TROUBLE WITH DC

USING A DIGITAL BFR FOR POINT ON WAVE CLOSING OF SHUNT REACTORS

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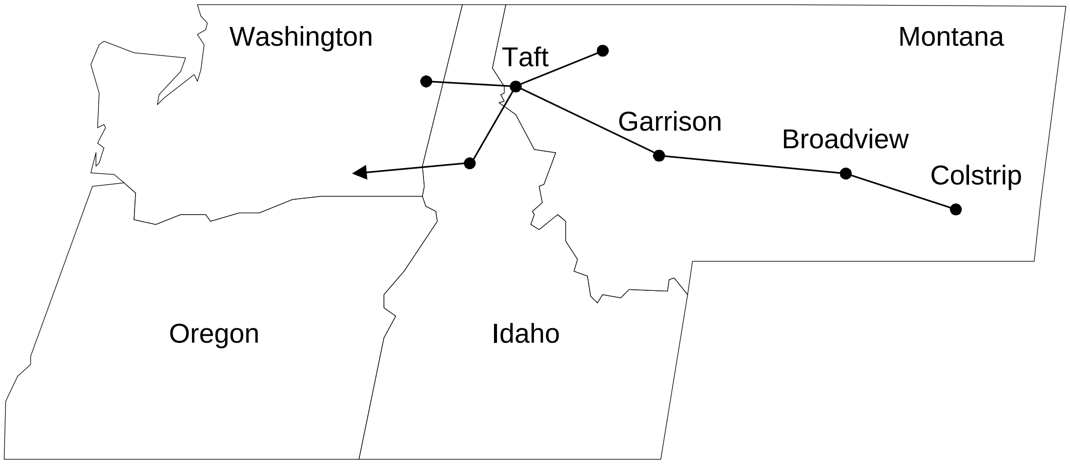
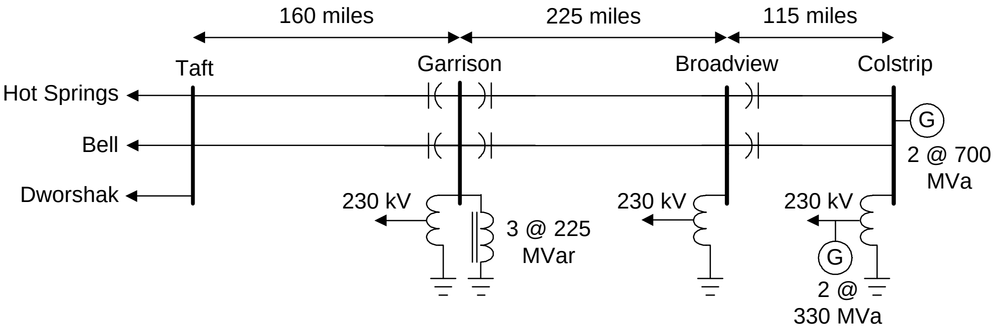
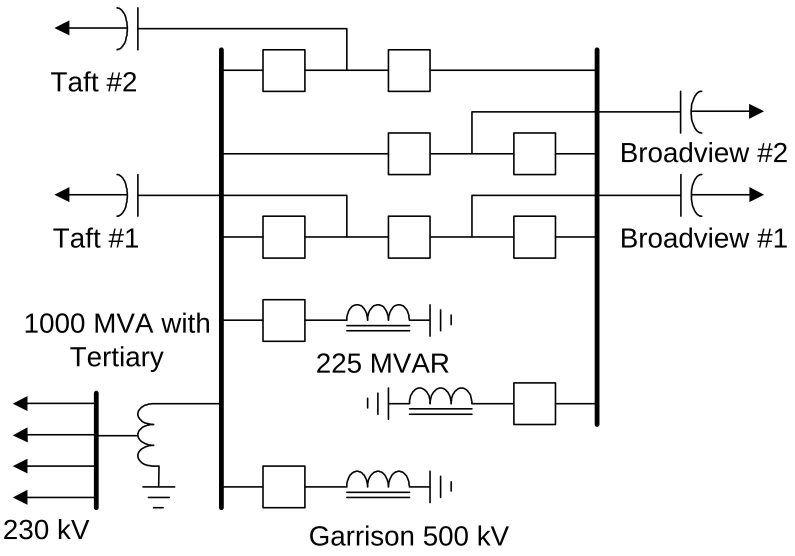
Introduction:

Bonneville Power Administration's (BPA) Garrison substation is located in west central Montana. This substation is an integral part of the 500 kV Colstrip corridor transmission system which integrates the output of the Colstrip generating station into the Pacific Northwest. Garrison substation has four 500 kV transmission lines. Two lines to the east of Garrison connect to NorthWestern Energy's (Montana Power) Broadview and Colstrip substations. Two lines to the west connect to BPA's Taft substation on the Idaho Montana border. All four 500 kV lines are series compensated and have single pole tripping. The following drawings show the geographic location of the system and the line configuration between Colstrip and Taft substations.





Garrison substation also has a 500 kV/230 kV auto transformer and four 230 kV lines that connect to other BPA and NorthWestern Energy substations. The Garrison 500 kV bus has three 225 MVar shunt reactors which created the problem and solution described in this paper. The following drawing shows the bus configuration at Garrison. The reactor breakers are SF6 live tank breakers. The line breakers are live tank air blast. The series capacitors provide 35% compensation. The auto transformer has a 34.5 kV tertiary which is not shown in the drawing. Two additional shunt reactors at Garrison are connected to the Broadview lines. These reactors include a fourth air core neutral reactor and are used to extinguish the secondary arc following a single pole trip. They are not switched. Secondary arc extinction on the Garrison Taft lines is accomplished with high speed ground switches at Garrison and Taft.



Because of the long lines with the large generation source at the eastern terminus, several special protection or remedial action schemes (RAS) are required on this corridor to achieve optimum transfer levels. Indications of open 500 kV transmission lines from Colstrip to Washington state are sent to redundant RAS controllers at Garrison substation. Depending upon line loadings, generation levels, and type of the line outage or outages, different remedial actions are initiated by the RAS controllers. Nearly any line outage results in the opening of at least two of the three shunt reactors at Garrison. The reactors are opened to provide high speed voltage support in the region. Other conditions can result in RAS tripping of Colstrip generation, forced separation at the Miles City DC converter station in eastern Montana, and forced tripping of other generation in northwest Montana.

The Problem:

The Garrison shunt reactors are connected to the 500 kV bus with SF6 circuit breakers. When the reactor is closed, a high DC offset current is often generated from saturation in the reactor energization current. The series capacitors block the DC component of the reactor current and force it to flow entirely through the transformer bank. This DC current sends the auto transformer into saturation, resulting in significant harmonic currents on the power system near Garrison. Several false operations of ground overcurrent relays on the 230 kV system resulted when the Garrison reactors were closed following a RAS initiated opening.

The necessity for controlled reactor energization near series capacitors was first recognized at Grizzly Substation in 1992, just prior to the 3rd AC Intertie development. At the time, all lines leaving Grizzly had series compensation except the Round Butte line. Reactor energization with a new SF6 breaker forced DC current through the transformer at Round Butte, resulting in the trip of a nearby generator at Pelton Dam.

This problem started in the early 1990s when BPA began using SF6 breakers for reactors instead of circuit switchers. The circuit switchers would energize the reactor by closing blades in air, a slow mechanism that would consistently energize near a voltage peak. An SF6 breaker however, has a fast contact mechanism that can energize nearly anywhere on the voltage waveform. In the worst case, reactor energization at a voltage zero (the preferred point for capacitor energization) creates a fully offset current waveform. The large DC component may take a full second to decay because of the low resistance of reactors. The large offset also means an offset flux in the reactor core, resulting in some saturation current and system harmonics. Reactor saturation is much milder and produces far fewer harmonics than transformer saturation.

Removing the capacitors was not an option at Garrison, nor was resetting the overcurrent ground relays. Resetting ground overcurrent relays was considered a band aid approach and conceivably would have to be done through out western Montana. BPA needed to fix the source of the problem, the reactor switching.

The Solution for Garrison:

The ideal solution was addition of point on wave (POW) closing to each of the Garrison reactors breakers. Point on wave closing can be used to optimize the closing of each pole of the circuit breaker, minimizing the reactor inrush current. Many circuit breaker manufactures offer POW closing options. Beginning in the early 1970s, BPA has experimented with vendor supplied POW devices and in-house built devices. BPA's experience with these older devices was not good. Newer technology has greatly improved the performance of recent POW devices. Unfortunately, the manufacturer of the reactor circuit breakers at Garrison did not offer a POW retrofit.

A new digital breaker failure relay (BFR) was available that offered many additional features, including POW closing. This BFR was installed at Garrison. By closing at a pre-selected point on the voltage waveform, power system transients can be minimized. The BFR POW logic has two sets of timers. One timer set is for closing relative to a voltage peak. The other timer set is for closing relative to a voltage zero crossing.

The POW timers are pre-set based on the breaker operate time. The BFR uses the timer settings to close its output contacts. Three output contacts, connected to the A, B, and C phase breaker close coils, are used for closing control. For this application a specific input/output board is required for the BFR. With this input/output board the BFR has a closing specification of +/-200 μs. After the close coils are energized, the breaker closes. With the timers set properly, the breaker will energize the reactors at the voltage peak.

The POW scheme at Garrison was modified to compensate for ambient temperatures. When ambient temperatures are at extremes, breaker close times change. For POW applications, the timers must automatically be adjusted to accommodate the different breaker close times across the temperature ranges. A communication interface (com interface) is used to read the ambient temperature from a digital temperature transducer (transducer) and change the BFR settings. The com interface also connects to a local data logger, provides an interconnection for remote interrogation, and serves as a local user maintenance interface.

Ambient temperatures at Garrison have gone below –40 degrees C, changing breaker-operate times enough to make POW closing ineffective without automated adjustments. Based on breaker operate times for SF6 breakers at different temperatures, BPA needed four different timer sets to control the breaker across four temperature ranges.

The BFR has three separate setting groups. Two timer-sets are available for a given setting group. Multiple setting groups multiply the availability of timers. BPA uses two setting groups, and both BFR timer-sets per group, to close at a voltage peak. Since one set is designed for zero crossing closing control and the other is for peak closing control, the timer values are different by ~4 ms.

Closing is initiated either by a manual close initiation or by the automatic voltage control scheme. The manual close initiation is through a physical input asserted by SCADA or local control switch. The automatic voltage control scheme senses voltage conditions, and opens or closes the breaker accordingly to remove or insert the reactor bank at Garrison. The feature replaced the existing automatic voltage control scheme.

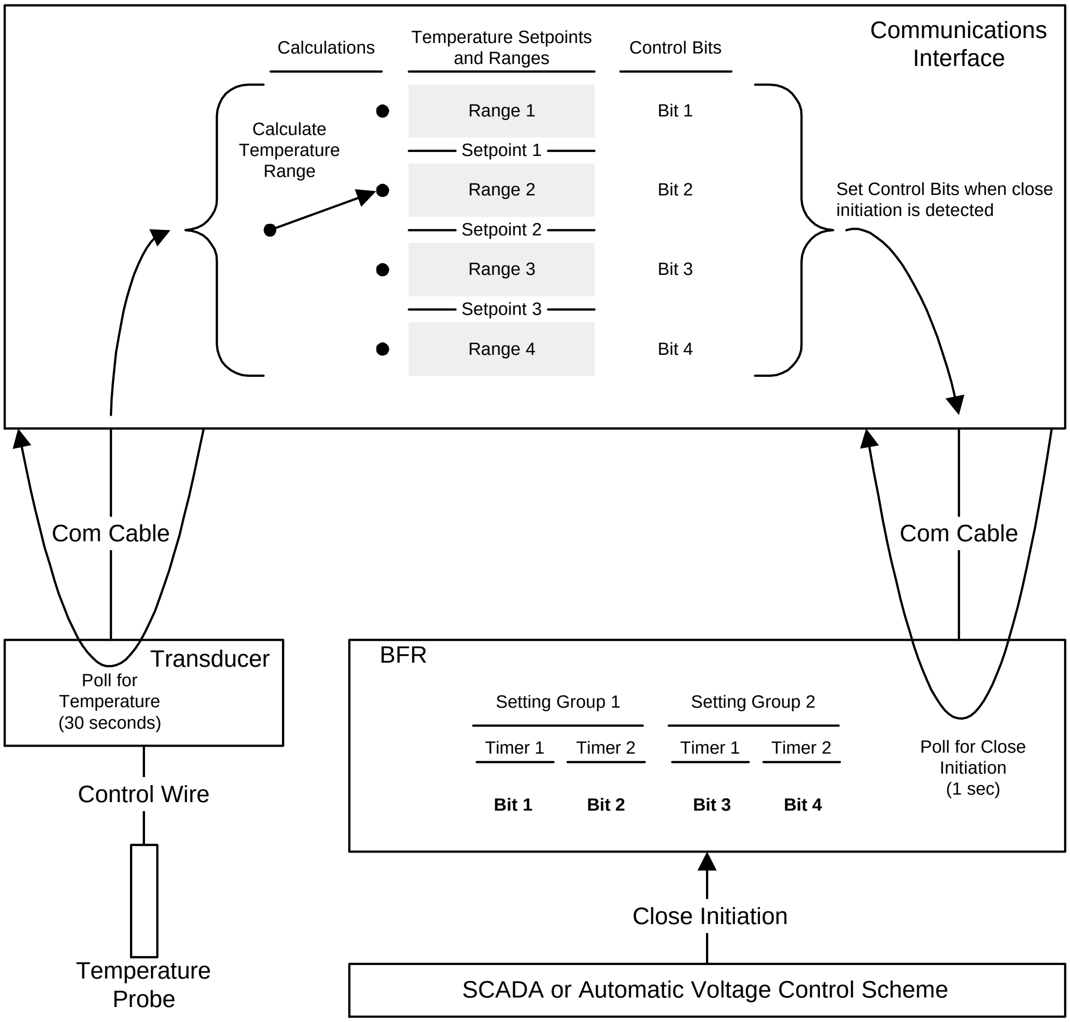
The com interface polls the temperature transducer every 30 seconds for the temperature data and polls the BFR every second for a close signal. When the com interface detects the close bit, it sets the appropriate control bits in the BFR. The appropriate control bits are determined based on logic equations and mathematical calculations that compare the actual temperature to the pre-set setpoints in the com interface. When closing is initiated, the BFR waits for the timers to be selected by the com interface and then closes output contacts using the selected timers.

The transducer is a resistive thermal device (RTD) that communicates serially. ASCII commands are transmitted to the transducer and an ASCII response is received. This data is parsed by the com interface to determine the ambient temperature.

At Garrison the four temperature ranges are separated by three setpoints. The transducer temperature is subtracted from each setpoint and the result is stored. The result is a positive number if the temperature is lower than the setpoint. The result is a negative number if the temperature is higher than the setpoint. The sign (positive or negative) of the stored result is used to select the proper temperature range.

The control bits are sent to the BFR based on the temperature range. Within the BFR, the control bits determine which setting group the BFR uses and which timer the BFR uses.

The following block diagram shows the overall scheme and the automated temperature adjustment.



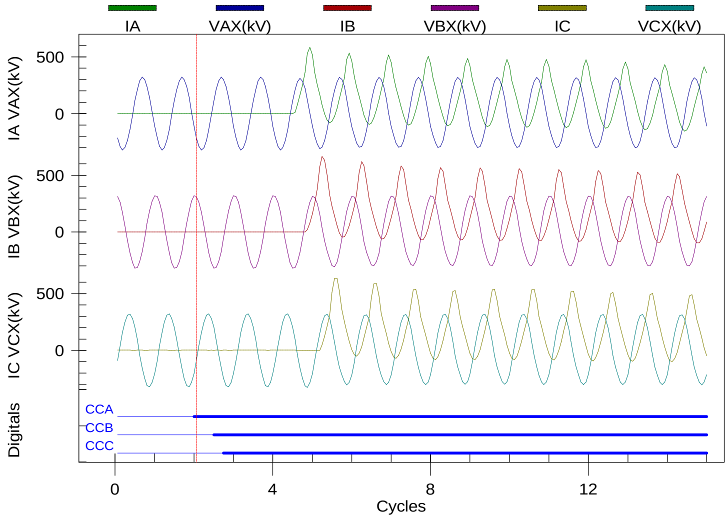
Several features of the com interface, BFR, and transducer were used to enhance the testing process and operation reports.

In order to record certain operation data after each close operation, the com interface retrieves data from the BFR and stores it in its database. When a close operation occurs the BFR generates an automatic event summary that is transmitted out its serial port to the com interface. The com interface then retrieves a breaker summary report from the BFR. This report is saved and the com interface then asks for the timer settings. These timer settings are saved and the breaker summary report is printed on a connected printer.

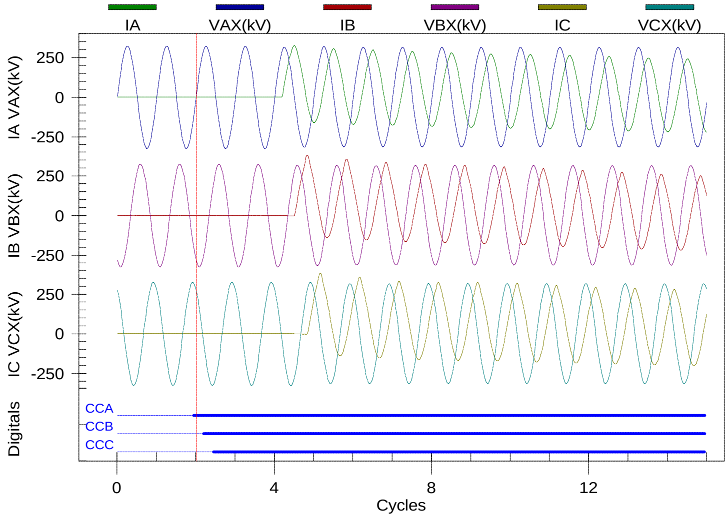
In order to retrieve data manually and make testing easier, the several commands were programmed into the com interface:

1. Display the temperature value (including any offset) that the com interface has stored in memory. The offset is for testing purposes.
2. Display the temperature value (without any offset) that the transducer is presently measuring. The offset is for testing purposes.
3. Display the active timer values that the BFR used for its most recent close operation.
4. Two user-programmed commands set a temporary temperature offset and display the temporary temperature.
5. Display the temperature setpoints that the com interface uses to determine the appropriate temperature range.

The following waveform recordings were made during the initial setup of the BFR POW closing at Garrison. The first recording was before the BFR close timers were optimized. Current offset is very evident.



Following adjustments of the BFR close timers, there is negligible offset when the reactor is energized.



Conclusions:

The reactor switching problem at Garrison has been resolved with this POW addition. The reporting feature has been used to identify breaker problems that need attention. BPA is now applying POW closing on some 230 kV and all new 500 kV shunt capacitors and reactors and is retrofitting several existing 500 kV shunt reactors. The number of customer complaints caused by reactive switching has been reduced.

BPA is also applying POW closing devices supplied by breaker manufactures for 500 kV shunt capacitors. This device offers some additional features which are not included at Garrison. A self learning feature to adjust close times if the breaker operating speed changes is included. The self learning feature may lead to problems. Automatic time adjustments to compensate for changes in breaker close times may hide a circuit breaker problem that really needs maintenance attention. Also, when maintenance crews work on a breaker, the previous knowledge is often lost or compromised, which requires several operations for relearning.

Another feature available on the breaker supplied POW device adjusts close time as battery voltage changes. This may not be too important for new circuit breakers as their operating times are quite consistent down to a minimum battery voltage. It may be possible to add a battery voltage sensor input to the com interface to change close times in the BFR POW scheme.

Ambient temperature changes may be less critical for many of the SF6 breakers at BPA. SF6 tank heaters are often installed, especially where the ambient temperatures are most extreme. The tank heaters may eliminate or reduce the need for closing time changes. If not, the gas temperature should be measured, not the ambient temperature.

Transformer energization may also benefit by controlling the close times of the circuit breaker. Optimized energization of a power transformer includes controlled POW closing of the first breaker pole followed by simultaneous closing the two remaining phases.

Most of BPA’s 500 kV transmission lines use a staggered close scheme to reduce transients. The staggered close scheme includes zinc oxide arrestors at the remote terminal. The staggered close scheme sequentially closes each pole after a delay of approximately one cycle. This close scheme has occasionally caused problems with nearby ground overcurrent relays. BPA is now considering POW closing on the 500 kV transmission lines.

The digital BFR also provides a wide range of breaker monitoring capabilities. This includes monitoring and logging breaker operating times and breaker interrupting currents. This information is used to asses the maintenance requirements for the circuit breaker. BPA uses capacitive coupled voltage transformers (CCVT) on the 500 kV system. Over time, the CCVT capacitors tend to change value which can lead to CCVT failure and also affect metering and relaying. The BFR can track the voltage changes between the CCVTs and indicate when a CCVT needs attention.

The digital BFR even provides the "traditional" breaker failure function—detecting the failure of a breaker to open during a fault condition. The BFR can also detect non-traditional, non-fault breaker problems such as pole disagreement, external flashover, and failure to interrupt line charging current. This BFR includes logic to automatically isolate the troubled circuit breaker by opening motor operated disconnect switches on both sides of the breaker once the transmission line is deenergized. All of these features are programmed within the BFR using various voltage and current elements.

BPA is very satisfied with this BFR POW control scheme. The BFR has become our standard device for all new 500 kV construction as well as replacement for older 500 kV BFRs. The additional features available in the relay have proven to be quite beneficial.

Author Biographies:

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Larry received his B.S. degree in Electrical Engineering from Washington State University in 1992. He worked for Pacific Gas & Electric Company from 1992 until 1995 as a Transmission System Protection Engineer. Larry joined Schweitzer Engineering Laboratories, Inc. (SEL) in 1995 as an Application Engineer. He provided technical training and technical support for customers. Assigned to development teams, he wrote instruction manuals, directional element functional tests, and differential relay acceptance tests. In 1997, Larry started the engineering services department at SEL providing specialized project support to consultants and utilities.

In January of 2000, Larry founded Relay Application Innovation, Inc. to provide electric power system protection applications, analysis, and training. He has performed protection services for a relay manufacturer, utilities, design consultants, industrial plants, and construction companies. Larry has written several application guides and a technical paper about power system protection, monitoring, and control. He is author of a patent for protection against slow circuit breaker closures while synchronizing a generator. As a representative of SEL, he served on the Executive Board for the Advisory Council of the Electrical and Computer Science department of Washington State University. Larry is a registered Professional Engineer in several states and is a member of the IEEE Power Engineering Society.

Jon F. Daume

Jon received his B.S. degree in Electrical Engineering from Iowa State University in 1967. Since 1968, he has been employed as a System Protection Engineer at Bonneville Power Administration. Jon has worked as a field engineer in Eugene, Oregon and served as the System Protection District Engineer in Richland, WA. In 1979, he accepted a position as a staff engineer in the System Protection Maintenance Group for BPA in

Vancouver, WA. Jon is currently the Principal System Protection and Control Engineer at BPA. He is a member and past chair of the WECC Relay Work Group and a member of the Planning Committee for the Hands-On Relay School. Jon has presented numerous papers and training classes for conferences, schools, electrical utilities and utility organizations in the United States and Canada.

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