
# TESTING AND EVALUATION OF DECOUPLER CAPACITIVE EFFECTS AND UTILIZATION OF THE DAIRYLAND MODEL PCRX

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## INTRODUCTION

Confirming effective cathodic protection on a target structure involves verification of accurate measured potentials to compare against industry criteria. This is often performed via an interrupted survey to remove certain errors, yet a capacitive effect on these readings may remain in place due to the presence of decouplers. The purpose of this paper is to inform the reader of the issues involved, focusing on testing methodologies applicable to evaluating decoupler effects in the field, leading to correct product selection and appropriate survey settings appropriate for a successful survey. This considers conventional Dairyland decouplers, the Dairyland model PCRX, and testing with no decouplers in place. Safety aspects are also discussed in the course of the testing regimes.

## TOPICS COVERED



## CATHODIC PROTECTION NEEDED

Effective cathodic protection of buried assets, such as pipelines, is essential in preventing external corrosion. With the end result of preventing failures leading to asset loss, human harm, and environmental damage, pipeline owners have the self interest in verifying that effective cathodic protection is in place. In addition, operators may have oversight by governmental authorities, such as the Pipeline and Hazardous Materials Safety Administration, part of the US Department of Transportation, with the aim of verifying that safe operation includes review of corrosion prevention effectiveness. Cathodic protection potential measurements are part of the verification process that determine if a pipeline is adequately protected. However, typical at-grade measurements of the buried pipeline cathodic protection levels are subject to errors which must be overcome.

## INTERRUPTED SURVEYS AS CATHODIC PROTECTION VERIFICATION

An interrupted survey is the typical method of addressing the IR error that results from reading a potential on a pipeline that receives current as part of a cathodic protection system. Current, flowing through the soil, produces the IR error between the reference cell located at the soil surface, and the pipeline surface located some distance below the technician. Interruption of that current, followed by an immediate potential reading on the pipeline addresses that issue, with measurement and recording via a field data collection device. A typical waveform measured between the pipeline and the reference cell at the soil surface could appear as shown below in Figure 1.

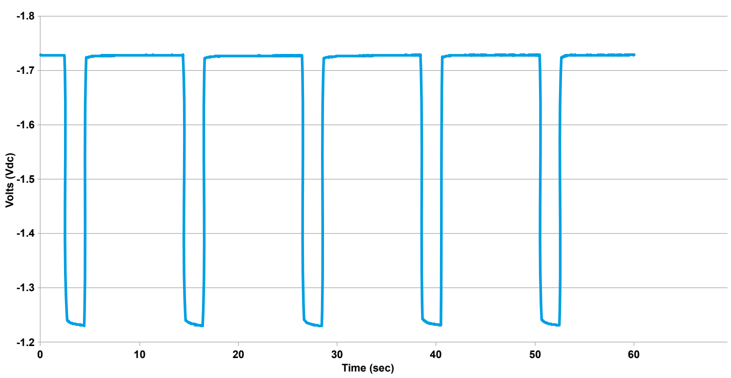


*Figure 1: Typical acceptable interrupted survey response*

## CAPACITIVE EFFECTS ON INTERRUPTED SURVEYS

As the pipeline environment contains additional complexity, other factors come into play which can affect an interrupted survey. Interrupted surveys involve GPS-synchronized interrupters being placed on all known current sources that contribute to the target pipeline. Decouplers are common solid-state devices used on pipelines, for such purposes as mitigation of induced AC voltage from nearby power transmission lines, over-voltage protection of isolation joints, and CP isolation while grounding electrical equipment. The presence of decouplers may contribute an additive capacitive effect to the pipeline, which can cause an interrupted signal to decay exponentially instead of abruptly, affecting the captured potential value taken at a point in time. This can affect the conclusions by the operator regarding the evaluation of effective cathodic protection, with the resulting potentials being found too electronegative, falsely indicating adequate protection. An example of a capacitive effect indicated by slowly changing potentials is shown in Figure 2. Evidence of capacitive effects, besides the wave shape, appears in the potentials that fail to plateau at the full ON value and remain too electronegative during the OFF period. OFF potentials much more electronegative than approximately -1.2V relative to copper-copper sulfate reference cell are likely in error.

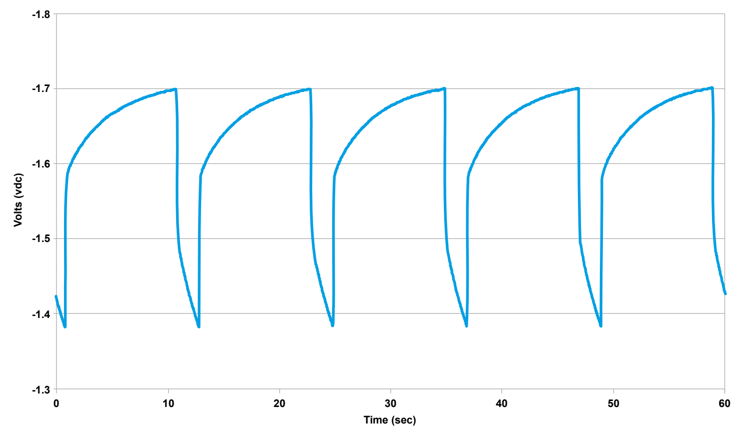


*Figure 2: Typical unacceptable interrupted survey response*

Another example, also indicating a failure to reach the full ON potential or a valid OFF potential, depicts the delayed waveform as a “shark fin” as seen in Figure 3.

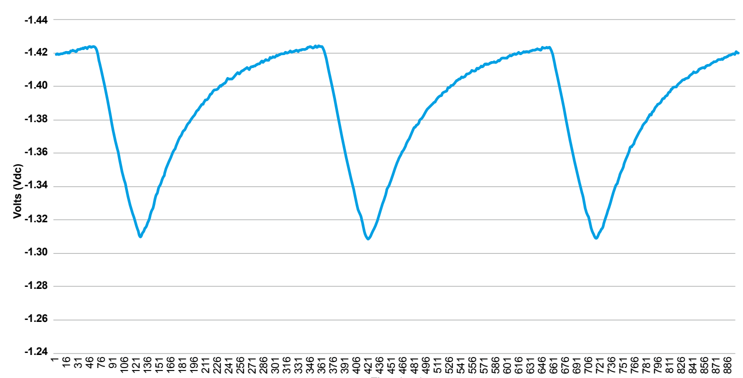


*Figure 3: Typical unacceptable interrupted survey response*

## PIPELINE SURVEY EVALUATION INTRODUCTION

A separate Dairyland paper, entitled “Dairyland PCRX: A Solution For Efficient, Accurate, and Safe Interrupted Surveys,” explains the reason for capacitive effects, while the focus of this paper is to address the process of evaluation and testing of pipelines that may have such effects present due to decouplers. Note that sources other than decouplers may contribute to capacitive effects.

The goal of this paper is to leave the reader aware of how to identify an unacceptable OFF potential, the process of evaluation of an existing pipeline regarding capacitive effects, data to be gathered, and comparison of conventional decouplers with PCRX response.

The most typical scenario involves the evaluation of an existing pipeline with conventional decouplers already installed. The user may already be aware of unacceptable polarized potentials from past surveys, such as typical responses seen in Figures 2 and 3 on the previous page. Evaluation involves interruption and cycling of all traditional current sources affecting the target pipeline using GPS-synchronized interrupters, with capture of resulting potentials, for combinations of:

- Conventional decouplers installed
- All decouplers removed (or other baseline measurement, subject to allowance)
- PCRX installed (assuming the need for the PCRX based upon results, or if the PCRX is being benchmarked against the other cases)

The case of removal of decouplers during testing is dependent upon certain safety considerations being addressed, discussed in the section “Removal of Existing Conventional Decouplers.”

Note that the order of these tests depends upon whether or not conventional decouplers are already installed. Evaluation prior to the installation of any decoupler, where the user has concerns that an intended decoupler installation could cause capacitive effects and wonders if there is a test method for such evaluation before purchase of a particular design of decoupler, will be considered first.

In summary, testing may proceed in one of two orders of operation, as shown in Figures 4 and 5.

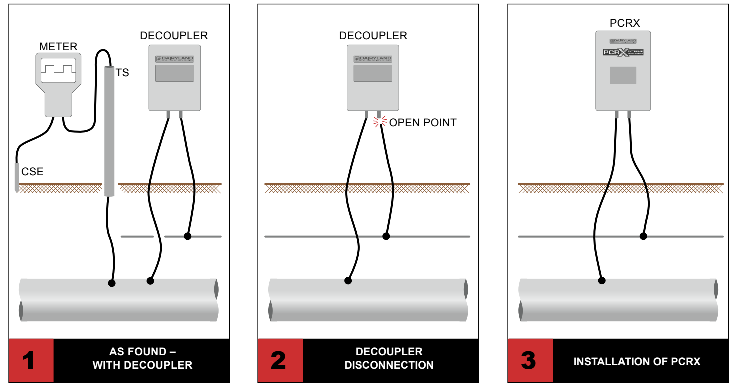


*Figure 4: Test sequence – conventional decouplers present initially*

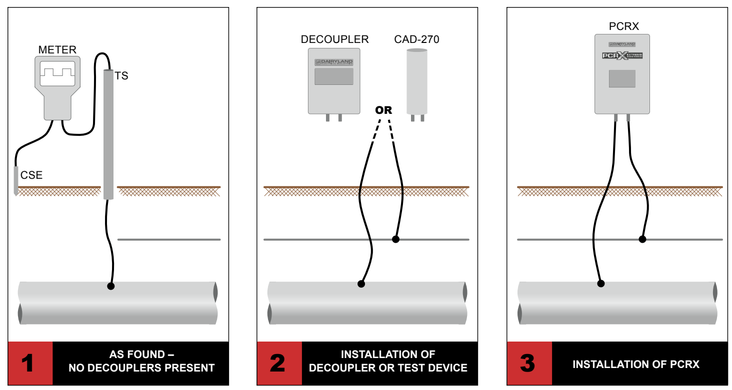


*Figure 5: Test sequence – no conventional decouplers installed*

## PLANNING NEEDED PRIOR TO INSTALLATION OF EITHER TYPE OF DECOUPLER

The operator needs a method to determine if capacitive effects are present on their pipeline, whether a conventional decoupler will allow for an efficient and accurate interrupted survey, or if a PCRX is required instead. If an operator has not acquired the appropriate decoupler due to unknown conditions about capacitive effects, certain evaluation methods can shed light on whether a conventional decoupler or a PCRX is the appropriate product to use. The following procedures provide guidance to the reader on how these issues can be addressed.

## Equipment Needed

The user site first requires the following minimum installation:

- Finished pipeline installation
- For an AC mitigation application, the installed grounding systems, with insulated conductor attachment both from the pipeline and grounding system to an accessible above-grade point or enclosure
- A functioning CP system, presumably with impressed current rectifiers
- GPS-synchronized interrupters installed on all current sources (including influencing foreign impressed current systems)
- Availability of either:
    - Spare conventional decouplers for each intended decoupler location, presumably also in the permanent pedestal or enclosure, itself already installed, or
    - Capacitive Assessment Device, model CAD-270: Dairyland test devices that mimic the effect of a conventional decoupler, at each intended decoupler location.
- Pipeline field data collection survey equipment, including display/recording equipment and Cu/CuSO4 reference cells
- Clamp-on AC rms ammeter, suitable for measurement to 80A


*Figure 6: Typical field equipment and interruption response*

## Overview of Plan

Consider the anticipated method for capturing or identifying the location of each decoupler site along the pipeline right-of-way for consistent recording and comparison. In addition, any other key features should be likewise located and identified, such as test stations, coupons, or other relevant structures.

Where a pipeline does not yet have decouplers installed and bonds are open between the pipeline and the grounding system, this is an opportunity to take measurements that represent the pipeline where CP has been applied and stabilized yet no capacitive decoupler effects are present. While cycling all current sources using interrupters, waveforms of polarized potentials can be obtained and recorded. Comparison of those values to a few spot measurements using an IR-free or interrupted coupon in the same pipeline segment is encouraged, as this can validate if the polarized potentials are consistent and accurate. These baseline readings will be compared against those with a conventional decoupler and the PCRX to show similarities and differences. Performing this pre-test is most valuable when waveforms are viewed by the user to confirm that the ON and OFF durations are as expected, that a polarized potential reading can be achieved, and that foreign sources are not present.

Viewing waveforms of the ON and OFF potentials during rectifier cycling can be extremely helpful, providing an immediate graphical indication of system response during the interrupted survey. The “no decoupler” scenario should display as a clean and rapidly changing potential trace, at the expected ON and OFF potentials. Users should examine and resolve significant deviations from the norm, as once established and recorded this baseline set of potentials will be the reference for other readings. An example of typical field equipment and an on-screen indication of an acceptable interrupted survey is shown in Figure 6.

## Foreign Influences, Invalidating Conditions, Optional Baseline Measurements

Waveforms and individual potential values can indicate foreign influence via shifted values when compared to expected, historical, or IR-free/interrupted coupon readings. The user may attempt to identify and correct such influence, if reasonable, before continuing with the evaluation.

Influences can include uninterrupted sources, such as:

- Failed or jumpered isolation joints
- Interference bonds to other pipelines
- Unaddressed rectifiers
- Directly connected galvanic anodes, mitigation conductors, or grounding systems

- Existing decouplers
- Neighboring pipeline CP voltage gradients encompassing the target pipeline
- Telluric effects from geomagnetic storms
- Stray DC rail current

Interference bonds will need to be considered by the user, as these normally become part of the delivery of CP current to the pipeline, and removal may be contrary to evaluation of the pipeline CP in its normal state. Inclusion during an interrupted survey will likely result in current exchange that will affect the survey conclusions.

The operator should determine the status of the target pipeline segment regarding electrical isolation, identifying which features or influences are on that segment. Existing decouplers may or may not be electrically on the same segment of pipeline being tested. For example, decouplers on the opposite side of a functional isolation joint that does not have any metallic bypasses around it would not be electrically connected to the target pipeline segment, and therefore not contribute to a capacitive effect. The user may attempt to clear other sources via disconnection and/or synchronized interruption. In some cases, such interfering sources cannot be identified or remediated. An example of this can be seen in Figure 7.

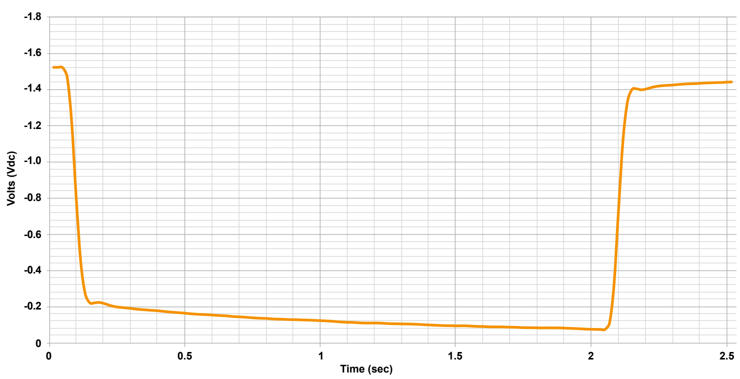


*Figure 7: Significant interference present, no decouplers attached*

Figure 7 indicates significant interference severely depressing the pipeline potentials. The pipeline owner indicated that the target pipeline was in a corridor with multiple pipelines and numerous foreign current sources. Such interference prevented the user from utilizing the "no decoupler" baseline measurement as a useful reference. Instead, the operator ended up comparing survey waveforms with conventional decouplers installed against those with the PCRX present to directly see the difference in response between these two types of decouplers during evaluation. A more typical interrupted waveform with no decouplers attached appears in Figure 8.

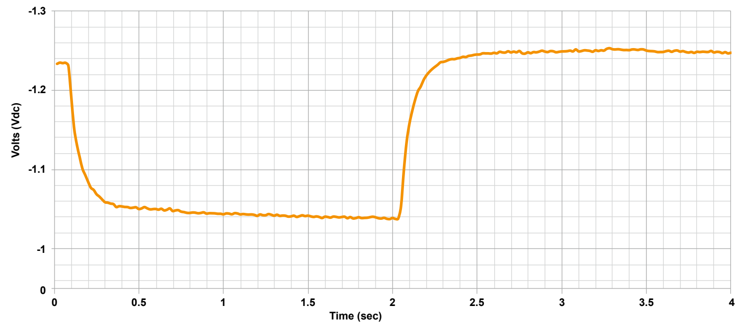


*Figure 8: Typical potentials, no decouplers present*

Where active foreign influence has been found present from testing described above as evidenced by unacceptably shifted potentials, without resolution, an alternate comparison value must be selected. One approach is to use an IR-free, or interrupted, coupon readings at one or several test stations along the survey location. While this method won't allow exact comparison to meter-by-meter data collection during a close interval survey (CIS), the readings should indicate an adequate baseline to the user such that comparison to readings taken with conventional decouplers and the PCRX allow valid conclusions. Alternatively, the PCRX could be compared directly with conventional decoupler response alone, without any other baseline measurement.

In the end, the user should note during evaluation whether or not known or observed interfering sources are present during the survey. Even if no known sources are present, the appearance of the OFF cycle waveform should be a clue as to possible unidentified contributors of direct current, based on the wave shape. With no decouplers present on the pipeline, and all other shorts or bonds cleared, waveforms that still exhibit a delayed OFF response are assumed to represent the as-found baseline condition against which conventional decouplers or the PCRX can be compared.

### Cycle Duration

One should note the OFF period duration needed to view an accurate polarized potential. This period likely will be short for an isolated pipeline that has no decouplers installed, relative to that required for a pipeline suffering from capacitive effects. The period required when observing a conventional decoupler likely will need to be extended to see the potential decay, however this will then not be an identical duration between the two tests, if compared. Consider if overlay and alignment of waveforms is intended, such that identical ON/OFF cycle durations are desired. The PCRX response will typically be fast compared to the conventional decoupler, allowing a shorter OFF cycle duration. The section "Testing After Installation of PCRX" will compare the three survey conditions (no decoupler, conventional decoupler, PCRX) on a common graph with identical cycle durations.

In summary regarding cycle duration, there may be one of two purposes served with an evaluation survey.

- Comparison of conventional decouplers against the PCRX. Here, the operator would likely use the same ON/OFF cycle durations for direct comparison. This typically will be the longer duration cycle needed to see the conventional decoupler response, while the faster PCRX response will be evident early in the cycle. Conversely, a longer cycle duration could be used to characterize the conventional decoupler, while a shorter cycle could capture the PCRX response.

- Prepare for and perform a Close Interval Survey (CIS): In this case, one would test to determine a duration that is optimized for fastest survey, utilizing the shortest OFF cycle that yields acceptable polarized potential capture.

### Safety

One last aspect to consider involves personnel safety. A coated pipeline, subject to AC induction from nearby power lines, will rise in voltage to a degree determined by a number of variables. Personnel contact with any metallic portion of the pipeline, test station posts or wires, or other conductive structures will be in contact with that voltage, relative to earth. Decouplers are most often used for mitigation of such AC voltage effects and following discussions will address the impact of connection and disconnection of decouplers under these influences, relative to safety. See "Safety Discussion," below.

## EVALUATION OF EXISTING CONVENTIONAL DECOUPLERS

### Introduction

The inclusion of conventional decouplers on a well-isolated pipeline system is often evident during an interrupted survey. Delayed OFF and ON waveform response, such as seen in Figure 2, may not yield capture of accurate polarized potentials. Specific effects on the target pipeline can be determined by attachment of decouplers at the intended decoupling locations, followed by evaluation of waveforms and values. For an existing pipeline with decouplers previously installed, the interrupted survey begins with this state first, with data capture at each decoupler location. In fact, this is the most common scenario that Dairyland has encountered – users finding capacitive effects present on conventional decouplers applied at some prior time and then proceeding to evaluation of the "no decoupler" and "with PCRX" conditions (if the PCRX is being evaluated or purchased). The operator will need to consider if decouplers can be removed and maintain a safe operating environment.

It is assumed that existing decouplers have been properly installed regarding product polarity. For Dairyland devices, the negative product terminal (typically left-hand terminal when facing the unit) should connect to the more negative structure and the positive to the more positive structure. These are typically the cathodically protected pipeline and the grounding system, respectively, however connection could be between two different cathodically protected pipelines or other arrangement. The general guidance above applies regardless of which structures are bonded to the decoupler. Incorrect polarity may cause CP current conduction through the decoupler under normal conditions, affecting the conclusions of a survey. Likewise, pipeline DC potentials in excess of the device threshold (for a given polarity) will cause the decoupler to conduct. See the Dairyland website article "Understanding Voltage Threshold Ratings for Decouplers and Over-voltage Protectors" for more information.

### Test Device Proxy for Conventional Decouplers

Where users are concerned about the response of a conventional decoupler prior to purchase and installation, with regard to making an intelligent purchasing decision relative to the model PCRX, they have a quandary. Purchasing conventional decouplers just to find upon evaluation that they notably affect the interrupted survey response is not a practical choice. For this situation, Dairyland has designed a test device that acts similar to the capacitive response of a conventional decoupler. The Capacitive Assessment Device, model CAD-270, allows a low-cost option to accomplish this testing.

If the CAD-270 is to be utilized, these would be temporarily installed at the intended site of a permanent future decoupler for the duration of the test. Use of the device should be done only under specified and limited conditions to facilitate data gathering, as it is not allowed for permanent installation. While a convenient and low-cost device, the CAD-270 differs from a standard Dairyland decoupler in that it:

- Must be used in non-classified (non-hazardous) areas, even if the intended permanent (future) decoupler location is in a hazardous area

- Does not have AC fault or lightning capability, thus not guaranteeing over-voltage protection for transient conditions

- Is a non-polar device (polarity is not marked or relevant)

- Is not UL-listed, therefore must be used on a temporary basis only in non-hazardous, non-code-covered connections (not in code-covered equipment grounding or bonding connections)

However, similar to a conventional decoupler, it will perform steady-state AC mitigation, passing 50/60Hz current, collapsing AC induction voltage, and appearing as a low impedance device – fully representative of any standard Dairyland decoupler. It may appropriately be used for AC mitigation and general bonding in "ordinary locations," but only on a temporary basis for testing.

The CAD-270 is generally needed to consider conventional decoupler response only when such decouplers have not yet been acquired. The pipeline, at this point, does not yet have any form of over-voltage protection, as that generally comes with the installation of the decouplers. While the test device can perform AC mitigation as it applies the capacitive effect to the pipeline for the purpose of trial survey evaluation, the above product limitations require the user to expeditiously perform the testing and acquire the resulting final decoupler design needed for permanent installation. Treating the CAD-270 as a permanent installation is an unacceptable use that could eventually result in failure of the device due to lightning or fault current, with the resulting lack of future over-voltage protection for the pipeline system and personnel.

**Conventional Decoupler Evaluation**

Returning now to consideration of existing conventional decouplers, such evaluation involves cycling interruption of all current sources while observing waveforms, with data capture at each of the decoupler locations. The duration of ON and OFF cycle periods should be adequate to see the system response. Although the capacitive effects likely will show a decaying response during the OFF cycle, such that a suitable cycle duration is in question, it should be chosen as a reasonable length to characterize the overall response. While this waveform might not be acceptable for acquiring a correct polarized potential on the pipeline, it is successful if it demonstrates and quantifies the capacitive effect for several purposes:

- Warning the operator that different techniques are needed on the target pipeline to capture polarized potentials
- Showing the duration of the exponential decay due to the entire system that makes up the target pipeline segment, including decouplers, soil characteristics, coatings, and other factors
- Allowing determination of typical errors in potential values due to capacitive effects relative to other reference measurements that will be taken
- Indicating if alteration of interrupted survey settings could yield an acceptable result, such as by lengthening the OFF cycle duration from a shorter standard setting (as well as proportionally lengthening the ON cycle)

The user will note that the capacitive effect applies to all attempted voltage changes on the system. This includes the ON cycle portion, with exponential increase up to the stabilized ON value, as the system reaches equilibrium. Should the ON potential not stabilize, that cycle duration is likely not long enough and should be extended in order to maintain cathodic protection as the survey continues.

**Measurements Needed**

The user should capture waveforms and potential values at each decoupler (or model CAD-270) location, timestamped and consistently geo-referenced for comparison to other reference measurements. Waveforms should have a long enough OFF cycle duration to adequately characterize the decoupler response, although this likely will not allow for decay to the equivalent potential seen with all decouplers removed. It is anticipated that the OFF cycle duration with conventional decouplers will be longer than that used when surveying either with all decouplers removed or with the PCRX installed, however consider the section above regarding selection of cycle duration.

In addition, manually measure and record the steady-state AC rms 50/60Hz current flowing through the device, using a clamp-on AC ammeter. Note that conventional Dairyland decouplers have a standard steady-state rating of 45 AC rms across multiple product lines, while the model PCR product line additionally has an optional 80A rating. The measured values should not exceed the product rating. It is important to note that measurements approaching or exceeding 40A AC rms indicate that steady-state conditions will likely exceed the rating of the PCRX, if that product is being considered, and the user should contact Dairyland for options. See also more extensive notes about current measurement in the section "Testing after installation of PCRX" and subsection "Measurements needed."

**Depolarization**

Operators synchronously cycle rectifiers to allow needed measurements during the OFF cycle while providing adequate cathodic protection during the ON cycle. Performed correctly, the pipeline will maintain consistent sets of potentials throughout the duration of the survey. Where inadequate CP is supplied to the pipeline, potentials will decay from the polarized value, ultimately toward the native potential of the metal involved.

Where decouplers are involved during an interrupted survey, the comment often arises that an extended OFF period may result in depolarization. This is generally not true, unless the duration was excessive and the capacitive effects were fully discharged or eliminated. Said differently, if the capacitive effect of a decoupler acts as an unintentional uninterrupted source, it is supplying current to the pipeline similar to any other uninterrupted source, such as a rectifier. The supply of current to the pipeline coating defects shifts the potential of the pipeline more negative, which can be easily seen in the slowed response during an OFF cycle. The fact that the pipeline potentials are too electronegative during the interrupted survey is evidence that current is being supplied to the pipeline. In turn, while yielding potentials that are not usable and must be corrected, the result of such current supply and electronegative potentials indicates that depolarization is not at work. Only when the capacitively supplied decoupler current is extinguished could depolarization begin.

## REMOVAL OF EXISTING CONVENTIONAL DECOUPLERS

A second possible survey condition exists where existing decouplers are removed from service in order to provide a baseline measurement with elimination of capacitive effects. This attempts to be the equivalent case to a pipeline prior to installation of any decouplers. In such a scheme, where the decouplers are employed in mitigation of active AC induction, removal cannot be casually performed without consideration of the safety impacts.

### Safety Discussion

Disconnection of decouplers must be carefully considered before any actions are taken, due to the possibility of hazardous AC steady-state induced voltage being present when the decouplers are removed and there is no connection of the pipeline to the grounding system. Decouplers perform an inherent AC voltage mitigation function, and their disconnection eliminates that safety function from the pipeline. Connection of decouplers where induction is present will instantly result in minor sparking, AC current flow, and AC voltage reduction. Removal results in sparking, interruption of AC current, and an instantaneous AC voltage increase. Sparking should not be allowed in classified hazardous locations, which may affect how installation and testing are performed. A full discussion of safety practices is not included here, hence the reader should reference additional information from Dairyland and industry.

Using industry guidelines and company safety practices, determine if some or all decouplers may be safely removed for the purpose of a test. NACE recommends in Standard Practice SP0177 that values above 15V should be mitigated for personnel safety. As decouplers are sequentially disconnected, the induced AC voltage on the pipeline typically increases with each device removed. Verification of the resulting open-circuit voltage can be made using a voltmeter and measuring between a pipeline connection and a grounding system or grounded structure, comparing to the NACE 15V criteria or other lower company criteria. Touch contact with the pipeline should not be made at a location where the decoupler has been removed unless such contact has been confirmed as safe via measurement. Disconnection of a single decoupler typically raises the local AC voltage on the pipeline by a limited amount, which increases as additional units are removed along the pipeline. However, this effect is greatly influenced by a number of factors and users should carefully evaluate if removal of decouplers is prudent and safe. Coordination should be made with other parties who may have access to other portions of the affected pipeline segment, regarding possible elevated touch voltage conditions that they did not expect to be present.

Related to the above, note that for the case involving a pipeline with no decouplers yet installed in an AC mitigation scheme, and there is no connection between the pipeline and grounding system, the same or elevated exposure exists. The unprotected pipeline is not limited in voltage due to AC steady-state induction, AC fault, or lightning conditions, until the appropriate decouplers have been connected to provide over-voltage protection and AC mitigation.

### Options if Decouplers Cannot be Removed

If all decouplers cannot be removed (only from this electrically continuous pipeline segment) to obtain a baseline measurement, then there are two options to consider.

1. An existing conventional decoupler will need to be swapped out with a PCRX unit one at a time. This presumes that no baseline measurement (all decouplers removed from the system) will be made, and comparison will only be made between a conventional decoupler and the PCRX. Data collection for this condition is only valid when all conventional decouplers have been swapped for PCRX units, otherwise a mixed system response will result, with added capacitance of the conventional decouplers still a part of the system. See the section “Testing After Installation of PCRX,” below.

2. To allow some form of reference, coupons may be used to represent the pipeline condition where no decouplers are present. While only occasionally spaced along the target pipeline, one or more coupons allow comparison of potential measurements to both responses involving conventional decouplers and PCRX. Coupons can be momentarily interrupted or be of the IR-free design.

### Isolated Pipeline Interrupted Response

Interrupted current response for an isolated pipeline without decouplers or other current sources should appear roughly similar to Figure 1. Where a user has already obtained potential waveforms and values where decouplers are present, test waveforms of the isolated pipeline typically show a faster response time.

Figure 7 showed an extreme case where unidentified interference shifted the OFF potentials of an isolated pipeline to become severely more electropositive. Such a result may be useful in flagging the user about notable interference to be examined and resolved but will not allow the data to be used for comparison with decoupler measurements for the purposes described in this test regime.

### Waveform Offset

It has been observed that potential waveforms taken at different points in time may have an apparent shift along the vertical axis (potentials). An example of this is shown in Figure 9, where a 13mV difference is present at the onset of the OFF cycle. Measurements to date typically show shifts of zero to 20mV, although a few cases observed have been up to 50mV. This shift is still being studied, and cause is speculated to be due to variations from reference cell errors or placement, CP output, interference, or soil conditions.

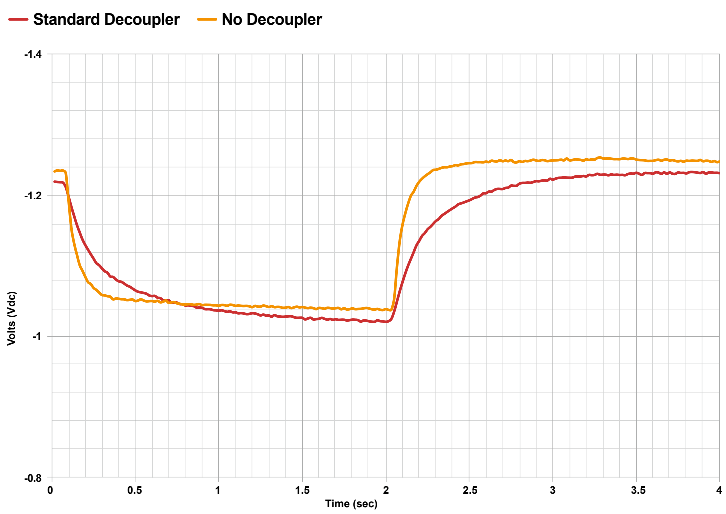


*Figure 9: Waveforms with offset present*

Users may consider if the potential values from offset waveforms will be used as-is or normalized and overlaid, with alignment based on the starting ON potential. As to which waveform is used as the reference, it is assumed that the condition with "no decouplers" acts as the reference or baseline measurement against which other waveforms will be aligned. This is based on an electrically isolated, cathodically protected pipeline being the simplest scheme against which decouplers with capacitive effects (or the PCRX) could be compared. Figure 10 shows the waveforms aligned.

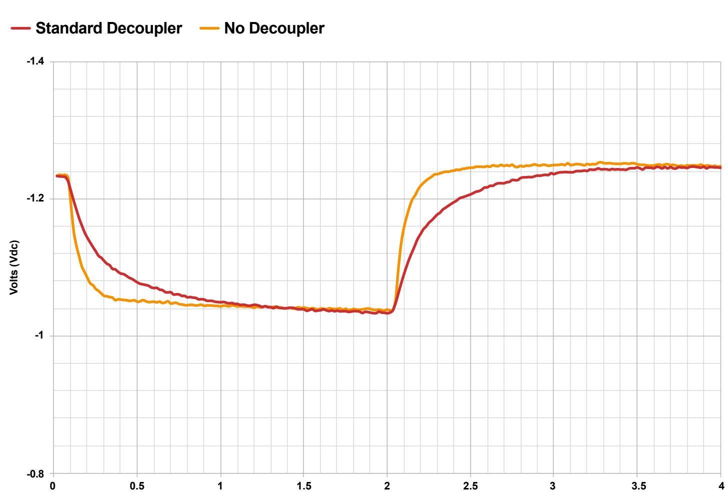


*Figure 10: Alignment of waveforms in Figure 9*

### Conclusion – No Decouplers Present

At this point, the user hopefully has a valid comparison between the interrupted response for the two conditions of with and without a conventional decoupler (or Capacitive Assessment Device, CAD-270, instead of the decoupler), showing if capacitive effects result in a measurable delay. For those pipeline segments that do not show an unacceptable delay with a conventional decoupler, such a decoupler is suitable for use on the pipeline. Where errors in potential measurements during interrupted surveys due to conventional decouplers are unacceptable, consideration of the PCRX will prove beneficial, discussed next.

## TESTING AFTER INSTALLATION OF PCRX

The PCRX design acts as if the device is camouflaged during interrupted surveys and does not appear to have a capacitive effect. Regardless of the order of test and installation outlined in Figures 4 and 5, the PCRX units can be installed following any analysis of conventional decouplers or other reference tests, such as with all decouplers removed. Evaluation and data recording should commence only after PCRX units have replaced all existing conventional decouplers on a particular isolated pipeline segment, as mixing of devices leaves the capacitance of conventional decouplers in play and affects the total system response. However, if no decouplers are on the segment as the PCRX is installed, evaluation of PCRX response is valid at any point during the addition of units to the pipeline, although not required. The user may elect to evaluate only when all PCRX units are installed, if desired, to assure that the effect of all installed devices is being considered.

### Cycle Duration

Reference the discussion in the earlier section for selection of the appropriate survey cycle durations, as determined by the purpose of the survey. The cycle time may be aligned to other measurements, requiring an identical period, or may be optimized (shortened) if speed of data collection is key.

### Measurements Needed

The user should capture waveforms and potential values at each PCRX location, timestamped and consistently geo-referenced for comparison to other reference measurements.

In addition, manually measure and record the steady-state AC rms 50/60Hz current flowing through the device soon after connection into the circuit, using a clamp-on AC ammeter. The user should verify that the measured current is not approaching or exceeding the 45A AC rms conduction limit as each unit is installed, as this could otherwise damage the PCRX. If the current approaches or exceeds 45A AC rms, temporarily add a bypass system between the PCRX terminal connections to help share the current. Options for temporary bypass include a spare conventional decoupler, a Capacitive Assessment Device CAD-270, another PCRX, or a wire jumper of adequate current rating. The first three choices will block DC while shunting AC current away from the target PCRX, sharing with the paralleled device. The wire jumper approach will affect CP until removed but is a possibility for temporary testing. As steady-state AC induction current through each PCRX may change as additional units are connected into the system, it is presumed that additional units will cause a reduction in current through any single PCRX to within the rating of 45A AC rms. This should be verified for each PCRX as it is installed. Ultimately, if current cannot be reduced to within the rating of any PCRX, then that unit must be disconnected from the system. This is not expected to be a common issue.

In order to measure the final steady-state AC through each PCRX, any parallel bypass methods must be removed. This is also required to see the PCRX performance during interrupted surveys.

A final note that qualifies the above steady-state current testing regards variations over time. Daily and seasonal changes in power line load current and soil resistivity will affect the resulting induction current through the PCRX. A measurement at one point in time may vary notably from another taken under different conditions. As a result, the allowable induction current through a given PCRX at a point in time should be limited to a value well below the ultimate rating of 45A AC rms in order to avoid product damage under maximum induction conditions. Worst case induction current conditions occur when power line load current is high and soil resistivity is also high. Operators may consider if these factors are known at the time of measurement, such that they can draw conclusions regarding alternating current measurements during PCRX testing.

### Comparison of Waveforms

Following are a set of waveforms where a PCRX has been compared to having 1) no decoupler present ("All Disconnected"), and 2) a conventional decoupler present. Figure 11 shows the data as captured.

There is a small offset, compared to the "All Disconnected" condition, of approximately 13mV more electropositive for the conventional decoupler, and about 16mV more electronegative for the PCRX. Aligning the waveforms for this offset results in Figure 12. There is very close alignment between pipeline potentials measured with no decouplers present and with the PCRX installed.

Figure 13 further expands the timescale of Figure 12 to show the PCRX more clearly. It is seen that the PCRX response follows the pipeline potentials of the "no decoupler" case very closely. For a given pipeline response, the user must still make the decision of which point on the timeline represents the appropriate polarized potential to be captured for comparison to industry protection criteria. The PCRX makes this process easier, by allowing for a fast decoupler response that does not affect survey potentials, as compared to conventional decouplers.

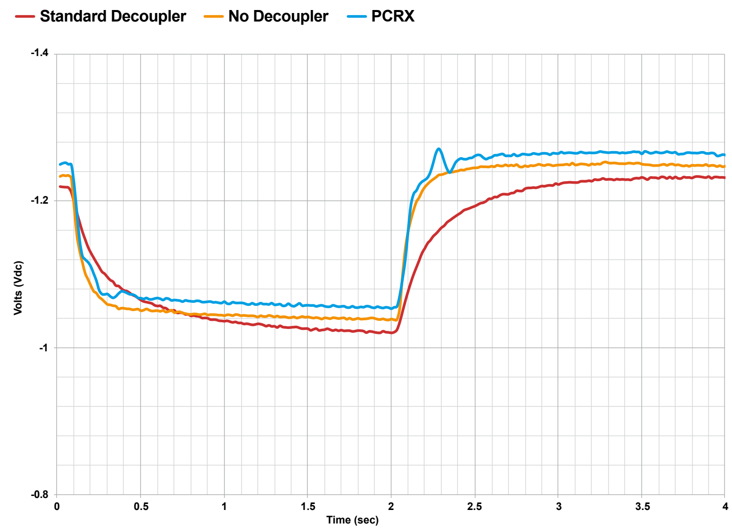


*Figure 11: Standard decoupler, all disconnected & PCRX compared*

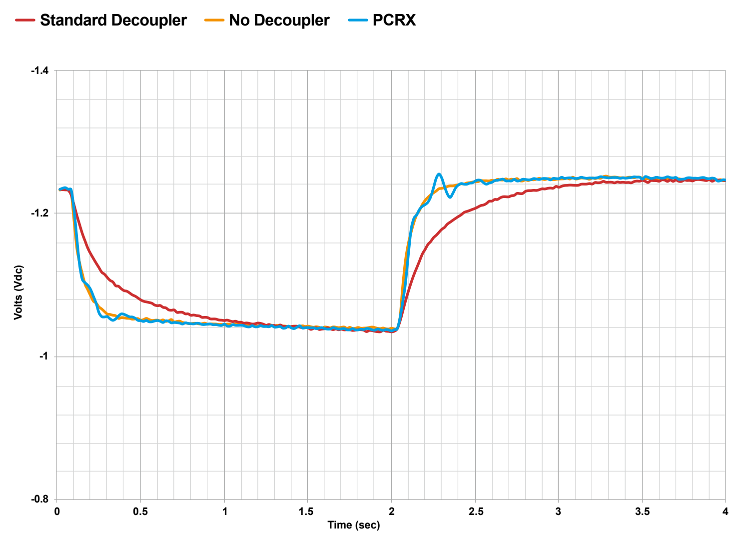


*Figure 12: Comparison in Figure 11, aligned*

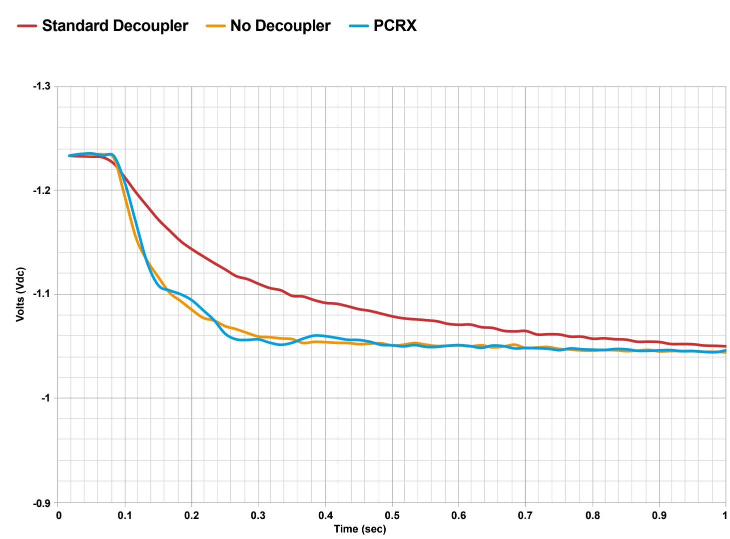


*Figure 13: Expanded view of Figure 12*

## SUMMARY

Interrupted surveys provide valuable data to the user about polarized potentials on pipelines, if various errors and influences can be accounted for. A valid survey relies upon consideration of effects that may influence data, including the knowledge of capacitive effects that may be present due to conventional decouplers. Many factors may cause interrupted survey effects, of which conventional decouplers are one possibility. Preparation for a survey includes determination of the electrical isolation of the target pipeline and of foreign influences. Characterizing the response of the pipeline to conventional decoupler capacitance allows the user to determine if these decouplers are suitable for inclusion while a survey occurs, or how a survey must be performed in the presence of such capacitance. Brief waveform analysis during interruption of all known current sources prior to a full survey will indicate if capacitive or other influences are present, and if the survey can be performed with valid data collection.

As an alternative, the PCRX does not appear as having capacitance during an interrupted survey. Characterizing the response of the PCRX is often accomplished by comparison to a reference measurement, either a test with all decouplers removed from the system or via a coupon or other reference. Evaluation will typically show that the survey response with the PCRX present is the same as the case where no decouplers are attached, generally allowing an accurate and rapid interrupted survey. Where a Close Interval Survey (CIS) with extensive data collection is involved, the time savings are notable, with high confidence in the data accuracy.