Investigating a 345 KV Line Misoperation From Problem Discovery to Problem Solved

(and everything in between)

Presented by

Cliff Harris

9th Annual Fault and Disturbance Analysis Conference

Atlanta, Georgia
May 1-2, 2006

ABSTRACT

Causes of relay misoperations can be difficult to find, especially in complex protection schemes. It is a rewarding (if not somewhat rare) experience when you can identify the problem, propose a fix, then perform thorough testing to re-create the misoperation and positively verify that the fix works.

On August 2, 2005 a misoperation occurred on Idaho Power Company's Midpoint-Kinport 345 KV line. Following a normal trip-close operation, the line tripped on reclose at the Midpoint end only. There was no fault condition at the time; load quantities were present. This paper explains the steps that were followed in investigating and solving this misoperation. Steps included:

1. Determine that a misoperation occurred
2. Gather and analyze the pertinent information
3. Identify the problem
4. Establish corrective action
5. Perform before and after tests using advanced testing techniques to verify the fix

BACKGROUND AND INFORMATION

Idaho Power Company is an investor-owned utility serving 450,000 customers in Idaho and Eastern Oregon. Idaho Power's generating capacity is 3116 MW; it has 4700 miles of transmission lines, and the service area covers 24000 square miles. In normal years, generation is a 60/40 mix of hydro and non-hydro (mostly thermal). The Idaho Power backbone transmission system (Figure 1) is comprised of 345 KV and 230 KV transmission lines connecting major thermal generation assets in Wyoming with substations in eastern and southern Idaho, and hydro generation assets in western Idaho with substations in southwestern Idaho. Summer peak usually occurs in July, when irrigation and air conditioning loads are high.

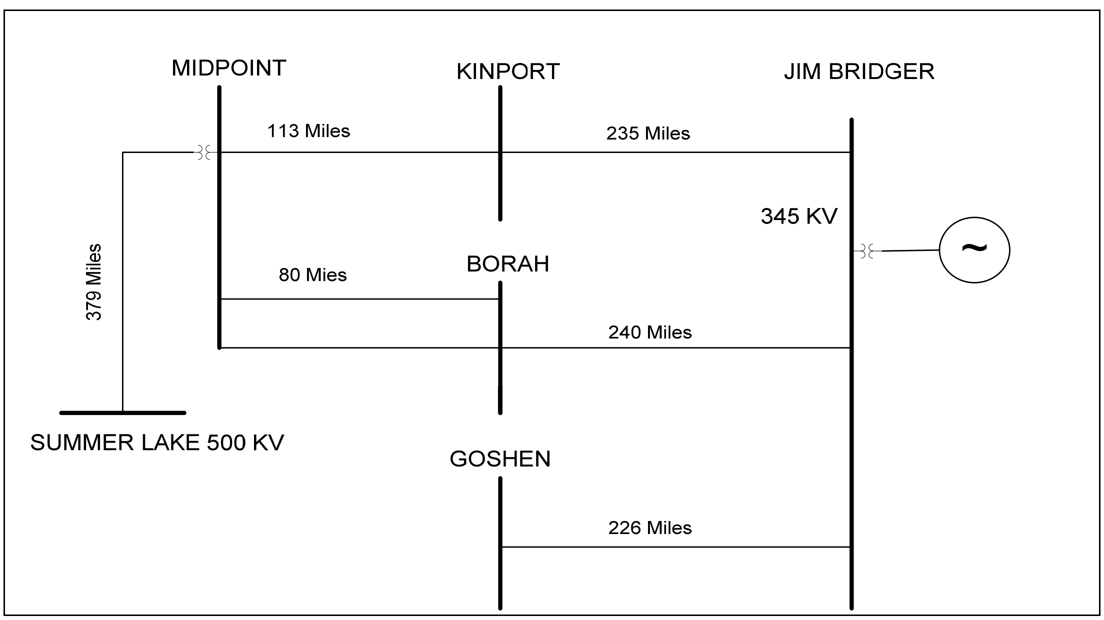

Figure 1 The Idaho Power Company 345 KV Backbone Transmission System

THE MISOPERATION

System Conditions:

On August 2, 2005, the Borah-Midpoint #1 line was out of service for air break maintenance. This resulted in higher than normal power flows on the Kinport-Midpoint line. Power flow on the Kinport-Midpoint line was 284 MW; normal flow is 191 MW. This will turn out to be a contributing factor to the misoperation.

Protection Systems:

Line protection for the Kinport-Midpoint line consists of a dual primary high-speed package. Primary #1 is a directional comparison scheme utilizing microwave communications channels. The relay employs a technique of superimposed currents and voltages to quickly determine fault direction. If the directional comparison relays at both ends of the line see the fault in the forward direction, and receive permission, a trip is processed. Primary #2 relay is a permissive over-reaching transfer trip scheme with distance phase and ground protection and utilizes microwave communications channels.

Midpoint-Kinport Trip:

At 17:17:06 on August 2, 2005, a phase B to ground fault occurred on the Midpoint-Kinport line due to a range fire under the line. Appropriate breakers at Midpoint and Kinport opened to clear the fault. Clearing time was approx. 2.5 cycles. The dispatch logs indicated that a trip-close-trip operation occurred. The line was closed back in at 18:05:01 on the same day. Initial analysis by system protection personnel showed nothing unusual; however, further analysis, conducted the next working day, showed a problem. The normal reclosing sequence took place—Midpoint breaker 301A closed 0.13 seconds after it opened, energizing the line from Midpoint. The Kinport breaker 306A closed upon hot line 5 seconds after it opened. The problem showed itself at this point--the Midpoint terminal tripped immediately after Kinport closed. According to DFR and relay event records, there was no fault present at the time Midpoint tripped. This was categorized as a false trip.

Figures 2A and 2B show DFR records for the phase 2-to-ground fault. Fault current at Midpoint was approximately 2100 amps. Fault current at Kinport was approximately 3800 amps.

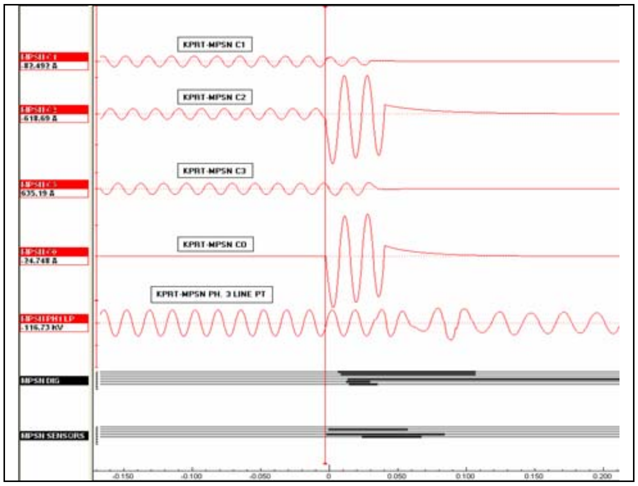

Figure 2A Kinport DFR record of Initial Fault

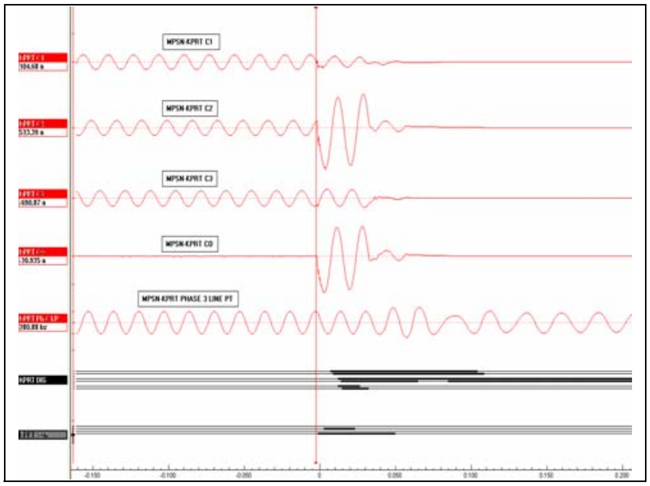

Figure 2B Midpoint Record of Initial Fault

Figure 3 shows the DFR record at Midpoint for the false operation. Note that current was load current—approximately 475 amps. No DFR analog trigger sensors were activated—the DFR triggered due to the relay trip applied. Midpoint tripped via the directional comparison relay.

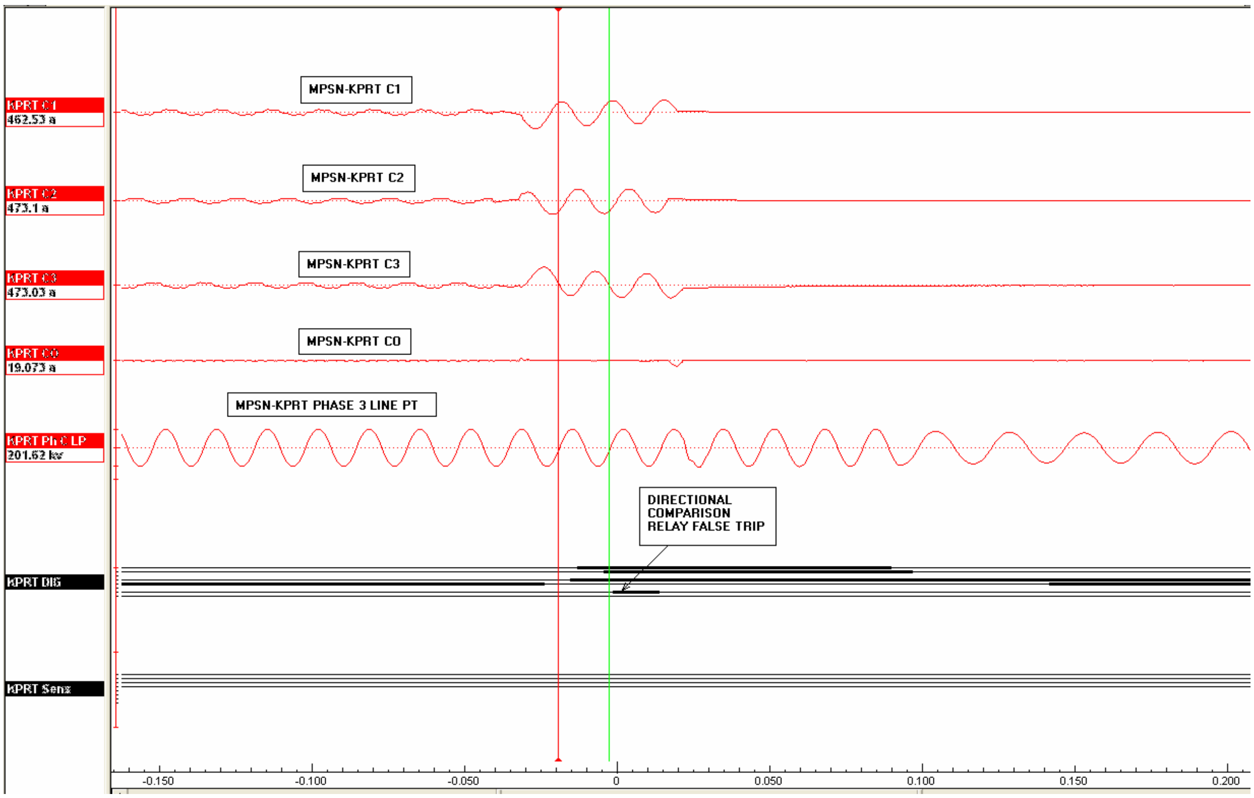

Figure 3 Midpoint DFR Record of False Trip

Reporting:

Idaho Power Company is a member of the Western Electricity Coordinating Council (WECC), one of the ten regional councils of NERC. Members are required to report misoperations that result in interruptions to major transmission path facilities. The responsible equipment must be repaired or removed from service within 22 hours of discovery of the misoperation. The faulty equipment must then be repaired or replaced (the equipment must be restored) within 20 business days or the line must be de-rated or taken out of service. We reported the incident, removed the directional comparison relays from service, and then began the investigation. The line remained in service, protected by primary #2 relay scheme.

INVESTIGATION AND ANALYSIS

The first step was to gather all the information to ensure the whole picture and all the facts were collected and considered. Relay records, digital fault recorder records, sequential events records, historical data, and dispatch records provided information for analysis. Idaho Power's fault and disturbance analysis is the responsibility of the System Protection and Communications department. Relay technicians and engineering personnel work together to review and analyze every protection operation. An engineer or specialist from the engineering team is assigned, on a rotating basis, to serve as the system operations analyst. This person reviews and analyzes transmission operations across the system, while the technicians review operations in their geographical regions only. This way, at least two sets of eyes look at each operation. Data is collected regionally and at our corporate headquarters, where the engineering team resides. Analysts check for proper breaker operation, clearing times, proper reclosing, relay targeting, proper operation of communications systems, and proper operation of monitoring systems. We keep a historical record of all operations.

Figure 4 shows the configuration of the 345 KV bus and breakers at Midpoint and Kinport substations. The Midpoint-Kinport line is controlled by breakers 301A and 302A at Midpoint and by 306A and 303A at Kinport.

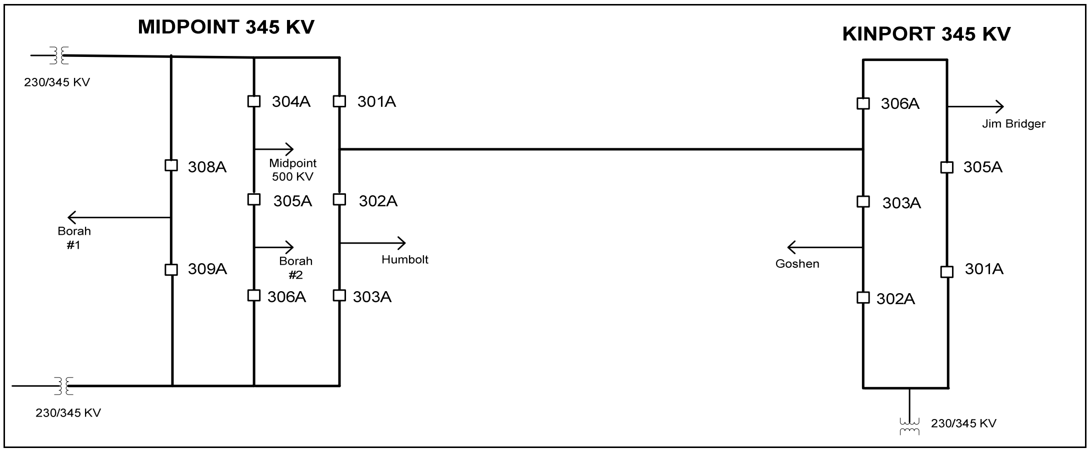

Figure 4 Midpoint (MPSN) and Kinport (KPRT) Single Line Diagram

Table 1 Sequence of Events

DATE	TIME	EVENT	NOTES
8-2-05	17:17:06.572	KPRT-MPSN DIR COMP RELAY TRANSMIT	Initial Phase B to Ground fault Inception
8-2-05	17:17:06.573	KPRT & MPSN DFR INITIATE	DFRs Triggered
8-2-05	17:17:06.573	MPSN-KPRT DIR COMP RELAY TRANSMIT	MPSN sends permission
8-2-05	17:17:06.580	KPRT-MPSN DIR COMP RELAY RECEIVE	KPRT receives permission
8-2-05	17:17:06.580	KPRT-MPSN DIR COMP RELAY TRIP	KPRT relay trip
8-2-05	17:17:06.582	MPSN-KPRT DIR COMP RELAY RECEIVE	MPSN receives permission
8-2-05	17:17:06.589	MPSN-KPRT DIR COMP RELAY TRIP	MPSN relay trip for initial fault
8-2-05	17:17:06.610	KPRT-MPSN 303A & 306A PCB'S OPEN	KPRT clears
8-2-05	17:17:06.646	MPSN-KPRT 301A & 302A PCB'S OPEN	MPSN clears
8-2-05	17:18:06.779	MPSN 301A PCB CLOSE	MPSN recloses
8-2-05	17:18:11.636	KPRT 306A PCB CLOSE	KPRT recloses
8-2-05	17:18:11.678	MPSN-KPRT DIR COMP RELAY TRANSMIT	The MPSN directional comparison relay sends permission to KPRT following the reclose at KPRT.
8-2-05	17:18:11.683	KPRT-MPSN DIR COMP RELAY TRANSMIT	KPRT sends to MPSN
8-2-05	17:18:11.690	KPRT-MPSN DIR COMP RELAY RECEIVE	
8-2-05	17:18:11.693	MPSN-KPRT DIR COMP RELAY RECEIVE	
8-2-05	17:18:11.695	MPSN-KPRT DIR COMP RELAY TRIP	MPSN-KPRT directional comparison relay false trip
8-2-05	17:18:11.705	MPSN DFR INITIATE	MPSN DFR triggers for misoperation
8-2-05	17:18:11.751	MPSN 301A PCB OPEN	MPSN opens due to false relay trip
8-2-05	17:18:11.780	KPRT 306A PCB OPEN	KPRT opens via open breaker transfer trip from MPSN

As can be seen from the sequence of events (Table 1), shortly after the Kinport end reclosed, the Midpoint directional comparison relay interpreted the load quantities as a fault condition and transmitted a permissive signal to Kinport. Kinport then sent permission to Midpoint, allowing the Midpoint relay to trip. The Kinport directional comparison relay did not trip. Kinport opened due to an open breaker transfer trip scheme. When the Midpoint breaker opened, the transfer trip was sent to Kinport to open Kinport 306A.

A check of historical records showed that this same type of misoperation occurred in 2001 but was never fully resolved. The problem occurs only when load currents on the Midpoint-Kinport line are higher than normal; the relay scheme has performed properly several times for normal load flows.

At this point, several glaring questions needed answered:

1. Why did the Midpoint directional comparison relay see the load condition as a fault and transmit permission shortly after the Kinport 306A reclose?
2. Why did the Kinport relay send permission back to Midpoint, allowing the Midpoint relay to trip?
3. Why didn't the Kinport directional comparison relay also trip?

Question 1: The Midpoint Directional Comparison Relay Trip

The directional comparison relay algorithm for determining direction is based on a quantity called the Directional Operating Signal (D_{op}), which utilizes superimposed voltage and current quantities. Superimposed voltages and currents are derived as a delta value of the present voltage and current versus the value one cycle earlier. A counter increments three counts for calculations which result in a forward declaration, and decrements three counts for reverse calculation results. When the counter reaches nine, forward operation is declared. DFR and relay records of the misoperation event at Midpoint were used to evaluate whether the Midpoint relay should have declared a forward direction. A spreadsheet was developed to check the (D_{op}) utilizing current and voltage values obtained from the primary #2 relay, which samples at 16 samples per second. The spreadsheet calculates the superimposed voltage and current values by comparing the fault value of current versus the value taken one cycle earlier (pre-fault), and the fault value of voltage versus the pre-fault voltage. For the voltage quantity, the relay algorithm (and thus the spreadsheet) accounts for fault angle by shifting the faulted voltage four samples in advance. This essentially puts the voltage and current in phase. As can be seen from Figure 5, forward direction was declared several times in succession during the time that Kinport closed and the Midpoint relay was seeing a transition from charging current to high flows into the Midpoint bus. In other words, the relay operated properly for the current and voltage values present during the Kinport re-close, based on the relay algorithm. Ideally, the relay should not have seen the quantities as a fault condition.

We reviewed relay settings and concluded that the settings were correct, and had been based upon sound EMTP (electro-magnetic transient program) studies. Decreasing relay sensitivity by increasing settings may result in failure to detect a remote end fault. The relay saw the condition as a fault during the transition from line charging to line loading conditions. This occurs during abnormally high load conditions and, since it is the nature of the relay at the settings applied, is not easily corrected.

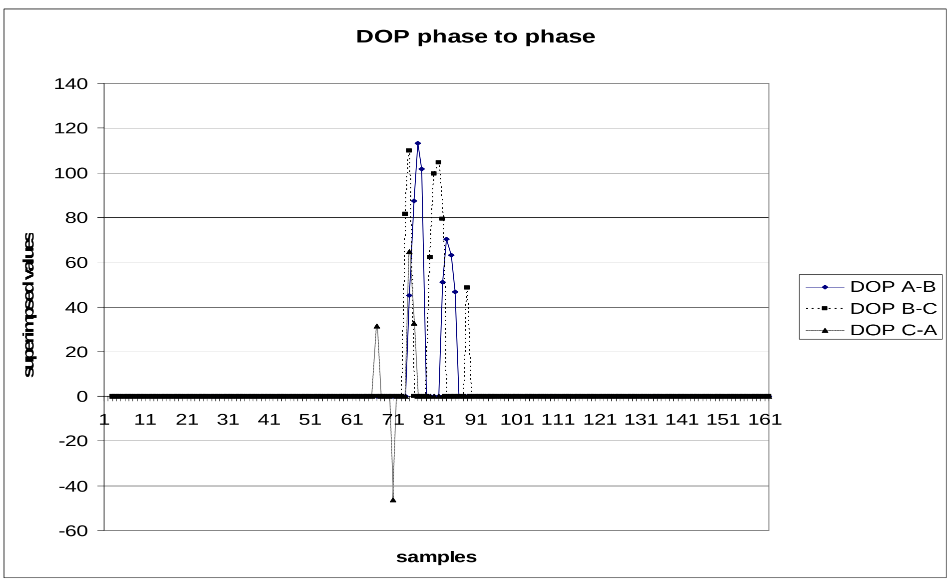

Figure 5 Directional Algorithm Analysis Chart

Question 2: Kinport Sends Permission to Midpoint

Since there were no fault quantities present at the time of the misoperation, and the Kinport directional comparison relay did not trip, information at Kinport was scarce. The primary #2 relay did not trigger and the DFR did not trigger. According to the SER, the Kinport relay did send permission to Midpoint, even though it appears that it did not interpret the quantities as a fault and did not target or trigger. The relay does employ a breaker open echo feature, intended to facilitate high-speed protection in the event one end of a line is open and the other end is closed. If a fault occurs on the open-ended line, the directional comparison relay at the closed end sends permission to the relay at the open end. The relay at the open end sends permission back to the detecting relay, allowing a high-speed trip. Breaker status is required, and is wired to the digital input of the relay. The relay echo back logic prevents repeating the permissive signal back to the sending end if the receiving end breaker is closed. At Kinport, breaker status indication is done by utilizing two breaker ‘B’ contacts connected in series. Breaker closed status is declared when either ‘B’ contact opens. Examination of the contact arrangement revealed that the 52B contact from 306A was actually a normally open contact from an auxiliary 52BX relay. This arrangement would result in a delay caused by the time it takes the auxiliary contact to open. The relay would not receive timely breaker status indication. Figure 6 shows the 52B portion of the relay and breaker control circuit.

At this point we established the following theory: when the Kinport breaker 306A re-closed, the Kinport directional comparison relay echoed the permission back to Midpoint due to its 52B contact from 306A still showing closed (indicating the breaker was still open—even though it was actually closed).

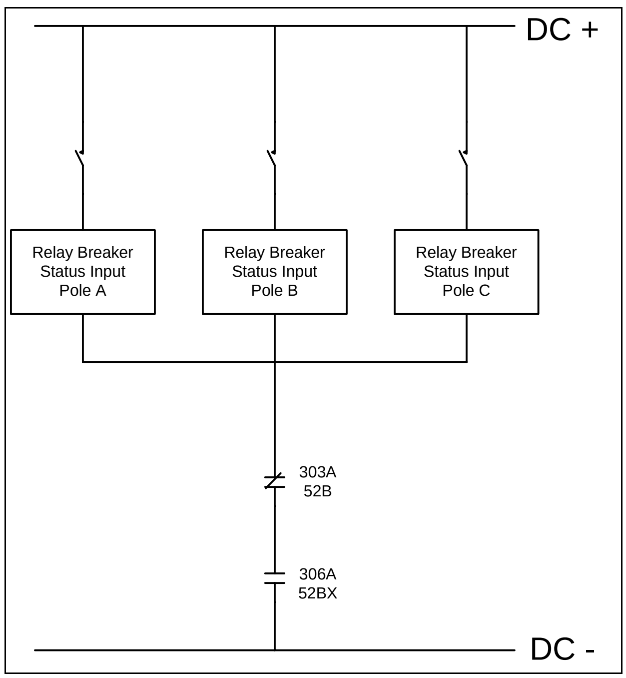

Figure 6 Kinport 52B Breaker Status Indication

Question 3: No Relay Trip at Kinport

Since the directional comparison relay at Kinport did not see a fault, it did not trip. It merely echoed back the permission to Midpoint to allow it to trip.

CORRECTIVE ACTION

The decision was made to replace the existing 52BX relay with a direct ‘B’ contact from breaker 306A. We were able to locate an unused ‘B’ contact for this purpose. We decided to wait to replace the contact until testing took place, to enable obtaining “As Found” and “As Left” test results.

TESTING AND VERIFICATION

At Idaho Power Company, we perform end-to-end testing when commissioning new pilot schemes or troubleshooting existing pilot schemes. End-to-end testing allows simultaneous injection of current and voltage quantities into the relays at both ends of a transmission line, to facilitate testing the entire scheme, including communications equipment and breakers. With the modern relay test equipment, the user can play back captured event records into a relay. The Midpoint DFR record was used to create the playback file. The native DFR record format was converted to COMTRADE format, then edited to eliminate unwanted analog and digital channels, since we only needed three voltages and three currents at the Midpoint terminal. The original DFR recording contained 32 analog channels and 56 digital channels.

The COMTRADE records we used are comprised of two files: the configuration file (.cfg), and the data file (.dat). The configuration file contains pertinent information about the recording device, such as the station name, recording device ID, number and type of channels, analog channel information, digital channel information, sampling rate information, and date/time stamps. We edited this file in Microsoft Notepad, changing the number of channels to 9 total (six analog and three digital channels). All unwanted channel information was deleted. The data file contains the actual data values. The format for this file is as follows: the first column contains the sample number. The second column is the time stamp for the data. The 3rd through 8th columns contain the data value for analog channels (C1, C2, C3, VA, VB, VC), and the 9th through 11th columns contain digital channel values (0 or 1). To edit the data file, we first opened the .dat file as a text file. This file was then imported into Microsoft Excel as a comma delimited file where it could be easily manipulated to delete unwanted columns of data. Next the file was saved as a .dat file simply by changing the extension from .csv (comma delimited) to .dat. The relay test equipment software requires .dat files for playback. Figure 7 shows the Midpoint configuration file and figure 8 shows a very small portion of the data file ready for playback.

```
MPSN DFR #2 (345KV),571,1999
87,32A,56D
1,KPRT C1,A,0,a,1.3084683839,0.0000000000,0,-32767,+32767,1,1,P
2,KPRT C2,B,0,a,1.3084683839,0.0000000000,0,-32767,+32767,1,1,P
3,KPRT C3,C,0,a,1.3084683839,0.0000000000,0,-32767,+32767,1,1,P
4,345 KV Pot Ph A,A,0,kv,0.0142492133,0.0000000000,0,-32767,+32767,1,1,P
5,345 KV Pot Ph B,B,0,kv,0.0142492133,0.0000000000,0,-32767,+32767,1,1,P
6,345 KV Pot Ph C,C,0,kv,0.0142492133,0.0000000000,0,-32767,+32767,1,1,P
7,Digital 1,,,0
8,Digital 2,,,0
9,Digital 3,,,0
60
1
6000.000,6136
02/08/2005,17:18:11.185000
02/08/2005,17:18:11.685000
ASCII
```

Figure 7 Midpoint COMTRADE Configuration File

```
1,0,0,-112,80,-19360,4928,13840,0,0,0
2,167,0,-112,64,-19040,3664,14784,0,0,0
3,333,0,-96,64,-18672,2400,15712,0,0,0
4,500,16,-96,48,-18240,1184,16576,0,0,0
5,667,32,-96,32,-17744,0,17376,0,0,0
6,833,32,-96,16,-17168,-1152,18080,0,0,0
7,1000,48,-96,0,-16528,-2256,18672,0,0,0
8,1167,64,-96,-16,-15824,-3344,19216,0,0,0
9,1333,80,-96,-16,-14992,-4384,19616,0,0,0
10,1500,80,-96,-32,-14080,-5472,19920,0,0,0
11,1667,96,-96,-48,-13056,-6592,20128,0,0,0
12,1833,96,-96,-48,-11968,-7744,20224,0,0,0
```

Figure 8 Small Portion of Midpoint COMTRADE Data File

Because there were no DFR or relay triggers for the Kinport end, we had to create the Kinport COMTRADE record from scratch. The configuration file from Midpoint was re-used since the number of analog and digital channels did not change. Channel names were changed as appropriate. To create the data file for the Kinport end, we simply copied the Midpoint COMTRADE data file, and modified the file such that the current values were set to 0 until the Kinport breaker closed. The mathematical signs of the analog values for the current channels were then reversed from those of the Midpoint file, as current flow at Kinport would be in the opposite direction of Midpoint when Kinport closed. A digital channel was utilized to send the breaker close signal to 306A. The relay test equipment software enables the use of a digital contact to close a logic output contact on the test equipment. This contact was connected to the 306A control close bus. This closing of 306A had to coincide exactly with the current values at Midpoint changing from charging current to load current. It was therefore necessary to know the breaker close time of 306A. Breaker close time was obtained from the Apparatus department, then later verified by test. The assigned digital channel was edited to a digital 1 in the data file at the appropriate sample to allow closing the breaker at the proper instant in time. The other two digital channels were retained for use if needed.

Now that we had COMTRADE records for both ends, we were ready for field testing of the scheme. At Midpoint, breaker simulators were used in place of the actual breakers. It was desired to leave the Midpoint-Kinport line in service throughout the testing. At Kinport, we needed to use the actual breaker 52B contact, so no breaker simulators were used. Breaker 306A would be used for closing during the test. The test quantities at Midpoint and Kinport were applied to the directional comparison relays at both ends, and the directional comparison relays were isolated to trip the breaker simulators at Midpoint and only breaker 306A at Kinport.

Test 1: As Found Test

The first test was performed with the original 52BX contact still in place. We wanted to verify that we could duplicate the misoperation by reproducing all conditions that were present during the misoperation. Figures 9 and 10 show the test files from the test equipment software used for playback into the relays. These figures show the equivalent analog signals for the COMTRADE files that were recorded from the DFR at Midpoint for the Midpoint terminal or created from scratch for the Kinport terminal. The currents and voltages were injected into the relays at both ends simultaneously using end-to-end testing technology; then the results were analyzed.

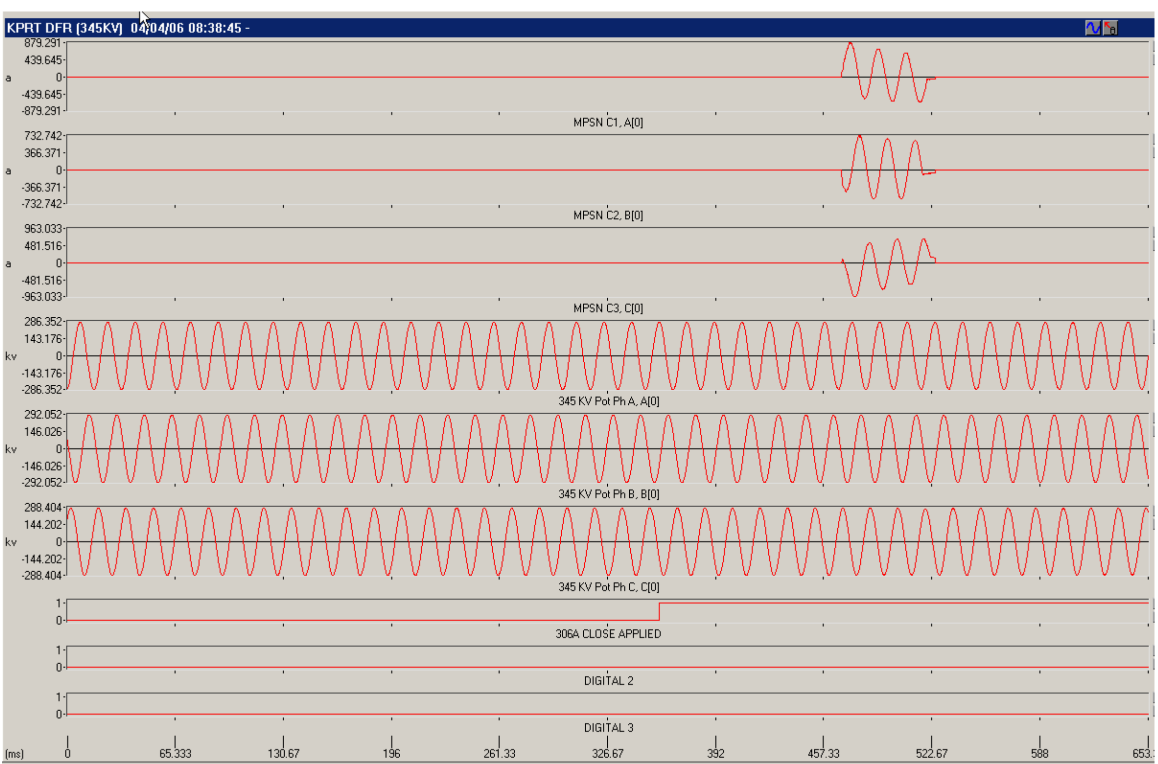

Figure 9 Kinport Playback Record

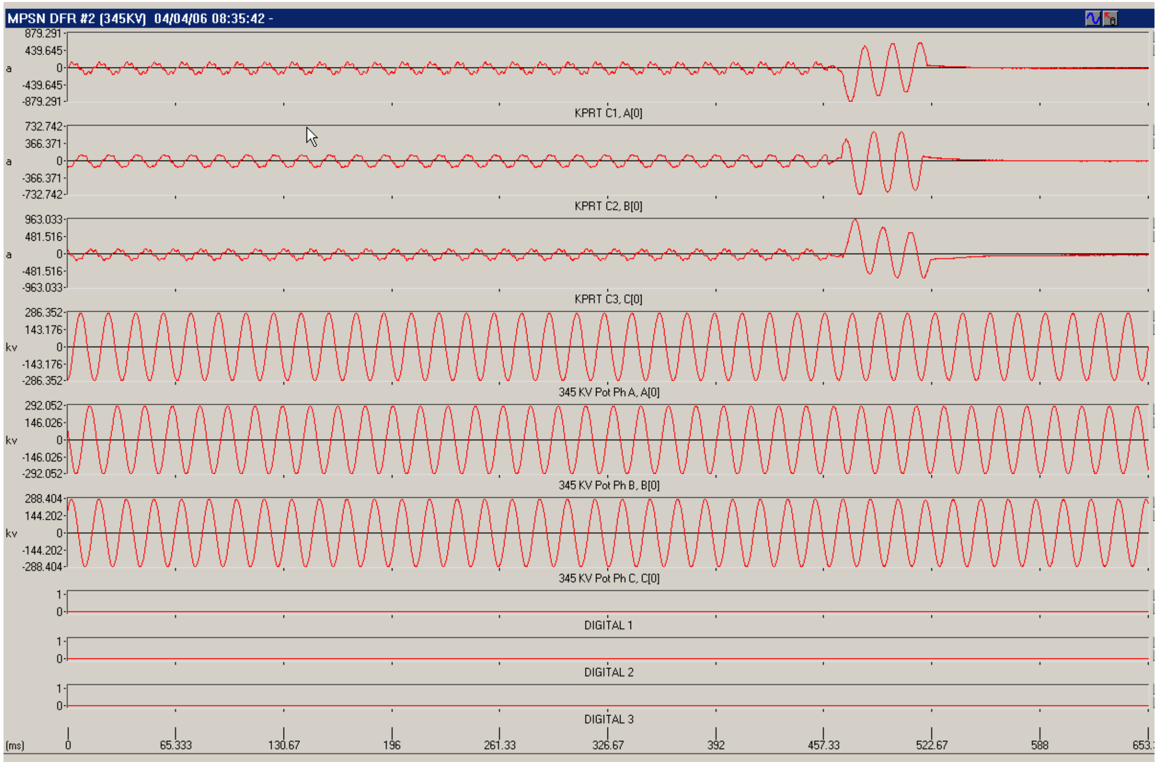

Figure 10 Midpoint Playback Record

The result of the As-Found end-to-end test was that Midpoint false tripped just as it had during the actual operation. The permission signal was sent from Midpoint and echoed back from Kinport to Midpoint resulting in a trip. We were able to successfully reproduce the misoperation. Timing tests on the 52BX contact showed the true nature of its delay. The 52BX contacts opened 36 ms after the breaker opened.

Test 2: As-Left Test

The 52BX auxiliary breaker contact was replaced with an actual high-speed 52B contact from the breaker 306A. The end-to-end test was repeated. The result: no false tripping at Midpoint. The Midpoint directional comparison relay sent permission to Kinport as before, but the Kinport 306A 52B contact opened much more quickly. By the time the permissive signal was received at Kinport, the 52B contact at Kinport was already open, indicating the breaker was closed. The directional comparison relay echo back logic prevented the permissive signal from being sent back to Midpoint. This test was repeated several times to ensure no misoperation would take place. The scheme operated properly with no misoperations. The direct 52B contact opened at the same time as the breaker main contacts (no delay).

We now felt confident that replacing the slow 52B contact at Kinport would prevent further misoperations. We had been able to duplicate the misoperation, make corrections as needed, and repeat the test to ensure the corrective action worked. The directional comparison relay scheme was returned to service.

Reporting:

Idaho Power Company contacted the WECC personnel via e-mail and let them know the date and time the directional comparison scheme was returned to service, as well as the circumstances that led to our decision to do so. We received correspondence back from the WECC stating that we had completed the process in compliance with WECC rules.

SUMMARY

Resolving protection misoperations can be a difficult, time consuming process. Event information must be gathered and analyzed to try to determine the cause. Sometimes a team of individuals brainstorm to look for clues and try to put the puzzle pieces together. Occasionally the problem is obvious, but often it is a subtle, less-suspicious thing, like a slow 52B contact.

Utilities are under the scrutiny of not only our customers but also regional and national energy councils. Reporting requirements must be met in order to avoid penalties. We are fortunate to have at our disposal some powerful tools that aid in the identification and verification of system operational problems. Digital fault recorders, sequential event recorders, microprocessor relays, SCADA systems, and other recording devices provide valuable information. Test equipment allows re-creation of events by playing back recorded quantities. Still, system protection personnel must be able to effectively analyze event records and protection scheme control schematics in order to form ideas and theories as to what may have happened. Tests can then be performed for verification. It is a rewarding experience when such theories can be put to the test, the problem identified and corrected, and the fix positively verified. These successes help reduce the sting of the instances where the mystery goes unsolved.

Author Biography:

Cliff Harris received his Associates Degree in Electronics Technology from Idaho State University in 1975. He joined Idaho Power Company in 1978 and has held numerous positions including Lineman, Relay Technician, and Metering Engineering Specialist. In 1992 he accepted a position as a System Protection Specialist in the System Protection Engineering Department, where he has worked since then. His duties include analysis of power system disturbances and operations, training coordination, management of monitoring systems, relay setting and coordination, and relay maintenance coordination. Cliff currently serves as the chairman of the Hands-On Relay School steering committee.