DAIRYLAND PCRX:

A SOLUTION FOR EFFICIENT, ACCURATE, AND SAFE INTERRUPTED SURVEYS

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INTRODUCTION

Interrupted surveys on protected structures such as underground pipelines with cathodic protection systems are often required. However, definitively proving that a cathodic protection system is providing the degree of corrosion protection expected can often be a time-consuming and error prone endeavor. Accurate potential values in the field can be elusive, with several factors affecting these measurements. Dairyland Electrical Industries has provided pipeline decoupling products for over thirty years and has recently introduced a new product called the PCRX which addresses one of the primary issues in most typical applications.

This paper is intended to educate the reader on some common issues that influence interrupted surveys, existing solutions to these issues, and a description of how the PCRX provides value in its groundbreaking approach to solving a key issue with interrupted surveys. For the purposes of this paper, underground pipelines will be the targeted protected structure.

A constructive background for the information presented here includes an overview of cathodic protection itself, interrupted surveys and associated issues, and the need for decoupling devices. It is assumed that the reader of this paper is knowledgeable in the methods of cathodic protection. A brief overview of the electrical parameters of cathodic protection will be discussed. Interrupted surveys and associated issues will be described as part of this paper's problem definition. In particular, interrupted surveys measuring the instant off potential of a pipeline relative to a copper-copper sulfate electrode (CSE) on impressed current CP systems will be the focal point of this paper. The need for decoupling devices will be covered as we transition from the problem description to the solution description.

PROBLEM DESCRIPTION

Interrupted Survey Review:

An interrupted survey aims to obtain a potential measurement taken with all cathodic protection (CP) current sources synchronously interrupted momentarily. The purpose of such a measurement is to evaluate the effectiveness of the CP system by determining the polarized potential of the pipeline (i.e. instant off potential). Interrupted surveys are typically done over the pipeline length as part of a Close-Interval Survey (CIS) regimen.

The purpose of an instant off potential measurement is to eliminate a measurement error component, namely IR drop. The IR drop makes the pipeline appear more electronegative than it actually is and can lead one to conclude that a pipeline is sufficiently protected when in fact it is not. The IR drop is a result of CP current flowing through the soil between a reference electrode and the surface of the pipe. Below in Figure 1 is a basic schematic of a cathodically protected pipeline.

As depicted in Figure 1, the pipeline itself exhibits longitudinal resistance and inductance, R_L and L_L respectively. Also, at play in this model is the shunt resistance and shunt capacitance through the pipeline coating, denoted by R_S and C_S respectively, as well as a voltage that is developed across the pipeline coating denoted by E_S. Further, the pipeline exhibits a DC corrosion potential with respect to the soil (E_P), which typically has a magnitude of approximately -0.6V when measured with respect to a CSE. Finally, there is a shunt resistance (R_P) between the outer surface of the coating and remote earth. The CP system rectifier and interrupting switch are denoted by V_R and S_1 respectively.

When the pipeline is protected by the CP system, S_1 is closed allowing DC current (I_{CP}) to be supplied to the pipeline via a ground bed (or anode bed) with a resistance noted as R_A. Should a CP survey measurement be taken with CP current applied, the IR drop through R_P would lead to erroneous and excessively electronegative potentials.

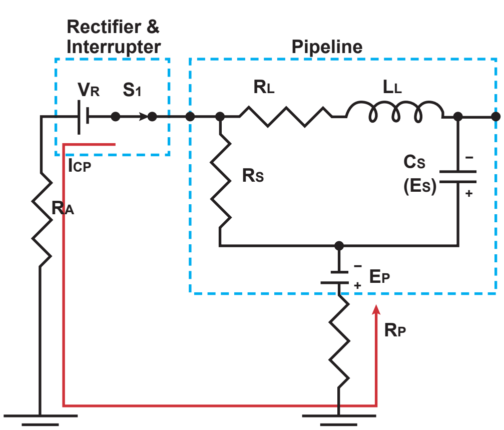


Figure 1

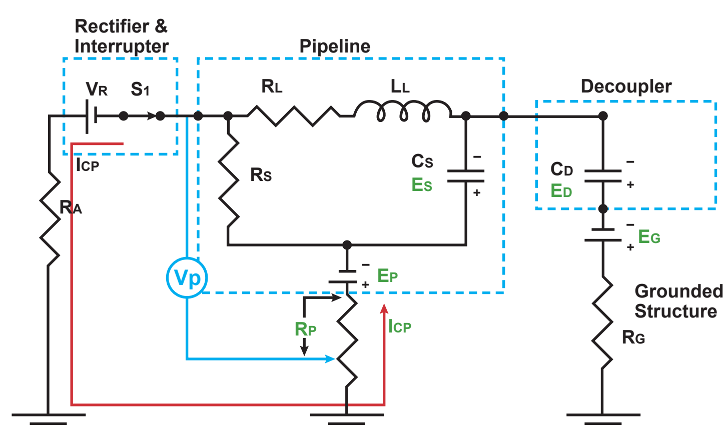


Figure 2

However, as will be explained in a later section, decouplers are often a vital part of the overall CP system, providing DC decoupling and AC continuity/grounding. When a decoupler is introduced to the system in Figure 1, the resulting schematic model is represented on the previous page, in Figure 2.

Now, with a decoupler (or set of decouplers) as part of the overall CP system, an additional capacitance (C_D) is added to the system, along with an associated voltage across the decoupler (E_D). The positive terminal of the decoupler is tied to remote earth via a grounding structure while the negative terminal is applied to the pipeline. The grounding structure has a corrosion potential denoted as E_G and a resistance to remote earth of R_G. Note the following equation that represents voltage equilibrium in this schematic model when CP current is applied.

$I_{CP} \times R_P + E_P + E_S = E_G + E_D$

When the CP current is interrupted, I_{CP} drops to zero. Therefore, to reach equilibrium in this circuit, the only other element that can make a corresponding change is the voltage across the decoupler (E_D). Ultimately, when CP current is interrupted, the voltage (E_D) must change by a value equal to $I_{CP} \times R_P$ in the on state. This results in a transient flow of current from the decoupler until the current is dissipated and until that current is dissipated, any potential measurements will be in error. This is depicted in Figure 3 below, with transient current (I_{TRANS}) flowing from the decoupler to the pipeline.

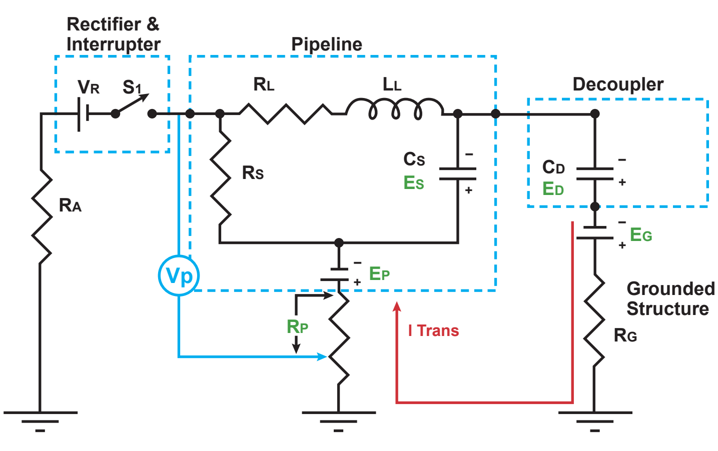


Figure 3

This transient flow of current takes time to fully dissipate, as will be discussed below. The graph in Figure 4 below is actual data taken on a pipeline with several decouplers in place and depicts the nature of this voltage dissipation. As can be seen in this example waveform, current was interrupted at approximately time = 0.1sec. One can still see a slight downward trend at time = 2.1sec when CP current was reapplied.

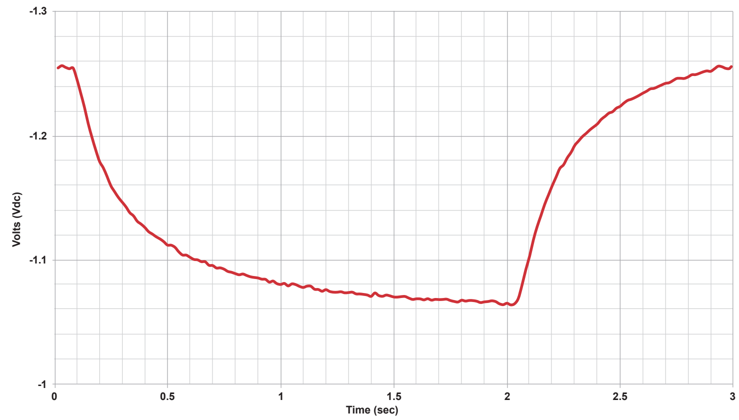


Figure 4

Taking into account that typical instant off potential measurements only capture a single data point (as opposed to a full waveform over time allowing post analysis), the question becomes at what point along this curve is that data point taken? As will be discussed, the amount of IR drop and the rate of dissipation can make the curve represented in Figure 4 highly variable. It is the nature of what is happening with the potentials within the system as described above in the seconds after CP current interruption that has a significant impact on the accuracy of the measurement, and in turn on the validity of the data captured for the entire pipeline. And while waveforms can be taken during the staging process for a CIS, there is no guarantee that this waveform will be consistent along the length of the pipeline being studied. This is the essence of the primary issue with many instant off interrupted surveys to date where decouplers are involved.

To take this analysis one step further, it is the rate of current dissipation and the overall time needed for this dissipation that further complicates an interrupted survey. The time needed for this dissipation to take place is a result of the RC constant of the circuit. In the typical cathodically protected pipeline structures as described in the previous figures and discussion, the RC constant is influenced as follows. The resistance portion of this RC time constant is influenced by both the pipeline's coating (R_S) and the pipeline coating's resistance to remote earth (R_P). As improvements in pipeline coatings have been made over the years, the R_S portion of this resistance has increased. In addition, the nature of R_P, which is largely dictated by soil conditions, is likely to vary over the length of any given pipeline segment as well as vary over time due to weather and soil moisture. These two factors have led to 1) increased RC time constants as coatings have improved and 2) a variable nature in the RC time constant over the length of the pipeline being studied. A final note relative to the resistance in the system that needs to be considered are holidays in the coating of the pipeline. It cannot be assumed that the coating along the length of the pipeline is homogeneous, and therefore a consistent RS along the length of the pipeline may be an impractical assumption. Damage or voids in the coating from any number of causes are likely, and ultimately the reason why a CP system is needed. This adds another variable to the RC constant along the length of the pipeline.

Another factor in this RC time constant is the capacitance of the system. As many pipelines share a corridor with overhead AC power transmission or distribution lines, induced AC is a problem that must mitigated. This is one of the primary reasons decouplers are applied to a CP system. And while the capacitance of one decoupler is a fixed value, multiple decouplers may be required along the length of the pipeline, therefore increasing the capacitive effect of several decouplers in parallel. This too will increase the RC time constant being dealt with.

In general, it takes roughly 5 RC time constants to dissipate the voltage in a system employing decouplers to an acceptable level for accurate instant off measurements. With the variable nature of the RC time constant as described above, predicting an appropriate yet efficient on/off cycle for rectifier interruption would be difficult at best. It would either rely on assumptions about the homogeneous nature of BOTH the pipeline coating AND the soil's resistivity along the length of the pipeline OR would have to account for sufficiently long on/off cycle times of the rectifier to guarantee decoupler voltage has been dissipated. However, extremely long on/off cycle time would lead to an inefficient survey.

It must also be noted that pipeline length and diameter are additional factors that can affect the parameters of the RC time constant. Longer pipelines will have more variability along the length of the pipeline due to soil inconsistencies, the fact that more holidays or defects are likely, and the distance from the rectifier (and anode bed), among other factors. Larger diameter pipelines will have a lower resistance to remote earth as there is more contact area. Each of these factors can affect the resistance that is part of the RC constant of the circuit.

In summary, the accuracy of an instant off interrupted survey data point can be influenced by many factors:

- Amount of CP current (I_{CP}).
- Soil resistivity: Resistance of pipeline to remote earth (R_P).
- Pipeline coating resistance (R_S).
- Pipeline coating holidays or other defects/voids.
- The length and diameter of the pipeline, and associated effects on resistance.
- The number of decouplers present.
- How long after the CP current has been interrupted that a data point is taken.

The Decoupler Dilemma

As noted, decouplers are a vital element of most CP systems, as they provide the following benefits:

- Blocking the flow of DC current to ground (under normal operating conditions).
- AC Voltage Mitigation (a safety concern).
- Over-voltage protection.
- Safety grounding.
- AC Fault Current and Lightning Impulse protection.

So, how can accurate and timely instant off interrupted surveys be conducted if decouplers are part of the system? There have historically been a few methods to deal with the effects described above. However, each practice noted below is not an ideal solution as will be described.

One common solution is to disconnect the decouplers in the system. This is effective in eliminating the transient current flow and the resulting voltage dissipation time, as the decoupler capacitance has been removed from the system. This can be accomplished by physically disconnecting leads or by the installation and use of decoupler isolation switches. However, there are several reasons why this option should be evaluated carefully. First and foremost, if induced AC is present and no decouplers are part of the system, unsafe voltages may be present on the pipeline. This presents a safety hazard to those conducting the interrupted survey or anyone else coming into contact with the pipeline. The other primary pitfall of this approach is the significant amount of time invested in disconnecting (and reconnecting) all decouplers in the pipeline segment being studied, compounding the time and cost needed to perform an interrupted survey.

Another method is to extend the on/off cycle of the rectifier(s) in order to ensure all voltages have stabilized. This has two drawbacks, one related to time and the other related to accuracy. Obviously, extending the on/off cycle time period will make a CIS study a slower and longer process. This becomes a trade-off between a sufficiently long on/off cycle (to ensure decoupler voltage dissipation) and an expedient and efficient CIS. One practice could be to minimize the length of the on/off cycle by taking a sample waveform of the pipeline to be studied and use this waveform to select an appropriate on/off cycle time period. However, even this can lead to measurement errors as noted above, as the RC time constant along the length of a pipeline is not likely to be consistent. It also requires one to take into account the many other factors that could be affecting the length of the pipeline being studied to ensure the on/off cycle is long enough.

SOLUTION DESCRIPTION

The issues described above have become more and more prevalent over time as both pipeline coatings have improved and as more instant off interrupted surveys have been conducted. As Dairyland Electrical Industries became more aware of reported issues from interrupted surveys, a concerted effort was started to understand the phenomenon and to ultimately develop a robust solution for the industry. Thousands of hours of research and development utilizing internal and external experts as well as extensive lab and field testing have culminated in the introduction of the PCRX decoupler.

The PCRX provides all the same benefits that Dairyland's standard solid-state decouplers have been providing for years. The added benefit is that the PCRX is able to greatly reduce the time for decoupler voltage dissipation while being able to remain in the circuit at all times during an interrupted survey. It does this through sophisticated and proprietary signal handling that provides the capacitance needed for AC mitigation and DC isolation, while effectively being able to react to CP current interruption in a fraction of the time of standard decouplers, virtually mimicking the response ofthe circuit with the decouplers disconnected.

The goal of the PCRX development effort was to allow for instant off interrupted survey data points to be taken in less than 500 milliseconds of CP current interruption, regardless of all the other factors that have typically influenced this potential measurement as noted previously. In other words, from the earlier discussion, the voltage across the decoupler should dissipate by roughly 5 RC time constants in less than 500 milliseconds. While this was the goal, individual pipeline situations may not always allow for such a short rectifier off cycle. Given all the factors that can influence the RC time constant, including outside influence on the pipeline, the proof of the PCRX performance was to compare its response in field trials. By comparing PCRX waveforms to waveforms with standard decouplers installed and without decouplers installed, solid conclusions could be drawn. The pipelines that were made available for this testing already had standard decouplers installed. The waveforms were taken in relatively close succession in the following order.

1. With standard decouplers installed.

2. With decouplers disconnected.

3. With the PCRX installed.

The expectation is that the PCRX would provide a similar waveform (per test location) as having no decoupler present at all. Without decouplers in the system, there would be no momentary flow of current from the decoupler in the seconds after CP current interruption, and therefore the time needed after current interruption to capture an accurate potential would be minimized.

Sample waveforms from interrupted surveys conducted on pipelines in use are shown below in Figures 5 and 6. Supplemental waveforms and data are given in the appendix. The locations and owners of these pipeline locations are confidential.

A few notes about the data collection methods and post analysis should be taken into account when reviewing the data presented here. To the extent possible, the data taken to prove and compare the effects of the PCRX was from a pipeline segment electrically isolated from external interference other than adjacent AC power lines.

The pipeline represented in Figure 5 was 24” in diameter and electrically continuous for approximately 32 miles in length. Coating type was fusion bonded epoxy. Soil conditions were typically sandy and dry. CP current demand was 3 amps. All applicable rectifiers were synchronously interrupted with an 8 second on and 2 second off cycle. Each of the waveforms were taken within the same day. Waveform data was collected at each of the applicable eight decoupler installation sites, taking reasonable care to place the CSE probe in the same spot for each measurement. The sequence of waveform collection started with standard decouplers in place, followed by having all decouplers disconnected, and finally by having PCRX decouplers installed at all locations along the pipeline. As decouplers were disconnected, precautions were taken to assess the open-circuit AC voltage present via induction.

Any DC shift in the waveforms from one measurement to the next at a given test location was normalized with respect to the initial waveform taken. This DC offset is often the result of changes in soil resistivity throughout the day, the nature of the intimate contact between the CSE probe and the soil (affected by moisture, humidity or dew), as well as subtle differences in CSE probe location and orientation. The amount of DC offset that was normalized ranged from near zero to approximately 40mV. For the purposes of these tests, this DC offset was considered normal measurement variation.

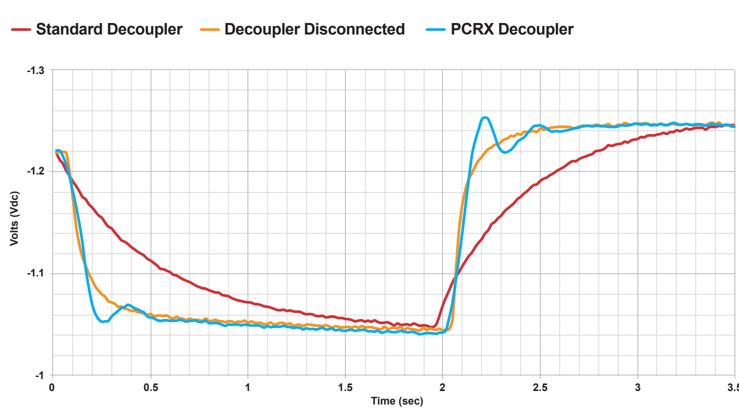


Figure 5: Test location CK-922

As depicted in Figure 5, the off cycle started at approximately time = 0.05 sec. One can see the relatively slow response of the standard decoupler (red line) in response to current interruption. It does appear to be stabilizing just as current is reapplied at time = 2 sec. With the decouplers disconnected (orange line) it can be seen that the pipeline reaches its polarized potential much faster, at approximately time = 0.5 seconds. The goal for the PCRX is to closely mimic the response of having no decoupler. In this case, the PCRX (blue line) does closely match the response time of the 'decoupler disconnected' condition. While not necessarily as applicable to instant off potential measurements, what can also be seen in this graph is the charging time of the decoupler once CP current is reapplied. Again, the standard decoupler responds much slower than having the decoupler disconnected or the PCRX.

Another set of waveforms taken on a different pipeline in another part of the country is shown in Figure 6 below. This pipeline was studied in the same fashion as described earlier. This pipeline was a mix of 6" and 8" diameter, with fusion bonded epoxy coating. Soil conditions were relatively moist. One key difference here is that this 2 mile length of pipeline lateral was NOT electrically isolated from the main pipeline. The effects will be described here. In this case, the initial 1 second off cycle was not long enough for the pipeline with standard decouplers installed to dissipate the voltage. As a result in this particular series of tests, all waveforms were taken before recognizing this, and thus the truncated waveform in red. However, one can still draw solid conclusions from this data. With the CP current interruption (off cycle start) taking place at approximately time = 0.5 sec, the contrasting rate of voltage dissipation between standard decouplers and either decouplers disconnected or PCRX decouplers is obvious (similar to the pipeline in Figure 5). It is also apparent that the PCRX performs nearly identically to having decouplers disconnected in the system.

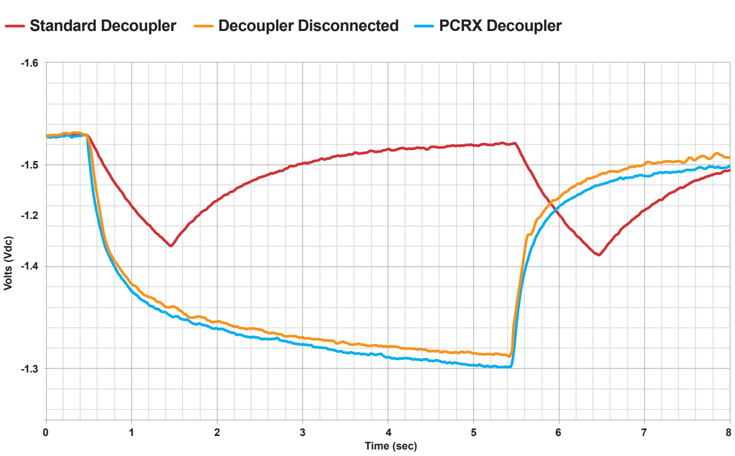


Figure 6: Test location WO-1

However, looking at this graph, one notices that the voltage with the decouplers disconnected or the PCRX decouplers quickly dissipates initially (within the first 500 msec), and then slowly continues to decay until CP current is reapplied. While not definitely proven in this testing, it does stand to reason that the main pipeline and its associated decouplers are exerting some influence on this lateral segment of pipeline. This is one reason why it is suggested to electrically isolate a segment of pipeline being studied as outside influences can affect an interrupted survey.

A final note on these particular data sets is that they are representative of the response of each decoupler condition (Standard vs. No Decoupler vs. PCRX Decoupler). The values within these particular data sets are specific to these pipelines and a particular test location along these pipelines. One should not draw conclusions as to how data presented would mimic the values of any other pipeline or test location.

Benefits of the PCRX

The benefits provided by the PCRX decoupler are likely apparent at this point. At the most basic level, the accuracy and validity of the data collected is increased, safety is maintained, and the cost of a typical CIS is reduced. Let us look at how each of these, in general terms, is accomplished.

With decouplers connected, the accuracy of a measured instant off potential has historically been dependent on when, after CP current interruption, a data point is taken by a data logger. In the case of longer RC time constants as has been the trend over recent years due to improvements in coatings, the time after CP current interruption for voltage dissipation may be longer than expected. However, a measurement taken any time before at least 5 RC time constants after CP current interruption would yield a potential that is excessively electronegative. In other words, the result could be a false positive, giving the impression that the pipeline is better protected than it actually is. Given the relatively low potentials at play within a CP system, a low voltage potential error could be a significant percentage error.

The safety of personnel and anyone else that may come into contact with the pipeline is maintained by eliminating the need or desire to remove decouplers from the pipeline. Because the PCRX continuously passes AC current to ground, no large or unsafe AC voltage will be present on the pipeline while a CIS is performed. In the case of a CIS performed in which all decouplers are disconnected, there could be hours or days while this protection is absent. Further, personnel performing the disconnection and reconnection of all decouplers need to take safety precautions to avoid exposure to potentially unsafe voltages. Also note that while PCRX decouplers remain in the circuit, they are also continuously providing an effective ground path for AC faults and lightning.

Finally, the time to conduct a CIS, and therefore its cost, are likely to be reduced. The steps needed to overcome the voltage dissipation time, regardless of method chosen, are often time consuming. If one were to choose to disconnect all decouplers from the pipeline before a CIS on a long pipeline segment with dozens of decouplers spanning many miles, a day or more could be spent in this effort alone. The same will hold true for reconnecting all decouplers. If decouplers were to remain in the circuit during a CIS, but rectifier on/off cycle times needed for reliable data were excessively long, this too could add significant time.

While it cannot be claimed that the PCRX will solve every instant off survey situation, the evidence does show that for typical installations, the PCRX family of decouplers will make it appear as though there are no decouplers present, and therefore no excessively long voltage dissipation times would be required for accurate potential measurements.

The previous overview of a representative waveform comparison is the essence of the PCRX. However, let us tie

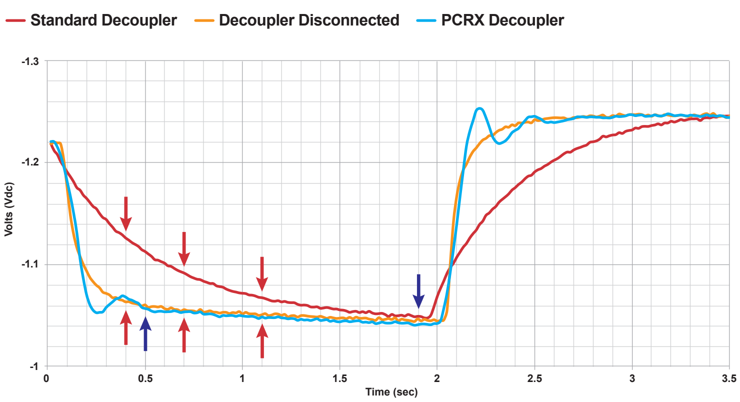


Figure 7: Test location CK-922

the discussion together using this same data for a graphical representation of PCRX benefits.

In Figure 7, two of the primary benefits of the PCRX are illustrated. First, looking at potential measurement accuracy, one can see that a singular instant off data point taken at any time before approximately 2 seconds into the off cycle would be in error. The error is the difference at any point in time between the red line and the blue or orange lines. The red arrows are representative of possible data point capture times. In this particular example, a data point taken at approximately 400 msec after CP current interruption (farthest left set of red arrows) would result in a measurement error of roughly 70 mV. Obviously, as measurements are captured later and later in the off cycle, the degree of error is reduced. This then ties into the other benefit of the PCRX. As indicated by the blue arrows in Figure 7, an accurate potential measurement with standard decouplers in place could not take place until nearly the 2 second mark of the off cycle. Conversely, with PCRX, an accurate potential measurement could be taken at approximately time = 0.5 seconds. In this example, that is a 1.5 second improvement (or a 75% reduction in off cycle time needed). Again, this data is only representative of one particular pipeline and a specific test location along that pipeline. The degree to which accuracy and/or time is improved with PCRX is dependent on the conditions present on any given pipeline.

PCRX vs. Standard Decouplers

It is a fair question to ask how one could determine whether or not a PCRX is needed for a given application. Another paper from Dairyland Electrical Industries covers this question in more detail, but an overview will be given here.

Recall from the earlier discussion regarding all the factors that influence the RC time constant of the circuit, which ultimately impacts the voltage dissipation time needed to obtain accurate instant off potentials. Some pipelines have a construction and are in an environment in which these factors produce a minimal RC time constant. For example, a large diameter, poorly coated pipeline, in moisture rich (low resistivity) soil is likely to have a relatively low RC time constant and resulting dissipation time. In contrast, a small diameter, well coated pipeline in dry (high resistivity) soil is likely to have a relatively high RC time constant and resulting dissipation time. This is a simplified version of reality, but the basic elements hold true. It is the relative scale of these factors and their interactions (through the RC circuit) which ultimately influence whether a PCRX or standard decoupler is best suited for the application.

One way to look at this dilemma is to always use PCRX decouplers, as this guards against the issues noted earlier in this paper. However, due to cost or other considerations, this may not be practical. Therefore, when in doubt, Dairyland suggests a characterization test of the pipeline to determine the extent of the voltage dissipation time. This test can be performed with standard decouplers in place, or if no decouplers have been installed (such as on a new pipeline), Dairyland offers a test device known as the CAD-270 that can be installed to perform this test. With waveforms taken at reasonable intervals along the pipeline, one can analyze these waveforms to determine if the dissipation times are excessive. In the case of excessive dissipation times, the pipeline would benefit from the PCRX. An additional benefit to performing this characterization test prior to the selection of specific decouplers is that induced steady state AC can also be measured, and an appropriate decoupler rating can also be chosen based on this.

Operational characteristics of the PCRX

There are some unique aspects of the PCRX that should be known in order to select the right model for a given application. Due to the proprietary operating characteristics of the PCRX, there is a distinction that must be made between the device's DC operating voltage and its blocking threshold voltage (also known as its clamping voltage). The DC operating voltage is defined as the maximum allowable DC voltage across the device's terminals to maintain DC isolation, after considering the AC voltage drop due to the AC current through the device. In contrast, the device's blocking threshold is the total voltage limit across the device terminals (volts ACpeak + volts DC) beyond which the device goes into conduction, allowing all current to flow through the device. The blocking threshold voltage has a wider range than the DC operating voltage.

The device's blocking threshold rating should be selected such that total voltage drop (ACpeak + DC) across the device's terminals during normal operating conditions remains well within the blocking threshold voltage range. For example, Figure 8 illustrates the DC operating voltage of a PCRX with -5.5/+2.5V blocking threshold operating at the maximum steady state AC current of 45Arms. At this steady state AC current, the PCRX impedance is 0.027 ohms which creates a 1.7VACpeak voltage drop across the PCRX, resulting in a DC operating voltage range of -3.8V

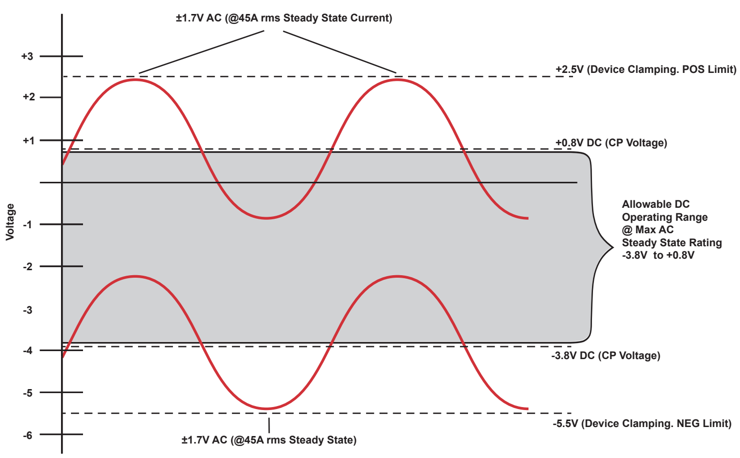


Figure 8: DC operating voltage for PCRX with -5.5/+2.5V blocking threshold operating at maximum steady state AC current rating

to +0.8V. Refer to the PCRX Technical Literature for details on how the PCRX impedance varies with AC current.

Other notes on the application of the PCRX

It must be noted that there could be other factors influencing a protected structure such as a pipeline that will influence an instant off survey, as well as many considerations to consider when planning a CIS. This paper is not intended to cover the vast number of possible interference issues or CIS considerations in any appreciable detail (other than those already discussed). However, a few of the more common issues that may influence instant off potential measurements are listed here.

- A non-electrically isolated pipeline segment: When a pipeline segment being studied via an instant off potential measurement is not electrically isolated from other pipelines or CP systems, clean and repeatable data may be difficult to produce.
- Nearby pipelines or CP systems: If a pipeline is in close proximity to another pipeline, rectifier, anode bed, or ground bed, current may stray from that system to the pipeline of interest. This has the possibility of acting as an uninterrupted source and shifting potentials more electronegative, thus affecting the survey results of the pipeline of interest.
- Telluric currents: Telluric currents are currents in the earth typically caused by disturbances in the earth's magnetic field. Given the unpredictable nature of these currents, telluric effects are beyond the scope of study of decoupler performance for this paper.
- Pipeline depolarization: There has been some industry conjecture that longer off cycles with CP current interrupted (and with decouplers present) will cause a pipeline to depolarize. As the phenomenon of decoupler voltage dissipation was studied in the development of the PCRX, it is apparent that a pipeline is still receiving current from the decouplers installed for a brief period of time after CP current interruption. The decoupler supplies current to the pipeline until the system reaches equilibrium. In general, depolarization was beyond the scope of study

for this paper. With that noted, shorter rectifier off cycles that would typically be allowed by the PCRX should provide both efficiency and user confidence regarding depolarization issues.

SUMMARY

The information presented in this paper has demonstrated several things related to instant off interrupted surveys and the effects of components in a CP system, including decouplers. While general in nature, the fundamental concepts discussed should resonate with most CP engineers and technicians and provide an appreciable understanding of many of the factors involved in interrupted surveys. As a review of the primary focus of this paper, a high-level summary is contained below.

Instant off interrupted surveys on protected structures with cathodic protection are subject to many variables that influence the accuracy, time, and cost of performing a Close-Interval Survey (CIS). When implemented for AC mitigation, DC blocking and safety grounding, decouplers can have a notable effect on the potential measured during an interrupted survey. Ultimately, many underlying circuit elements of the CP system have a direct impact on the RC time constant of the system which will impact the voltage dissipation time needed to obtain an accurate instant off potential measurement. When these factors produce excessively long dissipation times, it is either likely to cause measurement error or take considerable effort to mitigate.

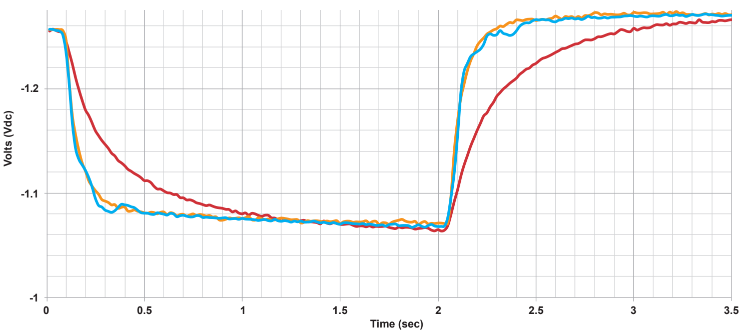
The advantages presented by the PCRX decoupler allow for interrupted surveys to be more accurate, in less time, while maintaining the safety benefits that decouplers are intended for. Accuracy is improved because the PCRX effectively camouflages itself from the system when CP current is interrupted, virtually eliminating the decoupler voltage dissipation time needed to reach an accurate polarized potential. CIS time can typically be reduced because mitigation efforts can be reduced or eliminated by not disconnecting decouplers or by having excessively long on/off rectifier cycles. Finally, safety is maintained as the decouplers can stay connected without adverse effects during the hours or days while a CIS is being performed. This is especially important for pipelines sharing a corridor with overhead AC lines.

The data presented in this paper (and supplemented in Appendix A) is representative of the operating characteristics of specific pipelines and specific test locations along those pipelines. This data is intended to illustrate the benefits noted within this paper and was a portion of the data used as validation of the performance of the PCRX during development. This data should not be used to draw any direct comparison to - or draw conclusions about - other pipelines or protected structures.

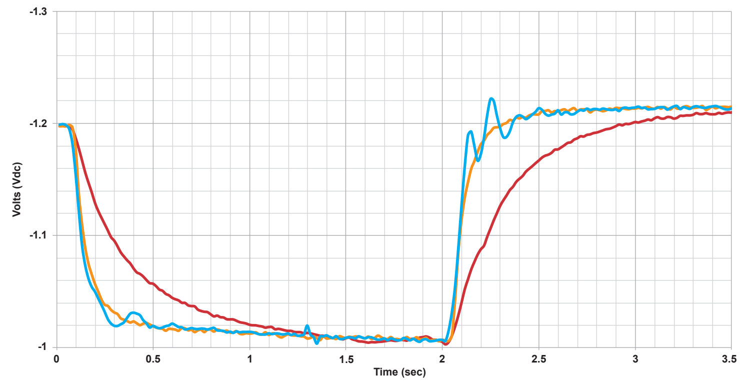
More information can be found at dairyland.com including PCRX ratings, certifications, accessories and other information related to this topic.

APPENDIX A

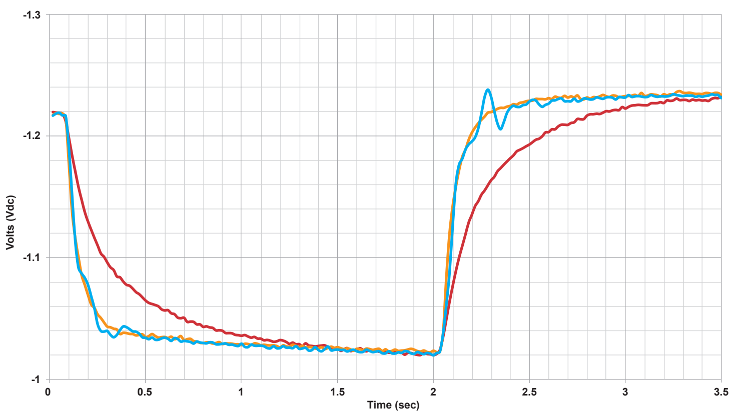
Appendix A contains interrupted survey waveforms performed during PCRX validation testing. This pipeline site was in the western United States. The pipeline was electrically isolated from external interference other than adjacent AC power lines. The pipeline was 24” diameter and the length of pipeline studied was approximately 32 miles. Pipeline coating fusion bonded epoxy and soil conditions were sandy and dry. Eight decouplers were installed on this pipeline segment.



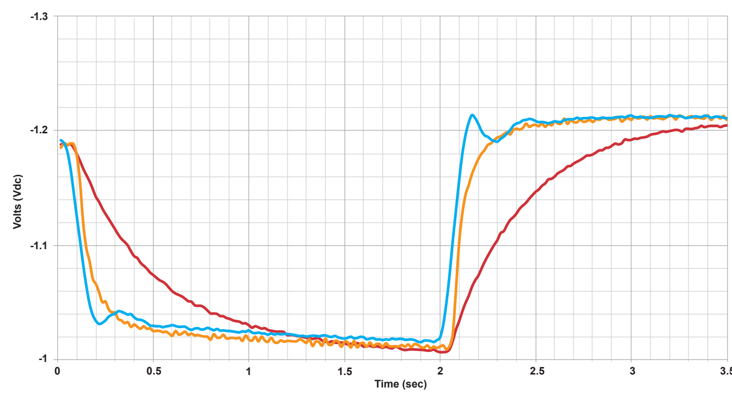
Test location CK-810



Test location CK-314



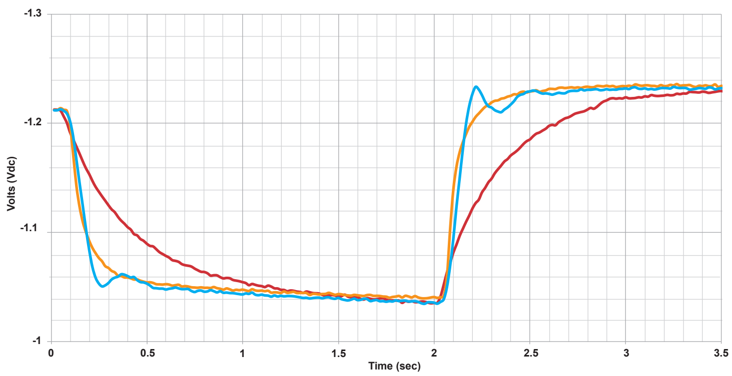
Test location CK-832



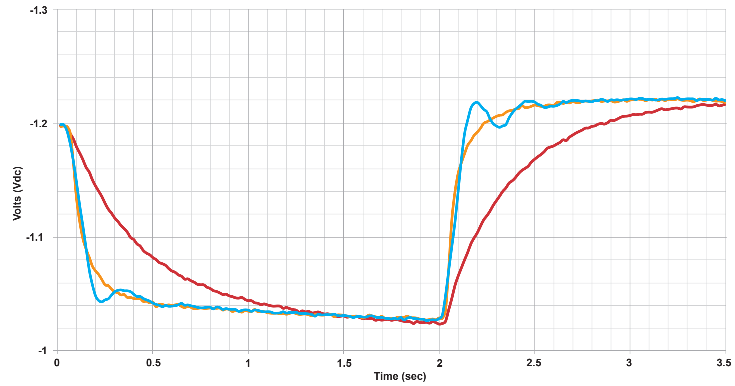
Test location CK-445

Standard Decoupler **Decoupler Disconnected** **PCRX Decoupler**

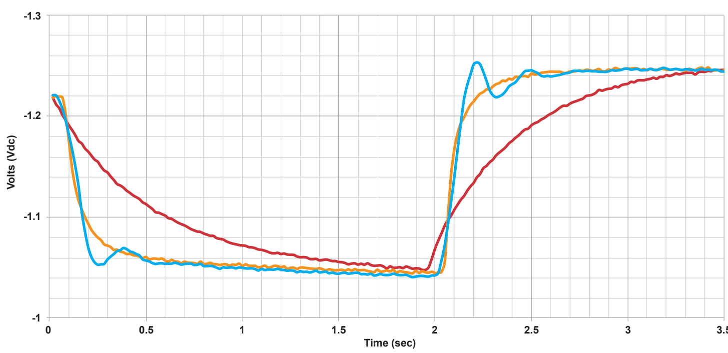
APPENDIX A



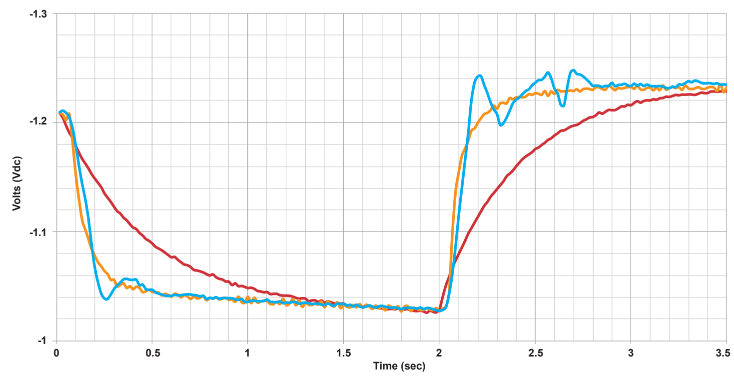
Test location CK-545



Test location CK-756



Test location CK-922

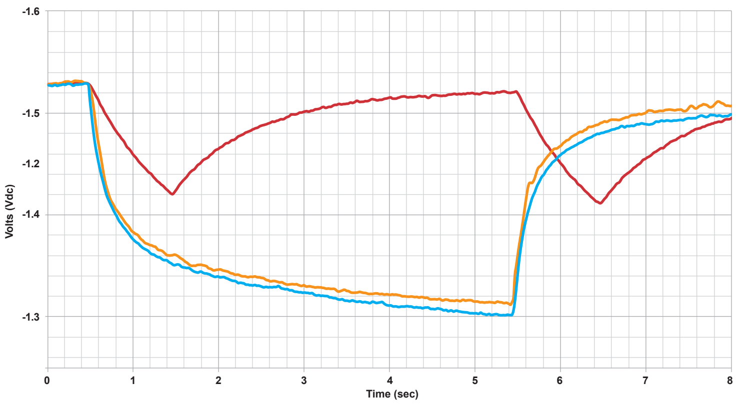


Test location CK-102

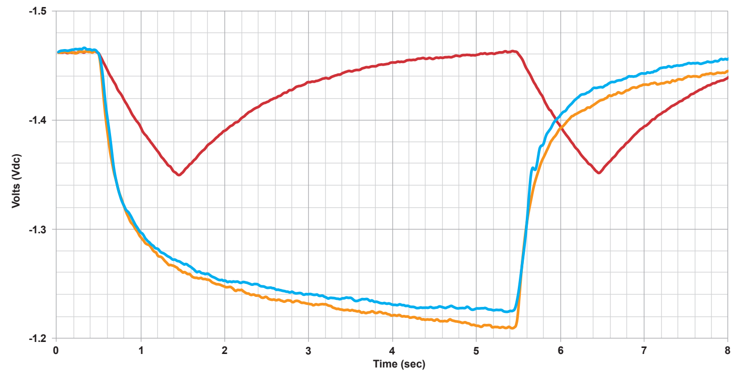
Standard Decoupler **Decoupler Disconnected** **PCRX Decoupler**

APPENDIX B

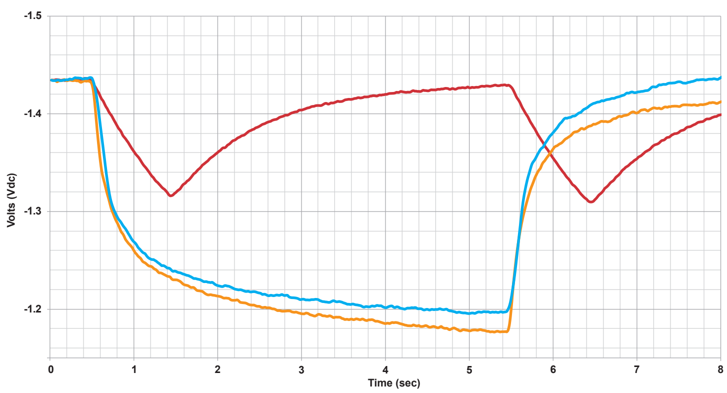
Appendix B contains interrupted survey waveforms performed during PCRX validation testing. This pipeline site was in the Midwestern United States. The pipeline segment studied was a pipeline lateral that was not electrically isolated from the main pipeline. This approximate 2 mile lateral was a mix of 6” and 8” diameter pipe with fusion bonded epoxy coating. Soil conditions were typical farm topsoil and moist. Eight decouplers were installed on this pipeline segment. The data taken with Standard Decouplers installed (red line) had an on/off cycle too short to capture full dissipation times.



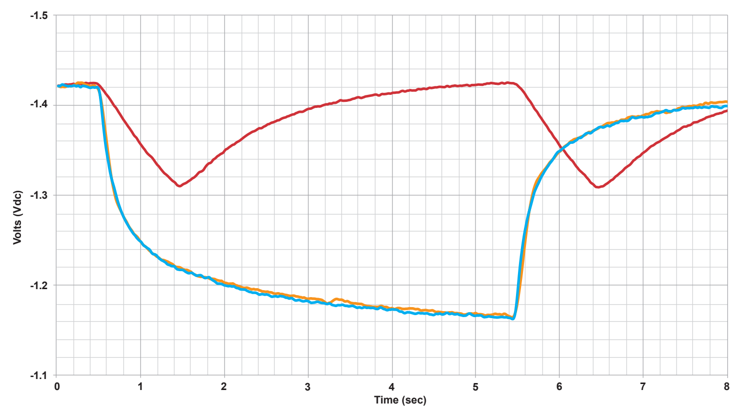
Test location WO-01



Test location WO-02

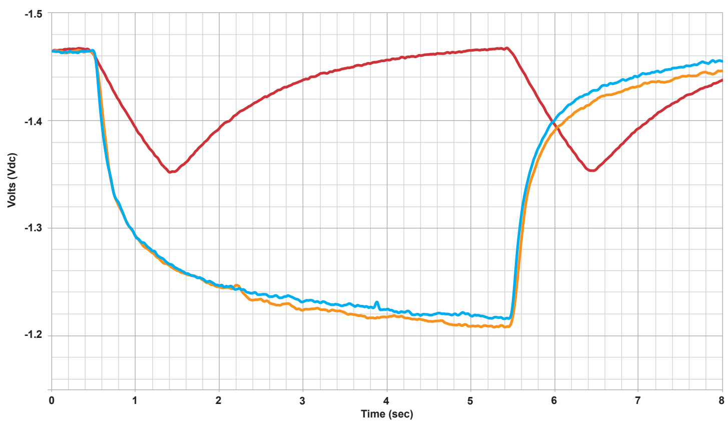


Test location WO-03

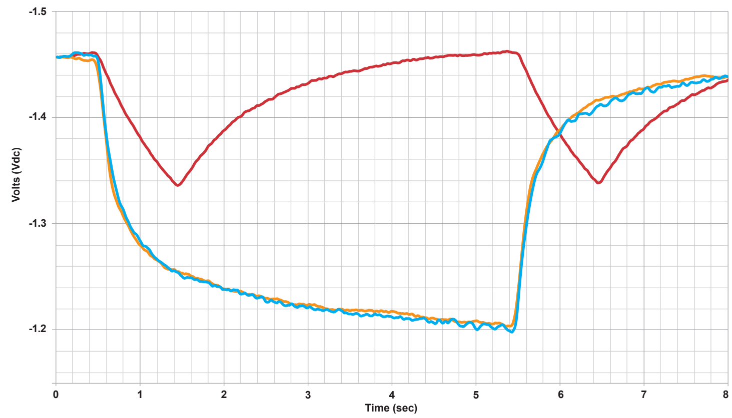


Test location WO-04

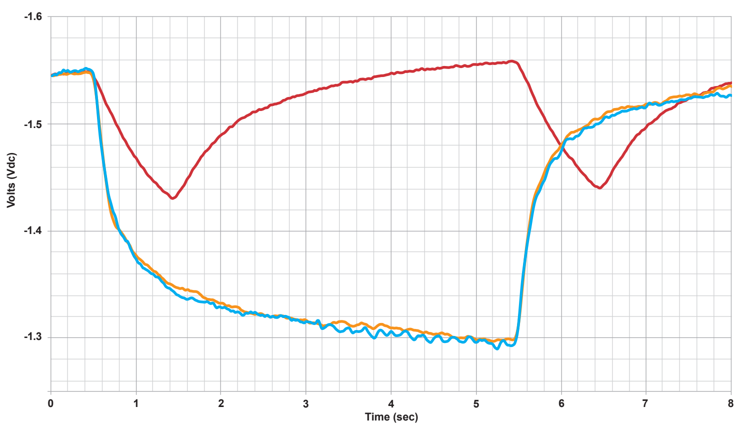
Standard Decoupler **Decoupler Disconnected** **PCRX Decoupler**



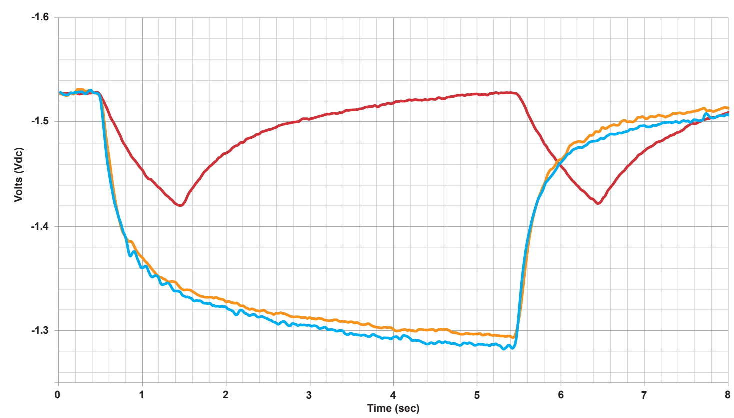
Test location WO-06



Test location WO-07



Test location WO-08

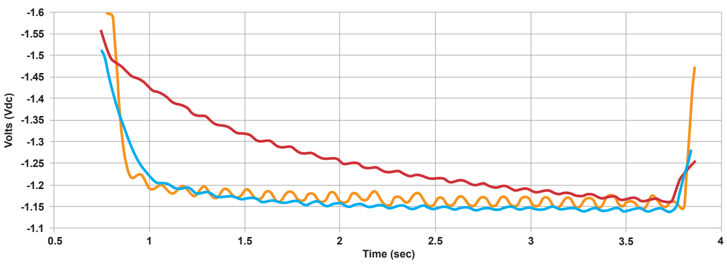


Test location WO-09

Standard Decoupler **Decoupler Disconnected** **PCRX Decoupler**

APPENDIX C

Appendix C contains an interrupted survey waveform performed during PCRX validation testing. As this testing was performed earlier (relative to that of Appendix A & B) in the validation process, not all environmental and pipeline conditions were captured. This pipeline site was in the Midwestern United States, near a mix of residential and commercial developments, with the pipeline running adjacent to overhead AC transmission lines as well as a railroad.



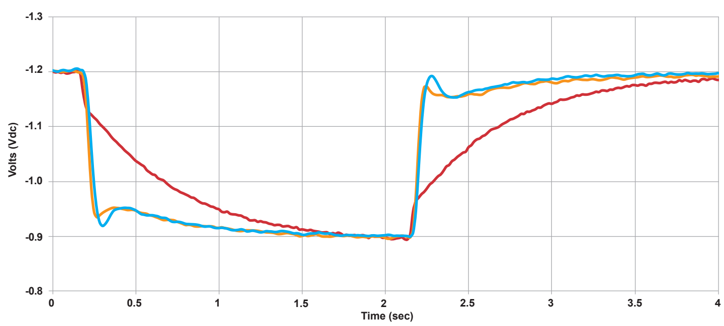
Standard Decoupler   Decoupler Disconnected   PCRX Decoupler

APPENDIX D

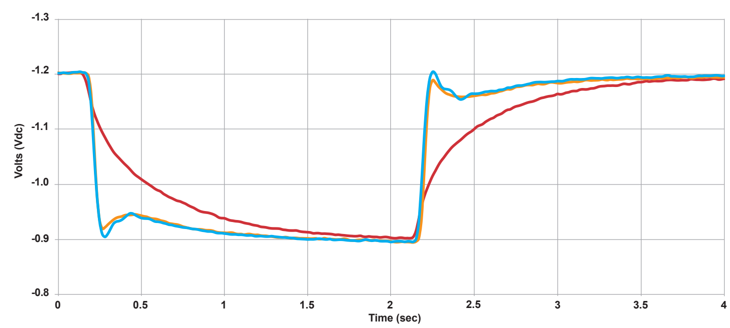
Appendix D contains interrupted survey waveforms performed on two parallel pipeline segments in the western United States. These segments were approximately 11 miles long, and each pipeline was 36” diameter with FBE coating. Soil conditions were gravel/sand and dry. The pipelines shared a common CP system but different grounding systems. These pipeline segments were running in a corridor with HVDC (as opposed to the more common HVAC) transmission lines.

Of note in this application is the presence of a deep well ground bed approximately four miles from one end of this segment. This deep well ground bed was connected to this pipeline through 5 standard Dairyland decouplers. The pipeline was electrically isolated from other interference sources for the purpose of this test to the extent possible. What the data below will show is how these remotely located decouplers will impact an interrupted survey.

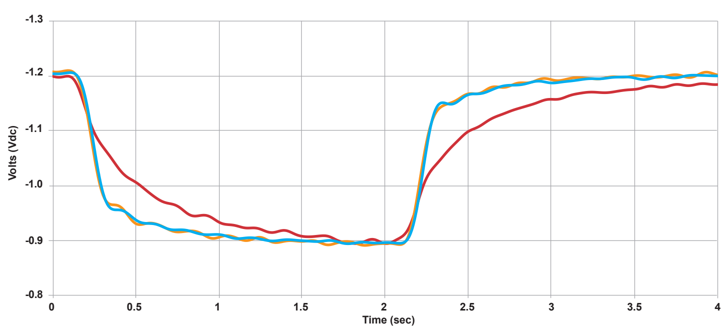
The first page of waveforms is from pipeline A, while the subsequent page of waveforms is from pipeline B. The first graphs in each series are from test sites farthest away from the above noted ground bed, while the last graphs in each series are from test sites closest to the ground bed. Notice how the ‘Decoupler Disconnected’ and ‘PCRX Decoupler’ potentials respond slower the closer to the ground bed the waveform is taken. As noted in the problem description, decouplers offer a source of current for a short time after CP current interruption. These remote decouplers which were not disconnected on the ground bed are providing that current, and thus results in a slower voltage dissipation to reach the pipeline’s off potential.



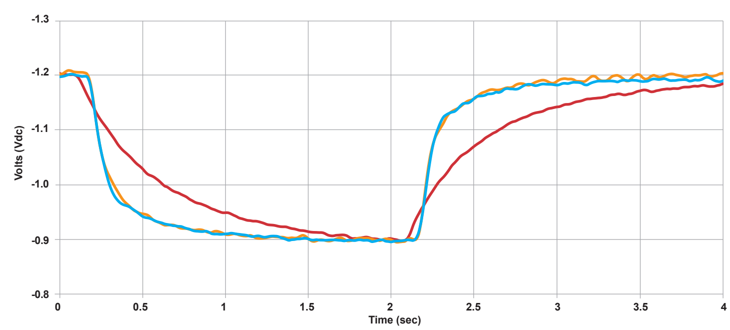
Test location KN-01A



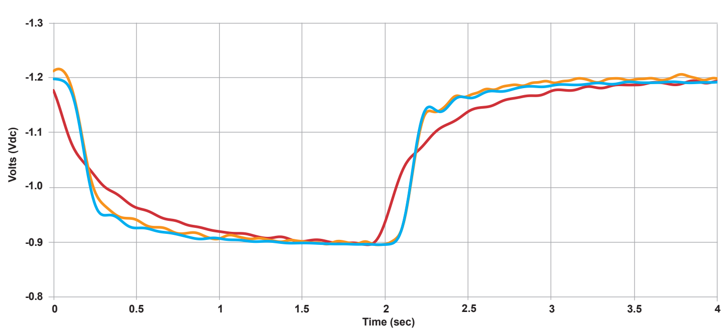
Test location KN-04A



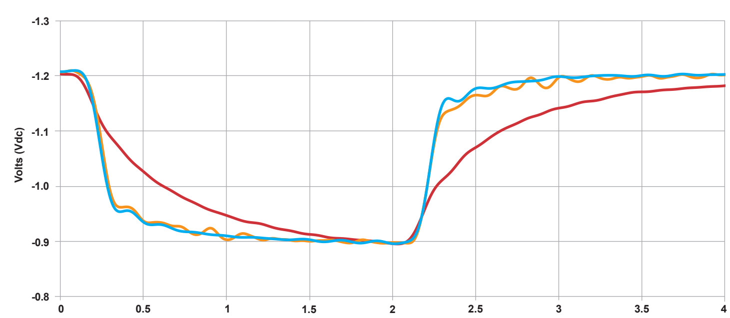
Test location KN-06A



Test location KN-08A

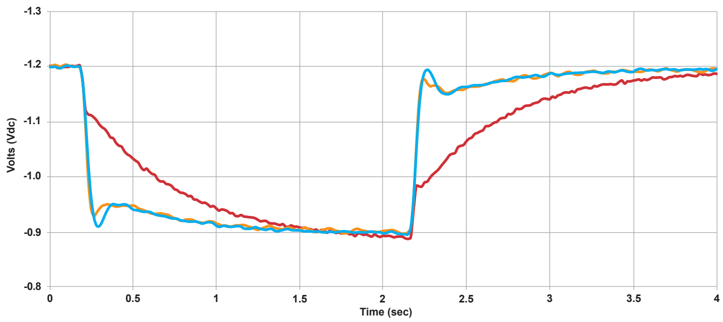


Test location KN-09A

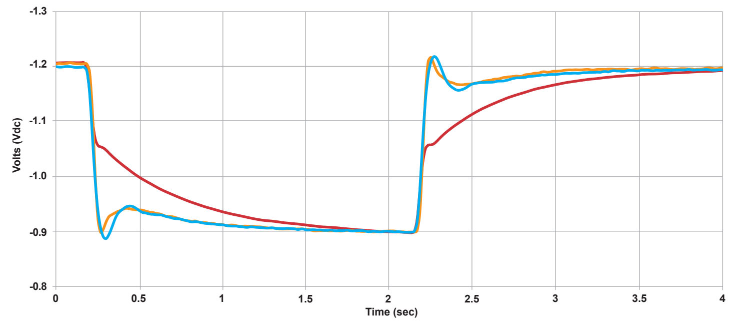


Test location KN-11A

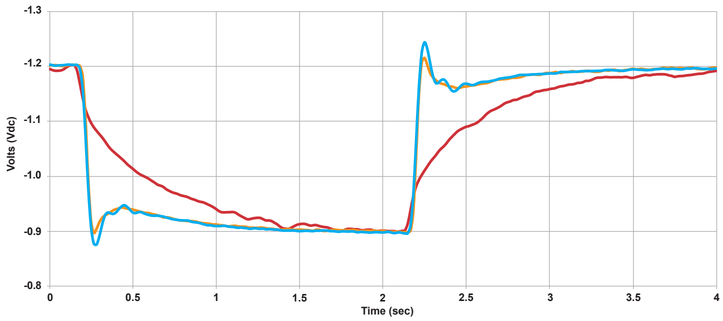
Standard Decoupler **Decoupler Disconnected** **PCRX Decoupler**



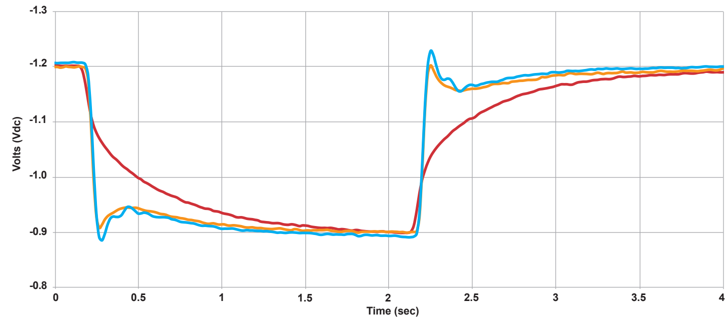
Test location KN-01B



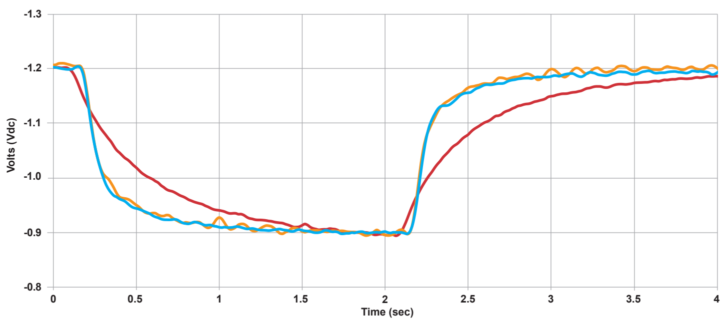
Test location KN-04B



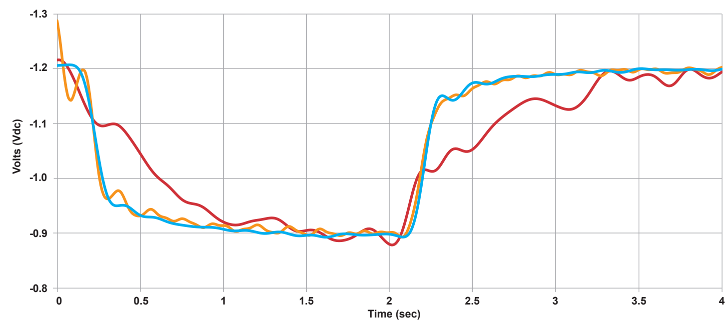
Test location KN-06B



Test location KN-08B



Test location KN-11B



Test location KN-14B

Standard Decoupler **Decoupler Disconnected** **PCRX Decoupler**

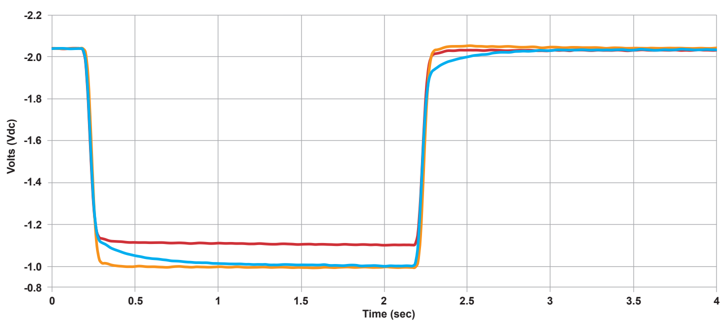
APPENDIX E

Appendix E contains interrupted survey data from an application where decouplers are used between a pipeline and gradient control mats. This test site was in the upper Midwest with the pipeline running within a HVAC corridor, although at the time of this testing there was virtually no induced AC due to very low power usage. The installation of the gradient control mats was taking place coincidentally with this testing, such that the backfill had little time to settle on and around the gradient control mat. Ultimately, this leads to a high resistance between the soil and the mat.

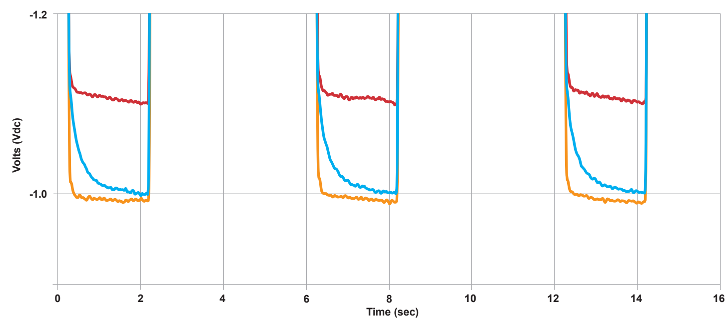
To simplify the analysis of this particular test location, this appendix shows two different views of the same waveforms at the same test location. The first waveform shows a “zoomed in” view of a single instant off cycle. With the off cycle set to two (2) seconds, this graph would appear to indicate two things. First, there appears to be an offset between the standard decoupler’s off potential and that of the no decoupler condition. Secondly, it would appear that the PCRX has a slower response to the CP current interruption as indicated by the blue line’s gradual curve to meet the no decoupler potential.

However, knowing the site conditions along with a different view of the waveforms leads to a different conclusion. The second graph is from the exact same data as the first, with the time frame extended and the vertical axis focused on just the off portion of the cycle. What is evident now is that the standard decoupler is still dissipating current and has not reached the true off potential…and likely would not for quite some time. From the discussion within the body of this paper with regard to RC time constants, this site with very high resistance will naturally have a relatively long dissipation time. And while the PCRX looks like it has a slow response, it is actually reaching the true off potential much quicker than the standard decoupler.

Note that this application is different from other case studies presented in that the grounding system is the gradient control mat with fresh gravel backfill. This creates a very high ground resistance that dominates the RC time constant. With decouplers disconnected, the grounding system of the gradient control mats is completely out of the circuit being measured, resulting in a nearly immediate instant off shift to the true polarized potential. With the PCRX installed, the high resistance of the grounding system is back in the circuit, resulting in a slower response indicated by the blue line.



Test location NG-06



Test location NG-06

Standard Decoupler **Decoupler Disconnected** **PCRX Decoupler**