	-1.319	-0.704
T/P18	-0.624	-1.250	-1.397	-0.760
T/P19	-0.589	-1.060	-1.116	-0.665

Note: All measured potentials are in volts with respect to the saturated CSE

The base potentials have measured; after the all DC sources have been switched-off for a week. Instant-on potential measuring, a suitable period of time "On/Off" as "1 second on and 4 seconds off" has been considered to prevent any significant polarization (in a reverse manner of instant-off measuring). A stable on-potential was obtained after 72 hours and instant-off potentials were measured by a period of time as "4seconds on and 1 second off". All five trans-rectifiers have been synchronized to supply 375 DC Amps as the maximum authorized current. For poor coated piping system a current density of the 12.5 mA/m^2 is reasonably expectable.[11]

LABROATORY TESTING

Laboratory studies are directed at the simulation of the controlled cathodic protection system in field conditions but in the shorter time and more controllable conditions. These studies were conducted in tap water as electrolyte (with resistivity about 1500 Ω.cm), a laboratory switching (ripple-less) rectifier was used as DC power source and two small pieces of bare steel were used as cathode and anode. A cathodic protection circuit was established and before energizing the base potential was measured. Since the Electrolyte container was held in shake less conditions, an area about 22 Cm^2 of bare steel (Cathode) was exposed.

Figure 2: Photographs of the mounted CP system for the net polarization monitoring

Figure 2 contains some photographs of the maintained laboratory cathodic protection system for the 100 mV criterion assessment by both instant-on and instant-off methods. Getting more reliable measurements the test was repeated for five times by different amount of current. Tests results are shown in table 2.

Table 2: Base, Instant-on, On, Instant -off potentials resulted from laboratory tests

Test No.	Current (mA)	Base potential	Instant On-potential	Steady On-potential	Instant Off-potential
1	12	-0.501	-1.131	-1.288	-0.656
2	16	-0.497	-1.295	-1.473	-0.667
3	19	-0.503	-1.345	-1.549	-0.702
4	25	-0.509	-1.492	-1.768	-0.786
5	30	-0.507	-1.503	-1.799	-0.801

Note: All measured potentials are in volts with respect to the saturated CSE

As seen in Table 2, the polarization potential measured results show that the current increasing is the cause of increasing in instant-on potential.

RESULTS AND DISCUSSION

The field study results were used for calculation of the polarization amount. As mentioned, the formation of polarization should be calculated by following equation:

$$\Delta V = \text{(Instant-off potential)} - \text{(Free corrosion potential)} \quad (4)$$

By Instant-on method, formation of polarization can be calculated by following equation:

$$\Delta V = \text{(ON-potential)} - \text{(Instant-on potential)} \quad (5)$$

With respect to the data reflected in table 1 obtained from field survey, Table 2 shows the polarization amounts resulted from above equations for all test points.

Table 3: Polarization value calculated by instant-on and instant-off methods

Test point	Instant-On Method ΔV=ON-(Instant-On) (Volts)	Instant-Off Method ΔV=(Instant-Off)-Base (Volts)
T/P1	0.315	0.281
T/P2	0.146	0.111
T/P3	0.169	0.143
T/P4	0.072	0.053
T/P5	0.116	0.113
T/P6	0.091	0.034
T/P7	0.112	0.104
T/P8	0.116	0.084
T/P9	0.018	0.041
T/P10	0.249	0.201
T/P11	0.267	0.217
T/P12	0.168	0.139
T/P13	0.170	0.175
T/P14	0.101	0.101
T/P15	0.147	0.142
T/P16	0.059	0.065
T/P17	0.108	0.115
T/P18	0.147	0.136
T/P19	0.056	0.076

Note: All measured potentials are in volts with respect to the saturated CSE

The data are shown in table 3 for clarity, are plotted against test points in Figure 3. This Figure shows the similarity of polarization measured by the two methods. Although, however, some points are not satisfied by the 100 mV polarization criterion, but it should be noted that comparison of the two methods is the main purpose of present work. Exception for some minor variations; this Figure shows the same plot resulted from both methods.

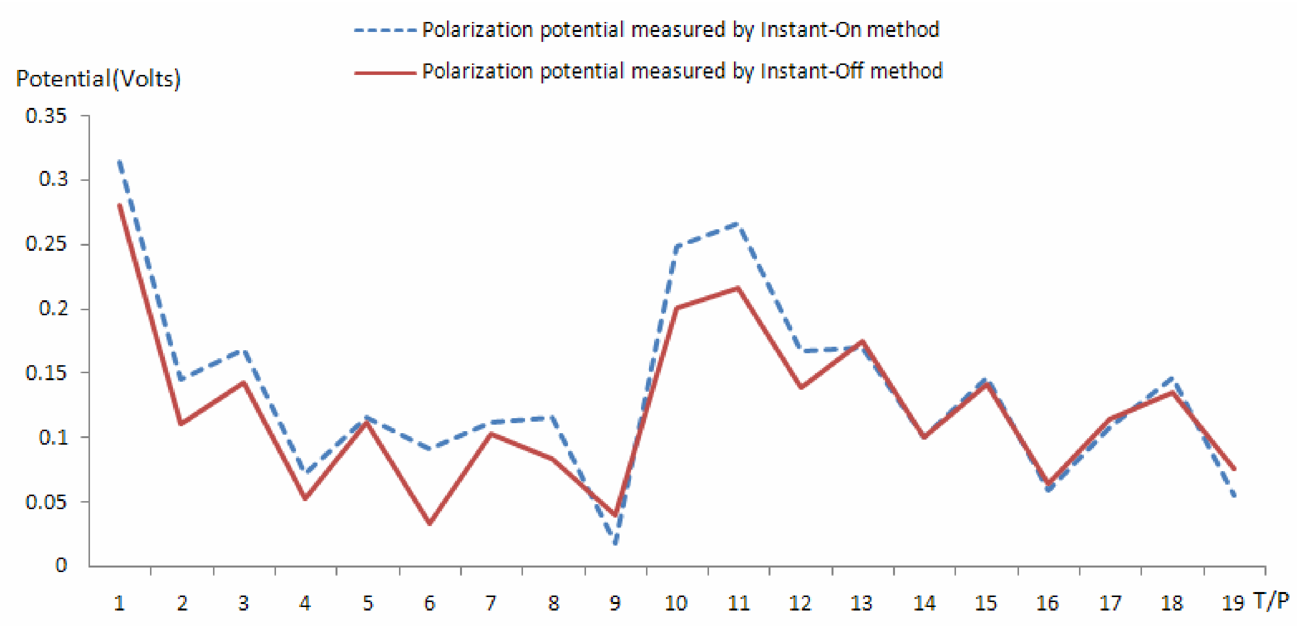

Figure 3: Field polarization values plotted with test points numbers

On the other hand, same results were obtained form laboratory tests. Table 4 shows these results.

Table 4: Polarization value calculated by instant-on and instant-off methods

Test Number	Instant-On Method ΔV=ON-(Instant-On) (Volts)	Instant-Off Method ΔV=(Instant-Off)-Base (Volts)
1	0.157	0.155
2	0.178	0.17
3	0.204	0.199
4	0.276	0.277
5	0.296	0.294

These data are also plotted in Figure4.In this case; the differences between polarization amounts calculated by instant-on and instant-off methods are negligible.

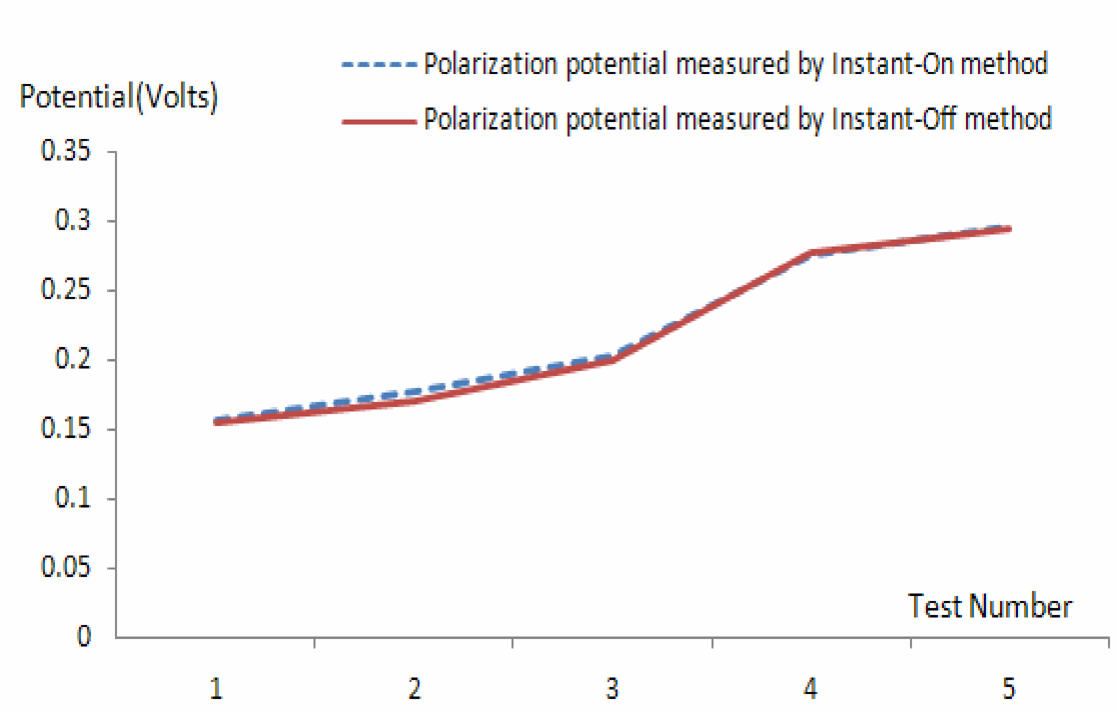

Figure 4: Laboratory polarization values plotted with test points numbers

As seen in Figure 1, the curve of potential changes by cathodic protection can be divided into two parts. First, the potential ascending path (PAP) by DC applying and second the potential descending path (PDP) by DC interrupts. In other words, a PAP is due to system energizing from free corrosion potential to the stable On-potential and, a PDP is due the permanent interrupting from the stable On-potential to free corrosion potential.

Theorically, the same voltage drop (IR $_{Drop}$) values are expected for both PAP and PDP, but sometimes a minor difference can be observed. Supposing a constant current (i.e. by galvano-static DC source), mentioned deviation is due to the changes in circuit resistivity. When a cathodic protection system will be energized for the first time, Voltage drop value is an immediate voltage increasing that is a function of the current amount which passes through the circuit and the total circuit resistivity other than polarization resistivity. Reversely, when a fully-polarized cathodic protection system will be interrupted, voltage drop is an immediate voltage decreasing that is a function of the interrupted current and total circuit resistivity includes polarization resistivity. So, polarization resistivity is the reason why PAP resistivity (and PAP voltage drop) is less than PDP resistivity (and PDP voltage drop). Polarization resistivity is attributed to the reversible polarization (due to the hydrogen film formation) and non-reversible polarization (due to the adherence film formation- e.g. Fe_3O_4). Also, non-reversible polarization is the reason for why even a completely depolarized potential is less than origin base potential. Theorically, the following relationship is accepted:

$$(IR_{Drop})_{PAP} + (\text{Polarization Potential})_{PAP} = (IR_{Drop})_{PDP} + (\text{Depolarization Potential})_{PDP} \qquad (5)$$

As mentioned, by a constant current, the voltage drop for PAP may be less than PDP. Reversely, the second portion of above equation or "Polarization/Depolarization potential" for PAP will be more than PDP. Depends on soil conditions a completely depolarization may take a long time.

CONCLUSIONS

The 100mV cathodic protection criterion is more desirable than other criteria for industrial plant with complexity of underground structure. Cost saving, lower electrical interferences, Lower DC source voltage, Lower likelihood of brittleness and SCC, fewer errors in measurement, lower electrolytic interferences, less soil alkalization, are the advantages of this criterion.
An IR_{Drop} is the unwanted portion of measured potential and it should be avoided for assessing cathodic protection levels and compliance with CP criteria.

The usefulness of the instant-on technique for assessing of 100mV criterion was illustrated. The goal was to make a comparison between the results obtained from this new technique and the 100 mV formation method. The results from laboratory and field experiences state the method can be used as a reliable method. As an instant-off method needs to suitable interruption time preventing significant depolarization, the Instant-on potential should be recorded before any polarization. Compared with instant-off method; it is thought that the likelihood of spike attributed errors may decrease by instant-on method.

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