Paper No.
10102

NACE INTERNATIONAL CORROSION 2010 CONFERENCE & EXPO

HIGH VOLTAGE DIRECT CURRENT INTERFERENCE WITH UNDERGROUND/UNDERWATER PIPELINES

Peter Nicholson
Managing Director
Cathodic Technology Limited
15-1 Marconi Court
Bolton, Ontario
Canada L7E 1E2
Email: peter@corrosion-rust.com

ABSTRACT

Underground/underwater pipelines are susceptible to corrosion from DC stray current originating from the operation of High Voltage Direct Current (HVDC) transmission systems. With increasing population growth and the demand for electrical power, HVDC transmission is an economical method of transporting electrical energy over long distances. There are two distinct types of HVDC transmission, monopolar and bipolar. Monopolar systems use the earth or preferably sea water as the return circuit, whereas bipolar systems only use the earth or sea water during electrical upsets or faults.

This paper will outline the effect of stray current that originates from an HVDC transmission system that runs parallel to and crosses a crude oil and natural gas pipeline system. Ground fault currents as high as 2800 amps have been recorded flowing into the ground electrode when the bipolar HVDC system reverts to monopolar operation during fault conditions or during scheduled maintenance.

Keywords: High Voltage Direct Current, HVDC, Monopolar, Bipolar, Interference, Interference Current, Fault Current, Imbalance Current, Stray Current, Intertie, Mercury Arc Valve Converters, Thyristor, Pipelines, Underground Utilities, Stray Current Mitigation Systems, Drainage, Current Drainage, Current Pickup, Current Discharge

INTRODUCTION

The first reported HVDC transmission system (Gotland 1) with mercury arc valve converters was commissioned in 1954. Since that time conversion methods have improved with thyristor control used principally today. The operating voltages have also increased with up to +/- 500,000 volts to ground; this allows for higher wattage transmission, increasing the power available to consumers.

The first North American HVDC transmission system was the British Colombia to Vancouver Island monopolar system in 1968, transmitting 312 mega watts at 260 KV through an undersea cable. This was followed by the Pacific Intertie, a bipolar system in 1970 transmitting 3100 mega watts, and the Nelson River bipolar system 1971 transmitting 1620 mega watts at +/-450 KV.

In 1991 the Quebec-New England Intertie was commissioned as a 2,000 mega watt system operating at +/- 450 KV. Since commissioning, the power capability has increased to approximately 2500 mega watts. This paper will detail the effect of this HVDC system on a crude oil natural gas transmission pipelines linking Portland Maine with Montreal Quebec.

The most recent HVDC system commissioned in North America is the Cross Sound Cable Interconnector, a monopolar system commissioned in 2002 operating at 330 MW, 40 Km in length and utilizing a light buried submarine cable system that connects the electric transmission grids of New England and Long Island, New York.

Monopolar HVDC systems use the earth (generally sea water) for return current flow. The power is generated as alternating current at the source then converted to DC current that flows over a cable to the load where it is converted back to alternating current by the thyristor's as shown in Figure No. 1. The return current flows through the earth from the load terminal to the source converter station.

Bipolar HVDC systems use two conductors - one from the source to the load and a return conductor from the load to the source. Bipolar systems also have a ground electrode to allow imbalance current to flow from the source to the load or from the load to the source through the ground. These imbalance currents are usually less than 100 amps and may flow continuously for hours; see Figure No. 2.

During a system upset or during planned maintenance, power may be transmitted over Line 1 or Line 2 with the return current flowing through the earth to return to the source. This can result in thousands of amperes of current flowing through the earth circuit causing direct current interference with underground/underwater pipelines and utilities.

CASE HISTORY

QUEBEC-NEW ENGLAND INTERIE

The Quebec-New England Intertie was commissioned in 1991 after extensive testing in 1990 at current levels of 700 amps. A number of utilities and pipelines were affected by DC fault currents. The rural electrical system in New England was significantly affected with saturation of distribution transformers from stray direct current. The initial concept for the HVDC transmission system was to have a bipolar system running from the generators at Radisson Quebec on James Bay to Sandy Pond northeast of Boston with intermediate stations at Littleton, New Hampshire (now decommissioned), Duncan, Quebec and Nicolet, Quebec (see Figure 3).

Following the initial testing, New England Power ran an aerial return conductor (insulated from the towers) on the HVDC towers from Sandy Pond to Duncan Quebec to reduce the fault current flow in the earth circuit in New England. This resulted in a change in the HVDC stray current pattern on the pipelines affected by the HVDC fault currents.

HVDC fault current has severe impact on underground/underwater pipelines. Current is picked up on underground pipelines and can travel in the wall of the pipeline for a considerable distance before discharging. Since HVDC faults are a steady state flow of current that can last from a few minutes to several days, severe damage can occur to a pipeline at the current discharge location.

Stray current mitigation systems were installed on the pipelines to safely drain the DC fault currents from the operating cross-country pipelines. The drainage scheme worked for a number of years; however, changes occurred over time. New pipelines were run, existing pipelines were modified and telephone utilities changed from lead sheathed cables to plastic or fibre optics. This resulted in the pipelines and utilities requesting a new series of fault tests. The first test occurred on November 4, 2006.

In conjunction with Quebec Hydro and New England Power, the pipelines established a test pattern that would be easy to recognise in the event that there was significant telluric activity during the test. At the half hour the test would start with 1200 amps discharged into the ground electrode at Duncan (the south electrode) for a period of 4 minutes. At the end of the 4 minute interval the current discharge would stop for 2 minutes, then 1200 amps would be discharged from the ground electrode at Radisson on James Bay for 2 minutes with current being picked up on the ground electrode at Duncan. This test pattern would be repeated hourly on the half hour from 07:30 hours to 19:30 hours - see Figure 4.

The first set of tests occurred on November 4, 2006 starting at 07:30 hours and continuing hourly on the half hour. Current flow and pipe-to-soil potentials were recorded for approximately 15 minutes at test stations in Maine and Quebec.
The results indicated that the pickup and discharge areas for the HVDC stray currents had changed in both magnitude and location. Immediately after commissioning in 1991, the current discharge area was principally in Quebec from the Vermont Border north to St. Cesaire. The November 4, 2006 test indicated that the current discharge area was principally south of the Canadian border in northern Vermont Figure 5. This necessitated a second test to

define the actual area of current pickup and discharge. With the onset of winter the test was postponed until June of 2007.

The second test started at 09:30 hours on June 18, 2007. During both tests a digital recorder was installed at Scenic Road in Quebec to record the pipe-to-soil potential of the crude oil pipeline every second. Figure 6 shows the recorded pipe-to-soil potentials from 09:15 hours to 16:59 hours on June 28, 2007. The chart shows that the test faults occurred as scheduled hourly on the half hour, with a potential swing of approximately 500 millivolts at this location.

In order to obtain as much information as possible during the June 2007 test, test stations in Vermont were refurbished and, where required, were also equipped with IR drop leads to measure current flow. The 18 inch and 24 inch crude oil pipelines are coated with coal tar enamel Kraft Rapp coated pipeline respectively with an abandoned bare 2 inch line in the middle of the right-of-way.

To get an accurate assessment of the effect of the HVDC stray currents, it was essential to record the current flow and pipe-to-soil potential of both the 18 inch and 24 inch lines. The current flow was recorded as a voltage across a length of the pipeline and the pipe-to-soil potential was recorded every second for approximately 20 minutes during the fault test, the set up is shown in Figure 7.

Going south from the Canadian border through Vermont, the HVDC stray currents were picked up on the pipelines. The magnitude increased through the Missisquoi River Valley, then diminished further south. Figure 8 shows the effect of the HVDC fault current on the pipe-to-soil potential of the 24 inch line at the first road south of the Canadian border. A fault current of 1200 amps caused a pipe-to-soil potential change of 300 millivolts. Figure 9 taken a mile south at the Missisquoi River crossing shows a potential change due to HVDC fault current at 1200 amps of 700 millivolts. At both of these locations when the south electrode was an anode (current discharge into the soil), current was picked up on the pipelines. When Radisson was an anode and Duncan a cathode, current discharge was noted on the pipelines at these locations. Figure 10 shows the current flow through the 24 inch pipeline at this location is less than at locations north and south of Mile Post 159.

At Collins Mill Road on the north side of Black Mountain, the pipe-to-soil potential shift had increased to 900 millivolts but was reversed Figure 11, indicating current discharge when Duncan is an anode. This pattern is observed through Black Mountain and reverses back to normal a normal condition (pickup) on the south side of Black Mountain at Tay Road, Irrasberg. This finding was very perplexing - to have a discharge area in the middle of a pick up section should not occur.

After further research, it was noted that on a geological survey of Vermont (see Figure 12), there is a narrow low resistance graphite ore body running northeast - southwest and crossing the pipeline right of way on the north slope of Black Mountain. It is postulated that the HVDC Current is discharging from the pipeline, going into the ground and traveling along the graphite ore body to the Duncan ground electrode.

Figure 13 shows the pipe-to-soil potential at Tay Road Irrasberg. The pipe-to-soil potential here demonstrated pickup, indicating that the pipeline is now clear of the current discharge area. Figure 14 is the companion current flow recording on the pipeline. The rapid fluctuations are due to telluric current, not the HVDC current.

Figure 15 shows the pipe-to-soil potential at Route 16 Barton several miles further south and indicates diminished current pickup. Figure 16 is a recording of the current flow through the pipeline at this location. Compared to the current flow recording further north, it is evident that the current flow has diminished.

In conclusion, HVDC fault current can have severe impact on underground/underwater pipelines. This type of DC current is picked up on underground pipelines and can travel in the wall of the pipeline for a considerable distance before discharging. Since HVDC faults are a steady state flow of current that can last from a few minutes to several days, severe damage can occur to a pipeline at the location where the current discharges.

Figure 17 shows the number of faults, the duration and magnitude of each fault. On March the 23, 2007, the south electrode was a cathode and received 1058 amps of current for 29 minutes. This means that the pipelines running from the Canadian border to south of Barton, Vermont were discharging current. On April 13, 2007 a fault occurred on the HVDC system and the Duncan electrode became an anode discharging 2,228 Amps for 17 minutes. System faults in the past which have lasted over 24 hours have been recorded previously. These long duration current flows can result in significant damage to a coated pipeline by concentrating the current discharge at holidays in the coating.

Pipeline operators need to be vigilant where there are pipelines affected by HVDC stray currents. Stray current mitigation systems should be installed and maintained in good working condition to ensure that the pipelines are not compromised by corrosion due to stray current discharge.

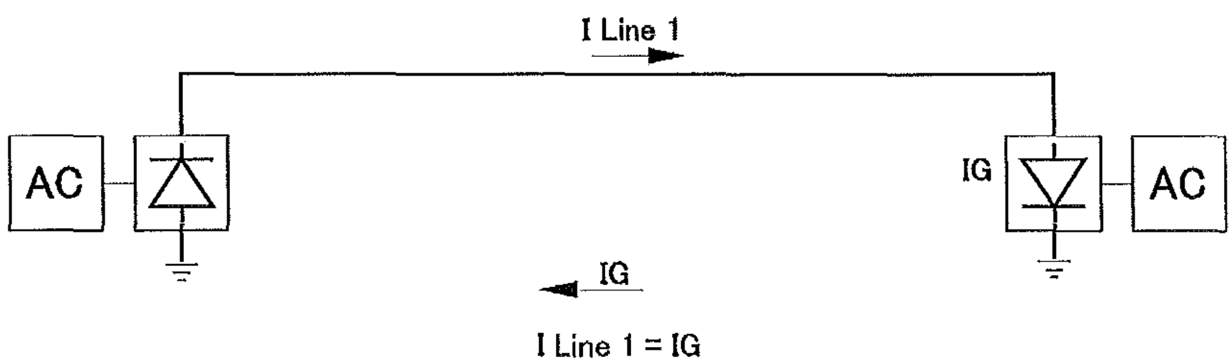
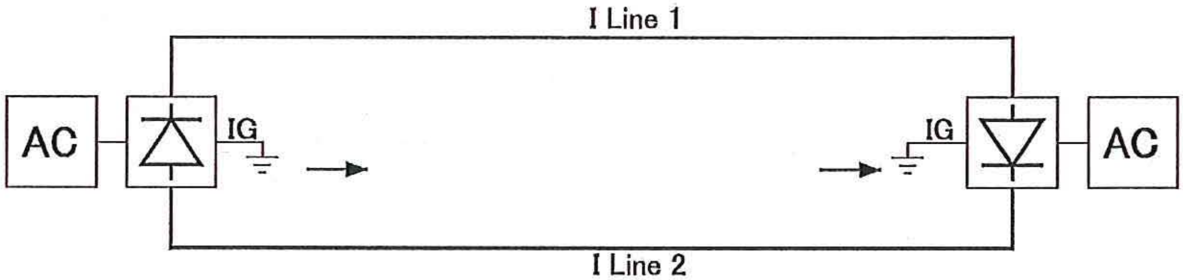


Figure No. 1 Monopolar System



IG = I Line 1 − I Line 2

Figure No. 2 Bipolar System

Figure 3 Map showing location of HVDC line in Red

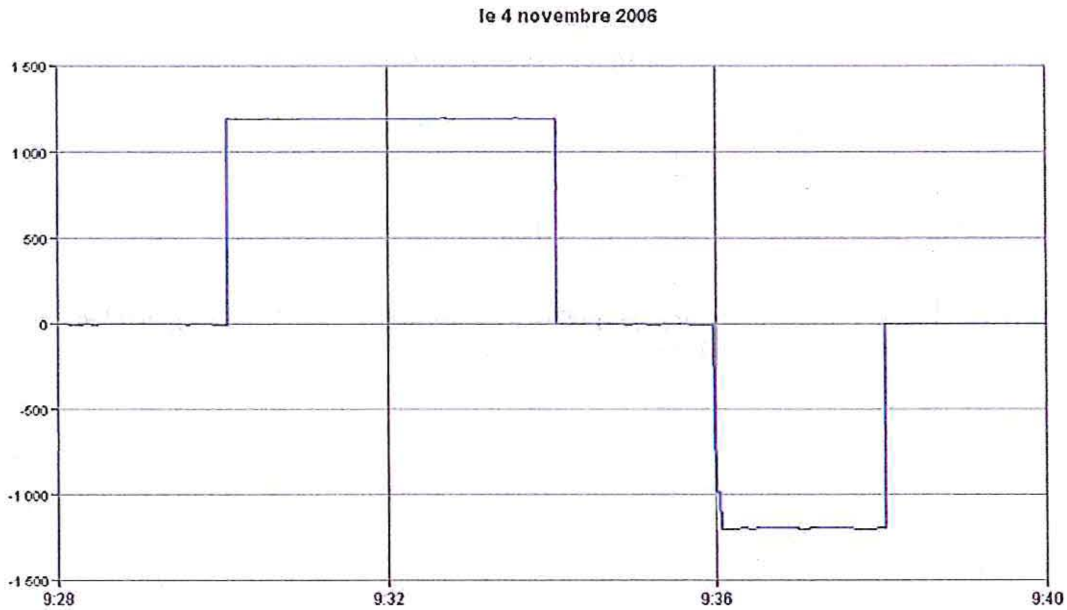


Figure 4 Test Pattern as Recorded at Duncan Ground Electrode

Figure 5 Area of Pickup and Discharge in Northern Vermont

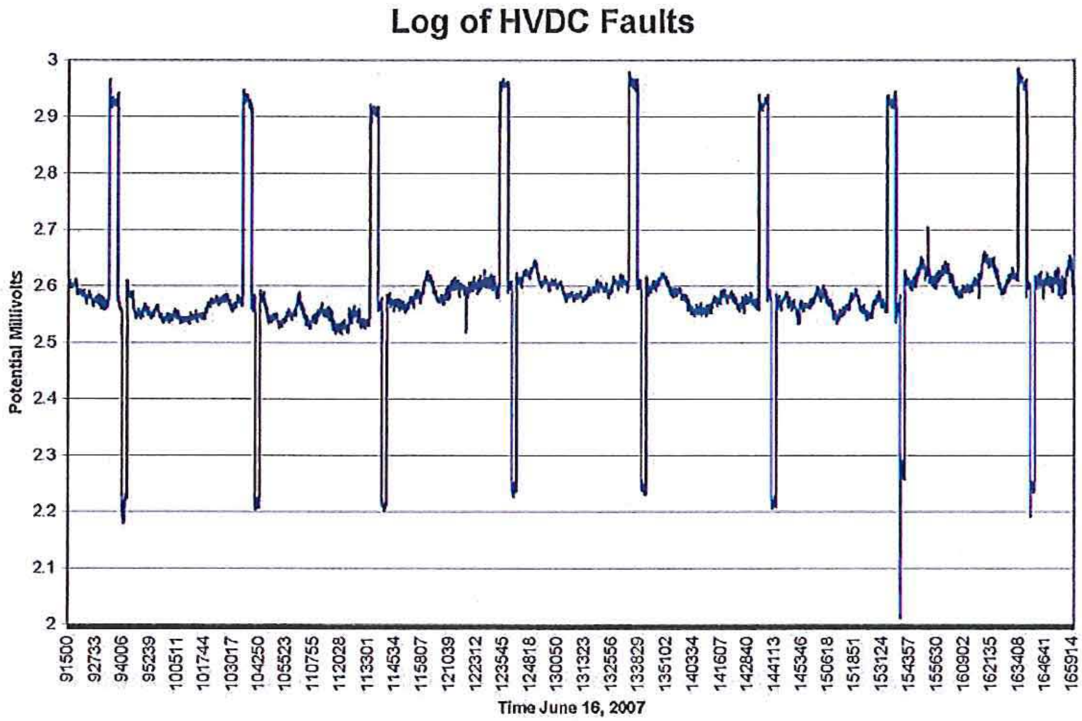


Figure 6 Log of HVDC Faults 09:30 hours to 17:00 hours June 18, 2007

Figure 7 Showing Four Mini-Loggers recording Pipe-to-soil potentials and current flow at a test station simultaneously

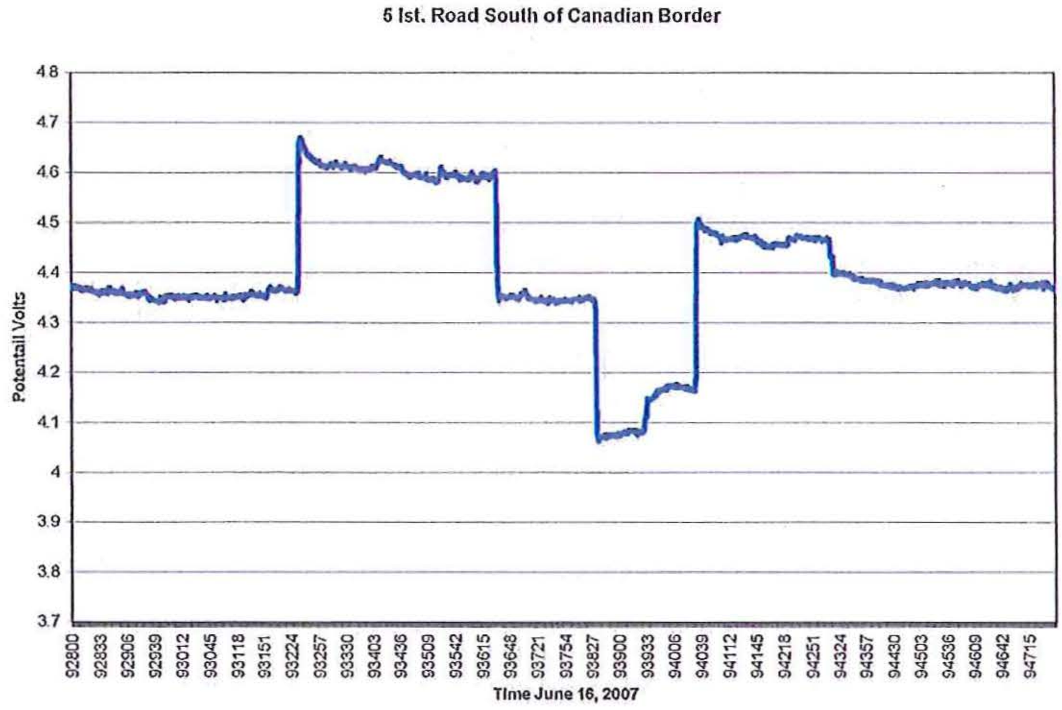


Figure 8 shows the HVDC test pattern effect on the pipe-to-soil Potential at the first Road crossing South of the Canadian Border

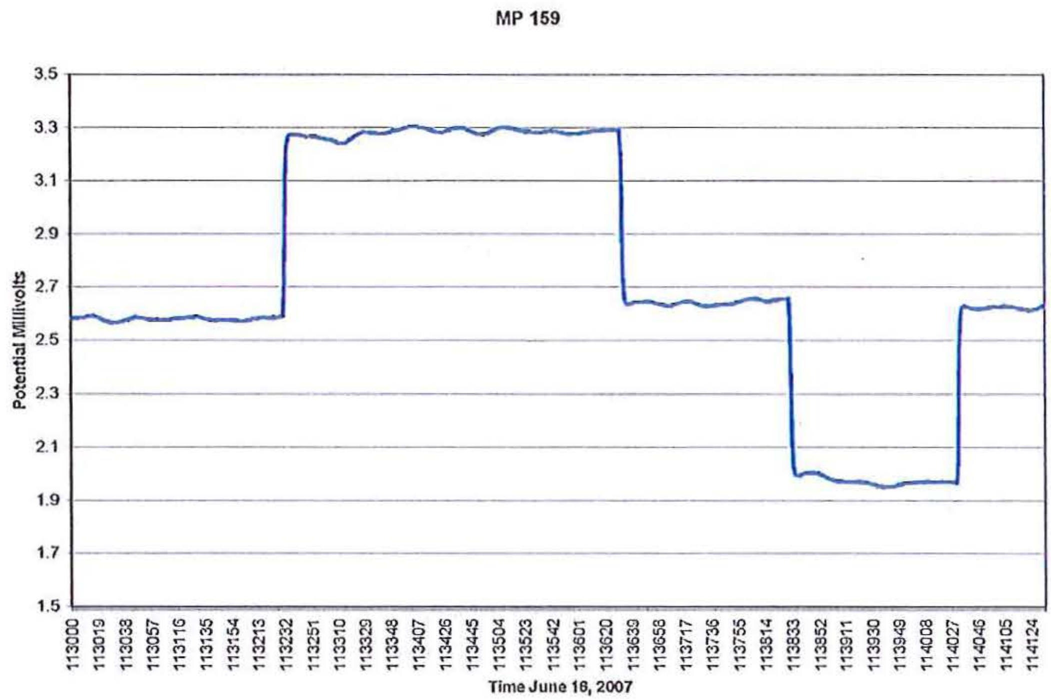


Figure 9 Mile Post 159

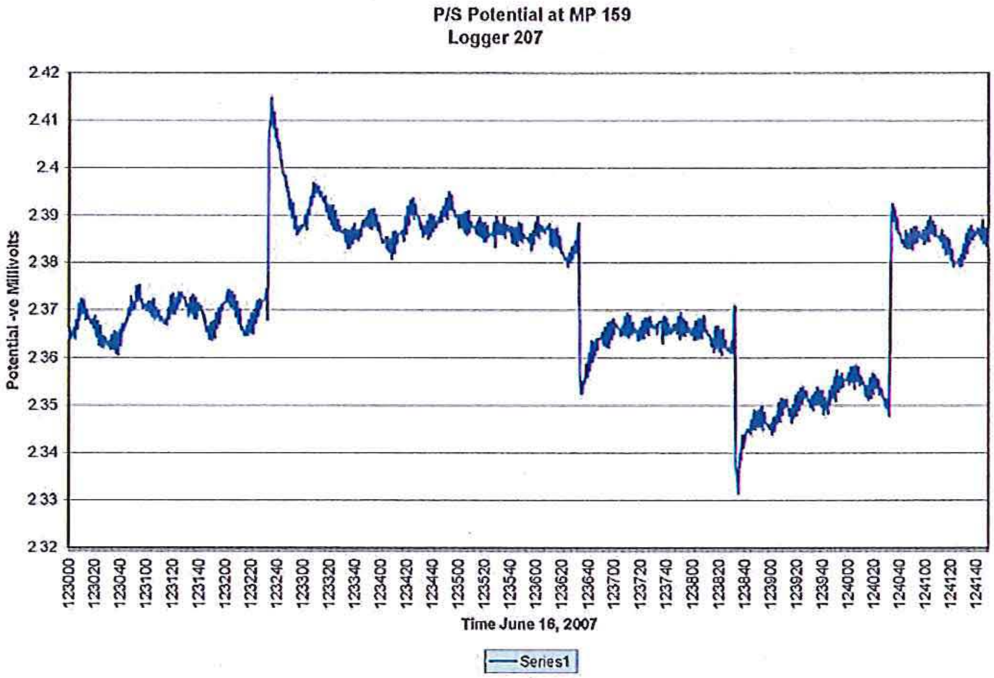


Figure 10 Current flow at MP 159

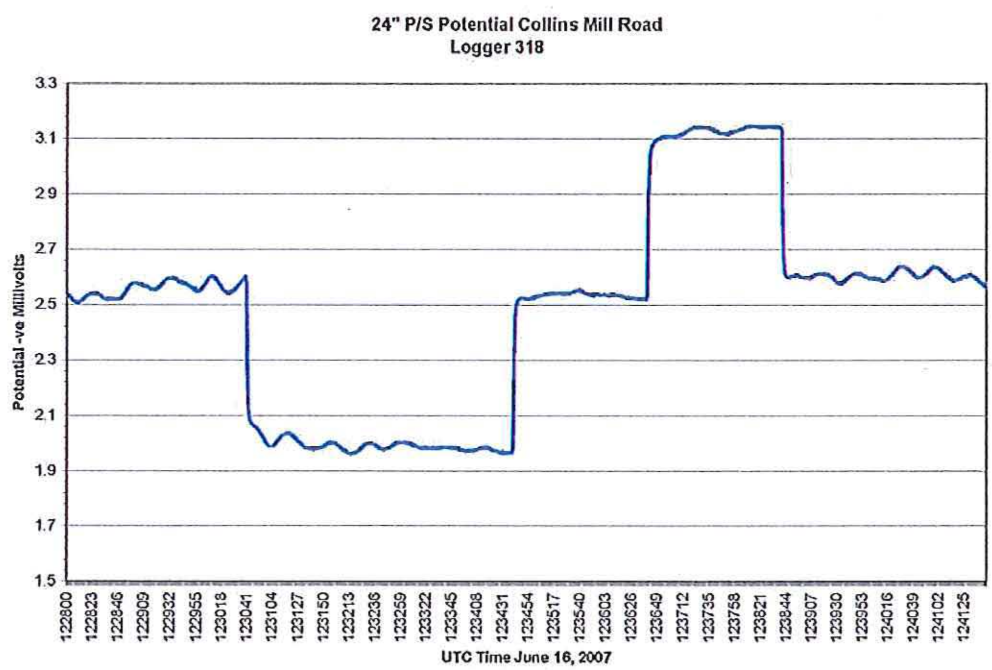


Figure 11 Pipe-to-soil Potential at Collins Mill Road showing Reversed Potentials

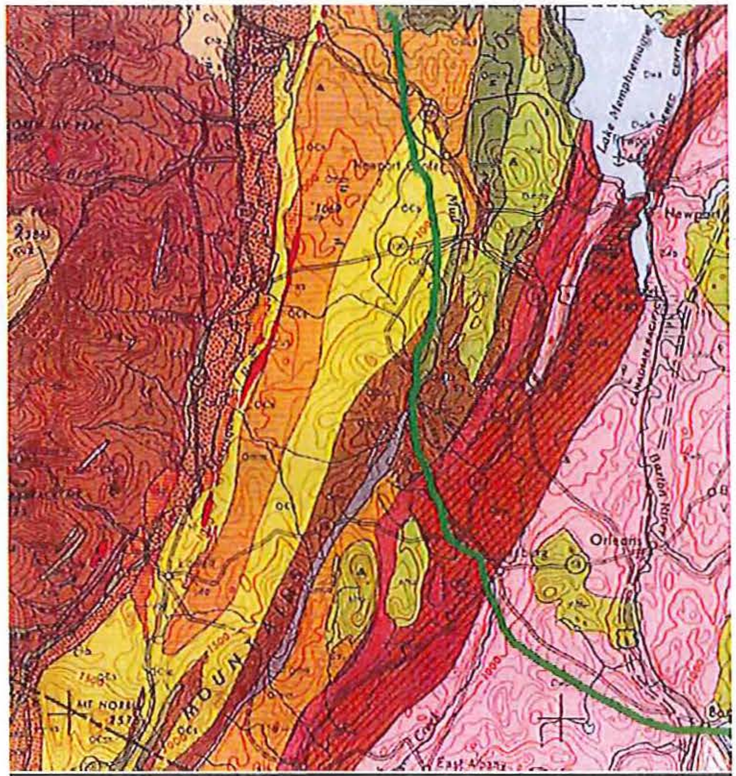


Figure 12 Geological Survey of Vermont
Pipelines shown as green line

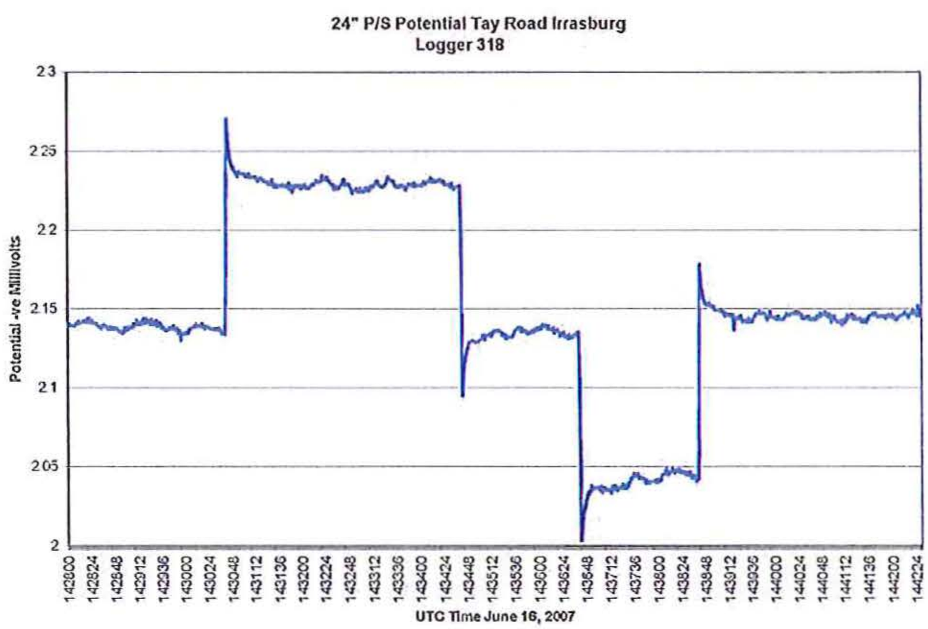


Figure 13 Pipe-to-soil Potential at Tay Road Irrasburg Showing HVDC Test Pattern

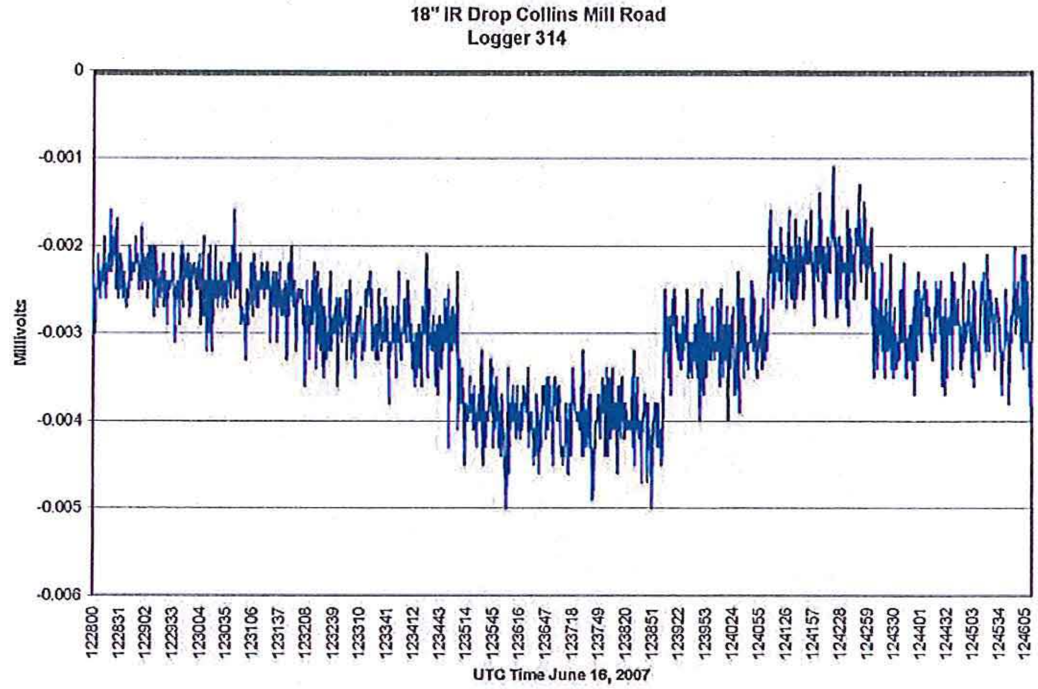


Figure 14 Current Flow at Collins Mill Road showing Increased Current Flow South when Duncan is an anode

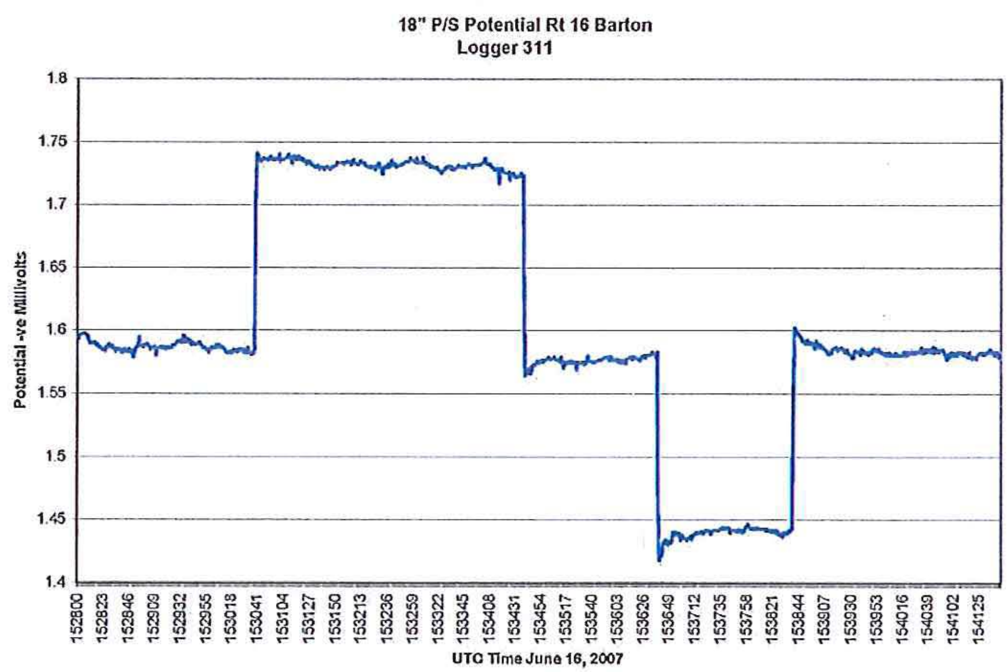


Figure 15 Pipe-to-soil Potential at Rt. 16 Barton Showing HVDC Test Pattern with diminished effect of HVDC Stray Currents

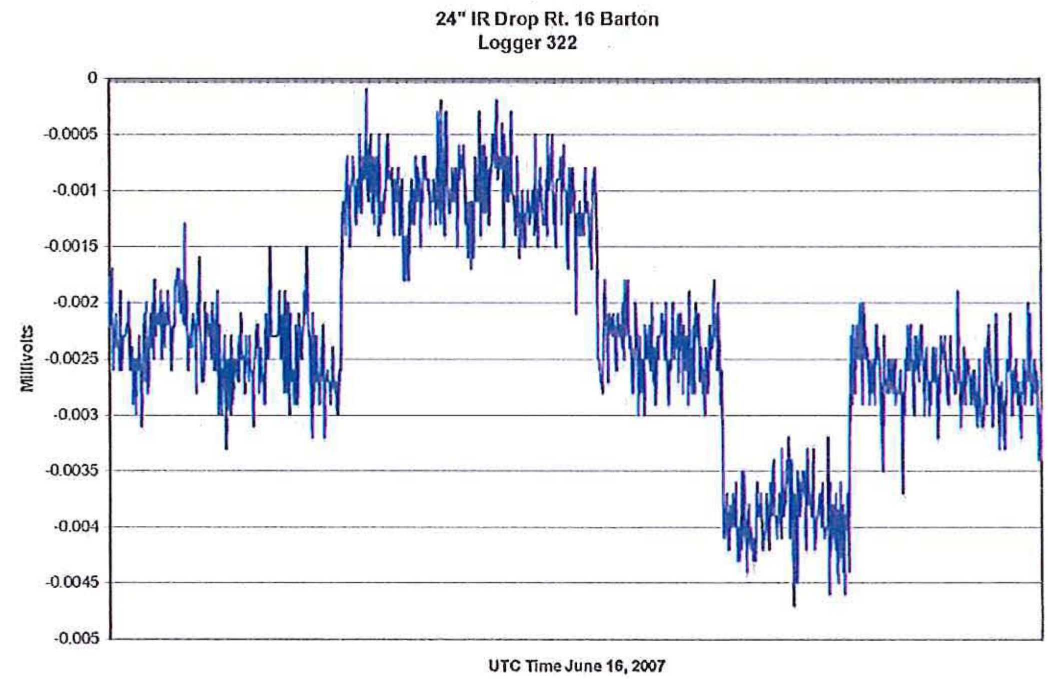


Figure 16 Current Flow at Rt. 16 Barton showing Decreased Current Flow South when Duncan is an Anode

Relevés de courants de terre
Électrode Duncan

Période couvrant du 1er mars au 30 avril 2007
Courants de plus de 20 amps et de plus de 2 min
Courant maximal atteint durant la période

Date	Durée (min)	Courant (amp)
Mars		
12	13	-1128
23	29	-1058
30	3	-233
Avril		
2	4	1574
13	17	2228

Du 21 au 30 avril, les données ne sont pas valides

Claude Roux
Hydro Québec

lundi 7 mai 2007

List of HVDC Fault Current at the Duncan Ground Electrode

The list covers the period from March 1 to April 30, 2007. Only fault currents greater than 20 amps and fault currents of longer than 2 minutes in duration are listed.

Date	Fault Duration Minutes	Fault Current Amps
March 12	13	-1128
March 23	29	-1058
March 30	3	-238
April; 2	4	1574
April 13	17	2228

From April 21 to 30, the data is not valid

Hydro Quebec

Figure 17 Log of HVDC Faults March 1 to April 30, 2007