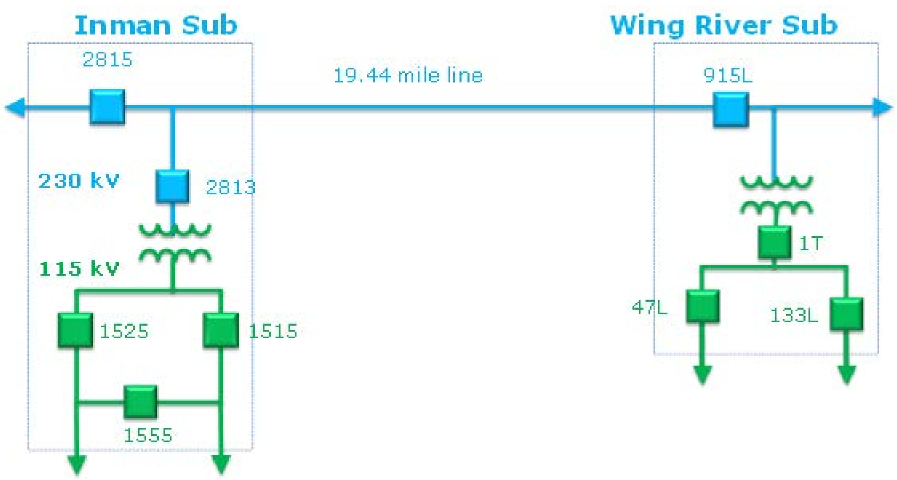
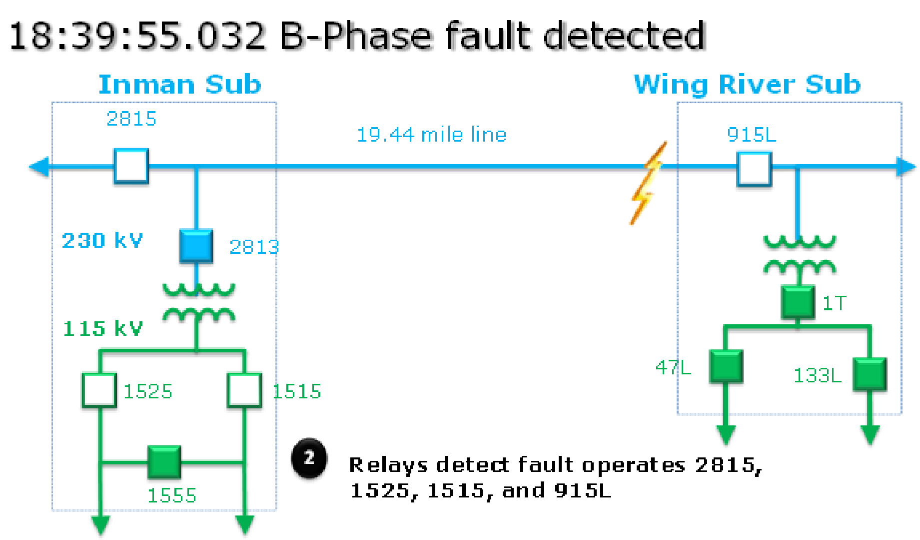
Anti-pump failure and a welded shut reclose contact is a Bad Combination

The 230 kV system shown in the figure below experienced a 230 kV permanent fault and excessive trip/closing over the next two hours on July 12, 2015. The Inman 230/115 kV substation is operated by one company, while the Wing River 230/115 kV Substation is operated by another, and the protection systems are owned and designed by a third utility.



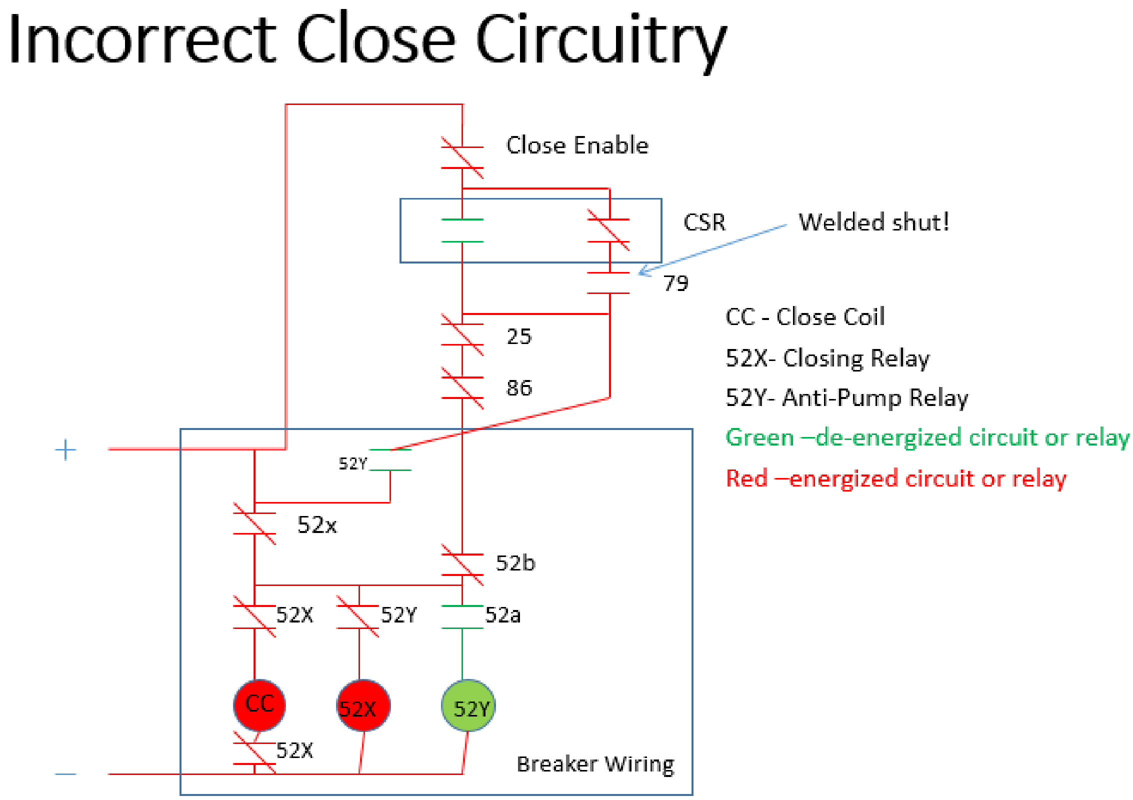
At 18:39:55.032, a momentary B-phase to ground occurred just 1.9 miles from Wing River Sustation. The protection systems at Inman for the Inman-Wing River 230 kV line (915 Line) correctly detected the B-Phase to ground fault and tripped Inman's 230 kV breaker 2815 and 115 kV breakers 1525 and 1515. While the protection systems at Wing River for the 915 Line correctly detected the B-Phase to ground fault and tripped Wing River's 230 kV breaker 915L.



The 230 kV breaker 915L at Wing River Substation reclosed prematurely within 0.6 seconds of tripping for the initial B-phase to ground fault. Luckily the B-phase to ground fault was temporary and was no longer present when breaker 915L reclosed. After further analysis, it was determined that 915L breaker close circuitry was wired incorrectly. The wiring error caused the output contact of the automatic reclose relay to weld shut and caused 915L to reclose prematurely.

Incorrect Close Circuitry Wiring

You can see in the figure below of how the anti-pump circuitry was wired incorrectly. The 52Y contact was incorrectly wired between the reclose contact (79) and the DC +. As you can see when the breaker opened the welded shut 79-contact energized the closing relay (52X), which then energized the Close Coil (CC). The close circuitry failed to keep the anti-pump relay (52Y) energized to prevent prevent the breaker from pumping while the 79-contact is energized.



The protection system at Inman correctly reclosed all the opened Inman breakers two seconds later (18:39:57).

230 kV Breaker Pumps into Permanent Fault

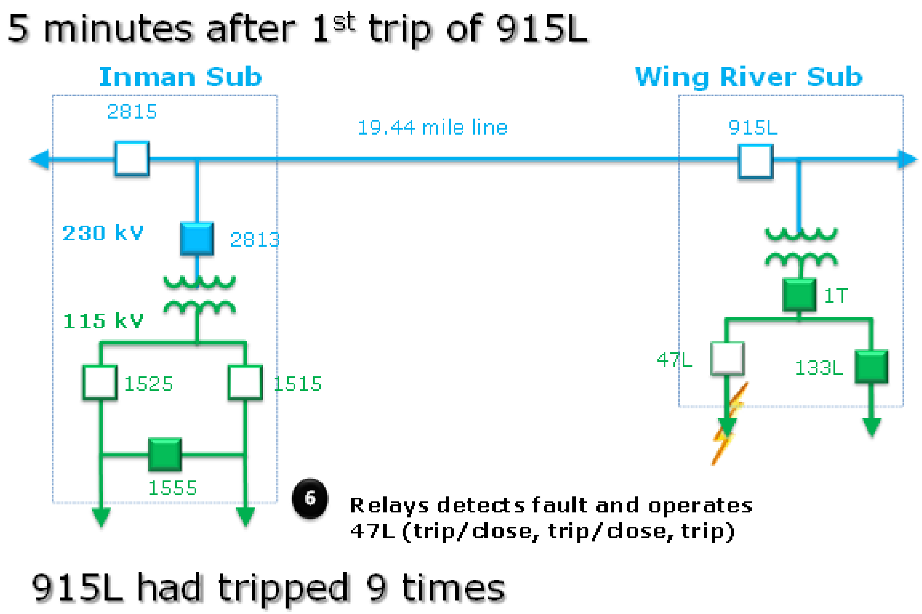
Nearly 2.5 seconds after the initial B-phase momentary fault, at 18:39:57.456 a second line-line-ground fault (A to B-Phase to ground) occurred just 2.43 miles from Wing River Sustation. The protection systems at Inman for the 915 Line correctly detected the A to B-Phase to ground fault and tripped Inman's 230 kV breaker 2815 and 115 kV breakers 1525 and 1515. Also, the protection systems at Wing River for the 915 Line correctly detected the A to B-Phase to ground fault and tripped Wing River's 230 kV breaker 915L.

Wing River 230 kV breaker 915L began to pump, closing into an evolving permanent fault. The remote end of the faulted line (Inman Substation) is connected to a protection system that has line connected potential transfomer (PT) and a line connected 230/115 kV autotransformer. At 18:39:58.595, 18:39:59.071, and 18:40:22.273 the Inman relays record event reports each time the Wing River breaker 915L closes into the fault even though Inman 230 kV breaker 2815 and 115 kV breakers 1525 and 1515 remained open. This was due to zero sequence fault current through Inman 230/115 kV transformer neutral when Wing River 230 kV breaker reclosed and tripped.

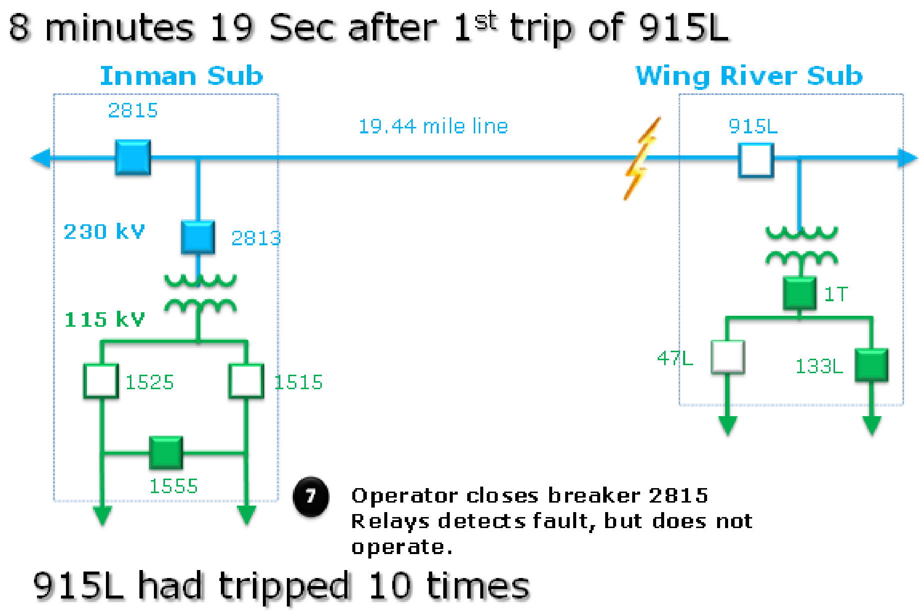
Relay Misoperation at Remote End

Wing River breaker 915L continues to close into the permanent fault approximately once every 1 minute and 45 seconds. This was long enough for the breaker to build up enough energy to close and trip. Each time breaker 915L closes, the relays at Wing River opperate correctly and trip the breaker within three cycles.

After 915L had tripped for the 8th and 9th time, Wing River 47L 115 kV Line relays detect and trip for an evolving fault on 47L. Wing River 115 kV breaker 47L correctly trips and closes three times before permantly opening due to reclose lock out.

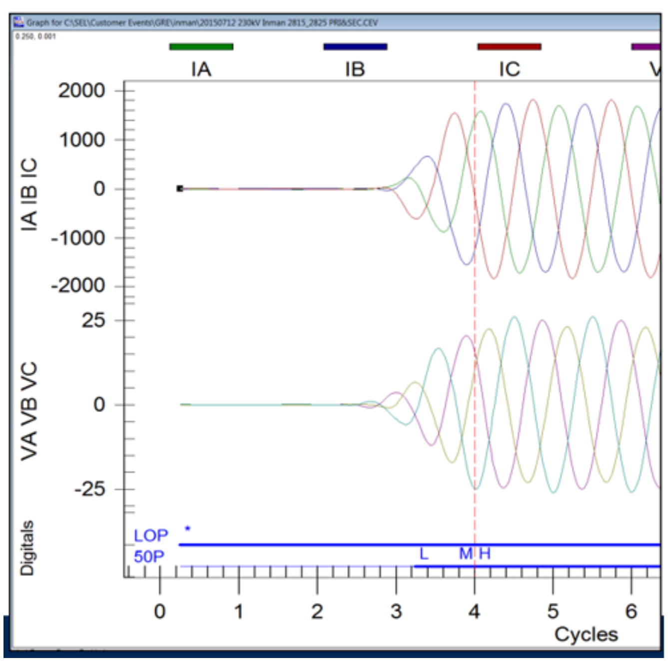


At 18:48:14 after 915L had tripped for the 10th time, the Inman Substation operator decides to close Inman 230 kV 2815 breaker, eight minutes and nineteen seconds after the initial event.



The Inman 230 kV system voltage was too low (approximately 25 kV Line to ground for each phase) to reset the Loss of Potential (LOP) element when breaker 2815 was placed in service. LOP due to the line connected potential transformers (PTs) and zero sequence fault currents blocked the distance elements. The phase over-current settings in the Inman primary relay switch-into-fault logic was incorrectly set at 2000 amps primary, while the in the Inman secondary relay it was set at 1600 Amps. Unfortunately the fault current was too low for the Primary relays to detect the fault. The phase over-current in the secondary relay picked up when closed into the fault, but it was incorrectly not programmed to trip.

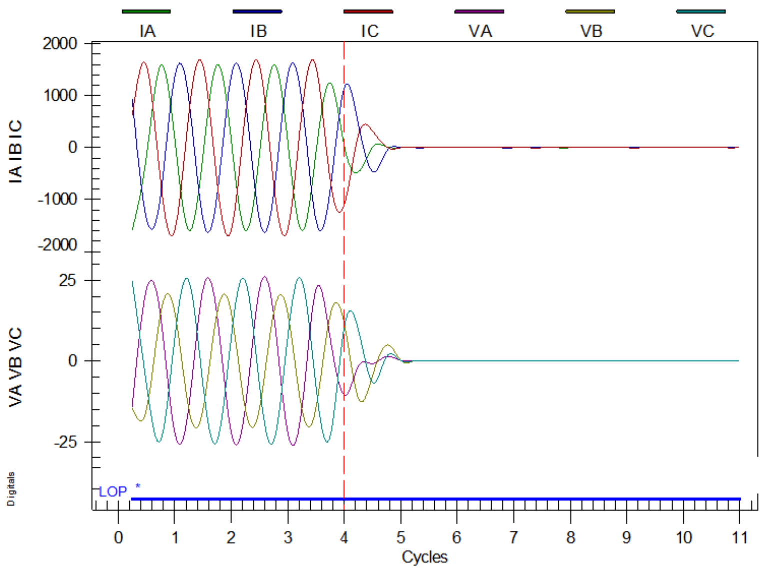
Inman Breaker 2815 Closed



- LOP blocked the distance elements (correctly per relay design). in this event as well, the voltages were not high enough to reset the LOP.
- The fault current just happened to fall between the two relays pickup and was around 1800 amps.
- 50H used in the 321 switch-into-fault logic was set to 2000 amps primary
- While the 50H in the 221G was set to 1600 amps primary. The 50H in the 221G picked up a during the fault at 18:48:14.937, but it is not programmed to trip.

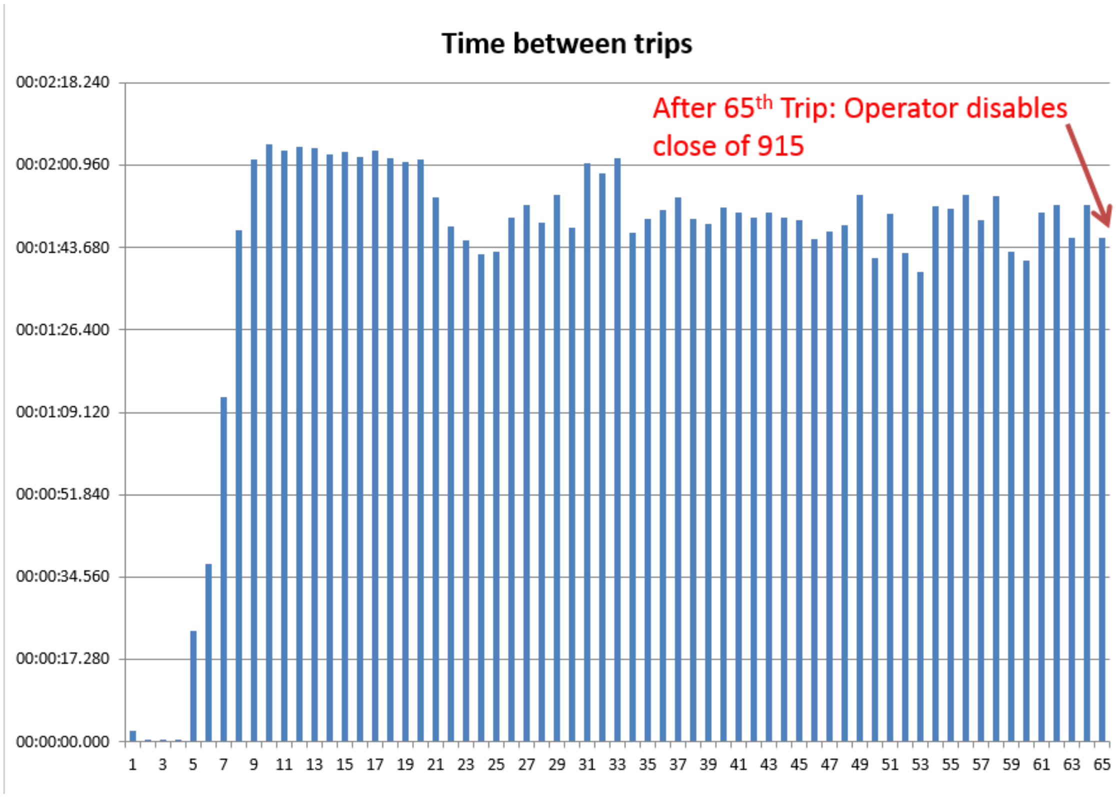
Inman operations recorded low voltage related alarms in numerous substations and under-voltage tripping of 41.6 kV circuit breakers in several others. The Tamarac Substation protection correctly detected fault and tripped 115 kV breaker 1515 when Inman 230 kV breaker 2815 was closed. Pelican Rapids 41.6kV breakers 465 and 475, and Wahpeton 41.6kV breakers 215 and 245 tripped due to low voltage. Fifteen seconds after closing into the fault, at 18:48:28 the Inman operator decides to open breaker 2815 due to low voltage alarms in the area.

Operator opens 2815 after 15 seconds



Excessive Trip/Closing of 915L

Unfortunately breaker 915L continues to pump into the fault a total of 65 times. Finally, the Wing River operator turned off the close enable switch of breaker 915L, just over a duration of 1 hour and 51 minutes from the initial event. Turning off the close enable switch prevents any SCADA, manual, or automatic reclosing of the breaker.



Lessons Learned

A Tornado had destroyed five structures on the Inman-Wing River 230 kV Line. Analysis of the events recorded by system operations SOE, local relaying, and remote DFR and relaying. Now let's review the lessons learned by relay engineering, control design engineering, field services testing, and system operations.

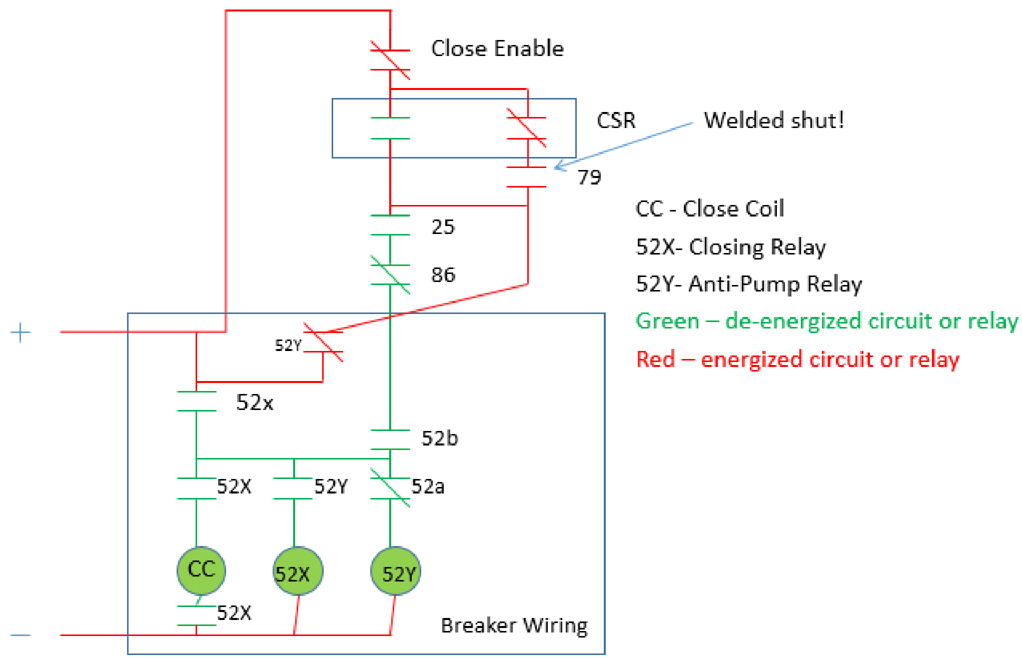
Settings

The protection system owner ran a coordination study and issued new settings to trip for ground current during LOP due to switching into a fault. Also evaluated other locations with line connected PTs and similar relays.

Close Circuitry Design

Engineering design reviewed the close circuitry design and went over step by step the correct design and operation of the close circuitry (see presentation slides 16-23). As you can see in the figure below of the corrected close circuitry, if the 79 contact is welded shut the 52Y relay remains energized preventing the breaker from pumping.

Corrected Close Circuitry



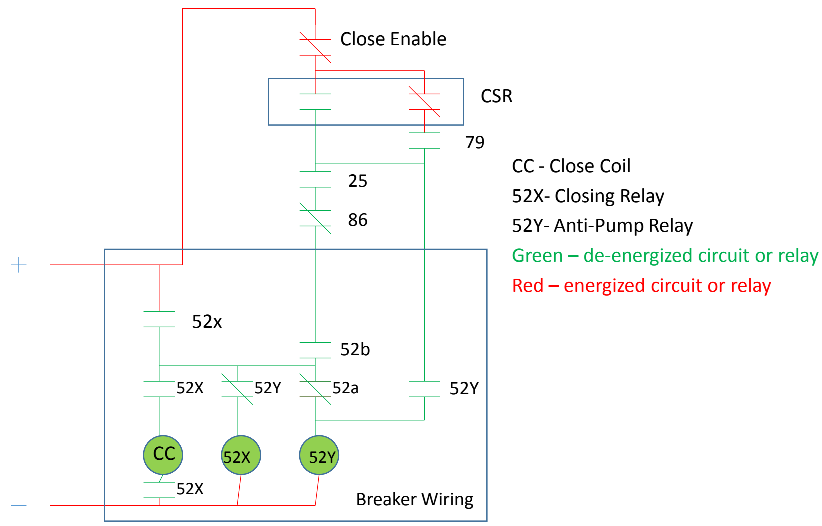
The close circuitry design for Great River Energy is comprised of six types of contacts external to the breaker.

1. Close Enable Contact: This contact follows the position of the Close Enable Switch handle. The contact is closed when the Close Enable Switch handle is in the "ON" position and open when it is in the "OFF" position. The Close Enable Switch can be turned "ON" or "OFF" locally in the control house or remotely via SCADA. Turning off the close enable switch prevents any SCADA, manual, or automatic reclosing of the breaker.
2. CSR contact 1: This contact (shown in green above) follows the position of the breaker Control Switch handle. The contact is closed when the breaker Control Switch handle is in the "Close" position, and open when it is in the "Trip" position. The contact opens when the handle is released and returns to the "Normal" position. The breaker Control Switch can be turned "Close" or "Trip" locally in the control house or remotely via SCADA.
3. CSR contact 2: This contact (shown in red above) follows the position of the breaker Control Switch handle. The contact is closed when the breaker Control Switch handle is in the "Close" position, and remains closed when the handle is released from "Close" and returns to the "Normal" position. This contact opens when it is in the "Trip" position, and remains opened when the handle is released from "Trip" and returns to the "Normal" position.
4. Automatic Reclosing Contact (79): The Automatic Reclosing Contact is typically programmed to close the breaker two times: 1) two seconds and then 2) fifteen seconds after tripping for a fault.
5. Sync Check Contact (25): The Sync Check contact is typically programmed to close when the breaker is open and the synch voltage angle is less than 30 degrees, the line is dead, the bus is dead, or the bus and line are dead.
6. Lockout Contact (86): Every lockout that trips a breaker will have a normally closed contact that would prevent the breaker from closing if that lockout has operated.

Some companies program the synch check logic within their Automatic Reclosing Contact and breaker Control Switch. Since Great River Energy has a separate Sync Check Contact, we have an additional wire from the Automatic Reclosing Contact to a 52Y contact within the breaker. This 52Y contact will keep the Anti-Pump relay (52Y) energized during any chattering or change of state of the Sync Check Contact.

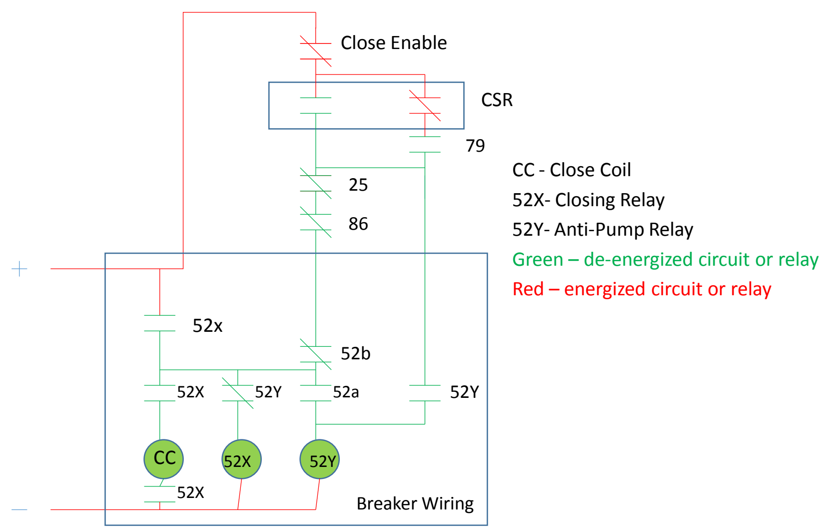
Now that the close circuitry external contacts have been described above, let's take a look at how the entire corrected close circuit path operates during the reclosing cycle. The initial step of the step of the seven step process is the breaker is closed and the transmission line is energized. The wires or relays that are energized with a DC potential are shown in red. The wires or relays that are de-energized with no DC potential are shown in green.

1) Close Circuitry-Breaker Closed



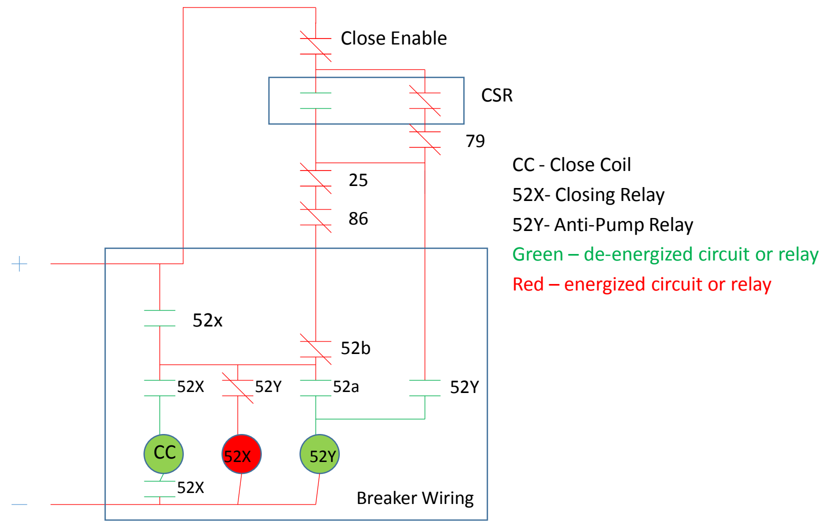
The second step in the reclosing cycle is when the relays have detected a fault on the transmission line and open the breaker. The 52b breaker contact closes and the 52a breaker contact opens. The 25 contact closes due to the transmission line potential going dead.

2) Close Circuitry-Breaker Open



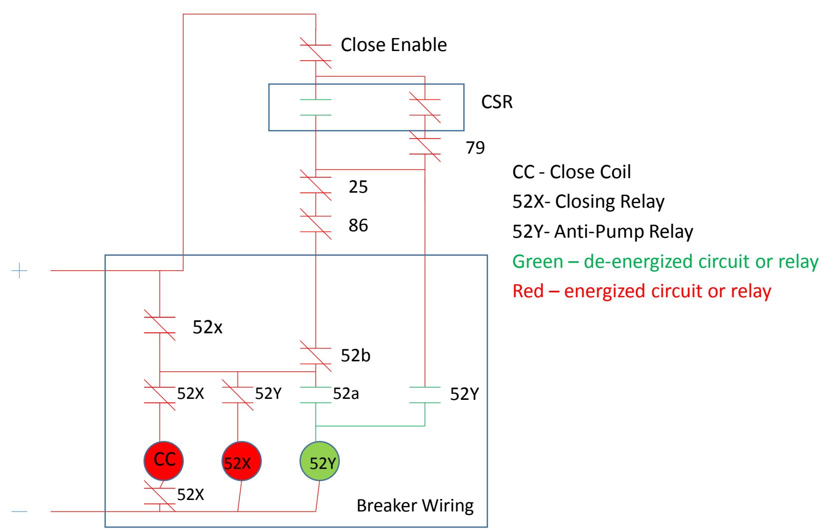
During the third step of the reclosing cycle the 79 contact closes two seconds after the relay detected the fault and/or received a reclose initiate, and tripped the breaker. The closed 79 contact then energizes the Closing Relay (52X).

3) Close Circuitry-79 Close



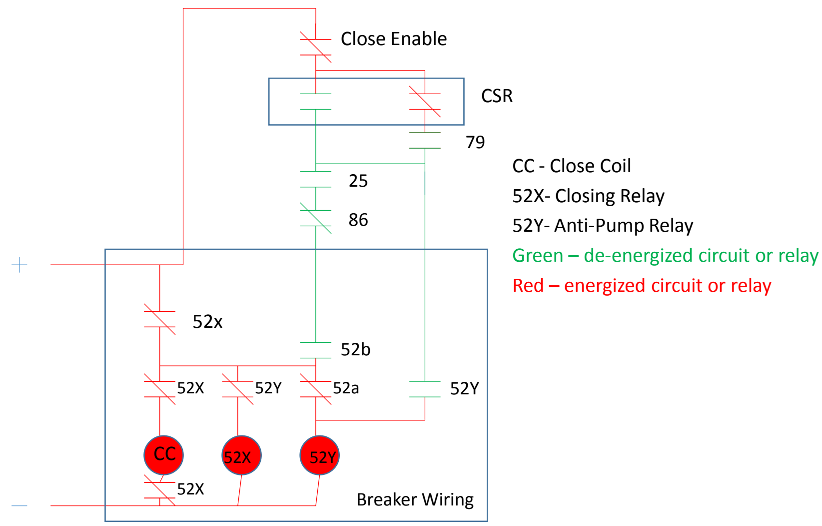
The energized closing relay changes the status of all 52X contacts during the fourth step. The closed 52x contacts surrounding the breaker close coil now allow the close coil to be energized.

4) Close Circuitry-52X



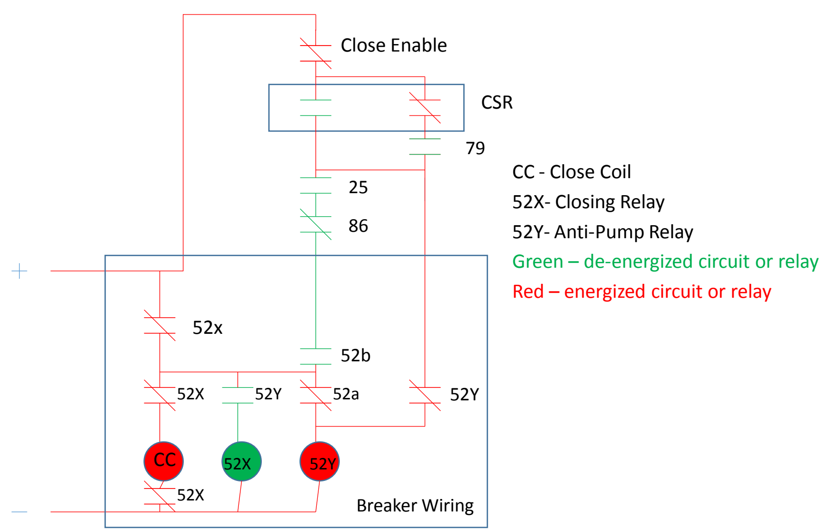
Step 5: The energized closed coil then closes the breaker. The breaker 52a and 52b contacts change state due to the breaker closing. The closed 52a contact energizes the Anti-Pump relay (52Y). The automatic reclosing relay detects a successful reclose and opens the 79 contact.

5) Close Circuitry-CC

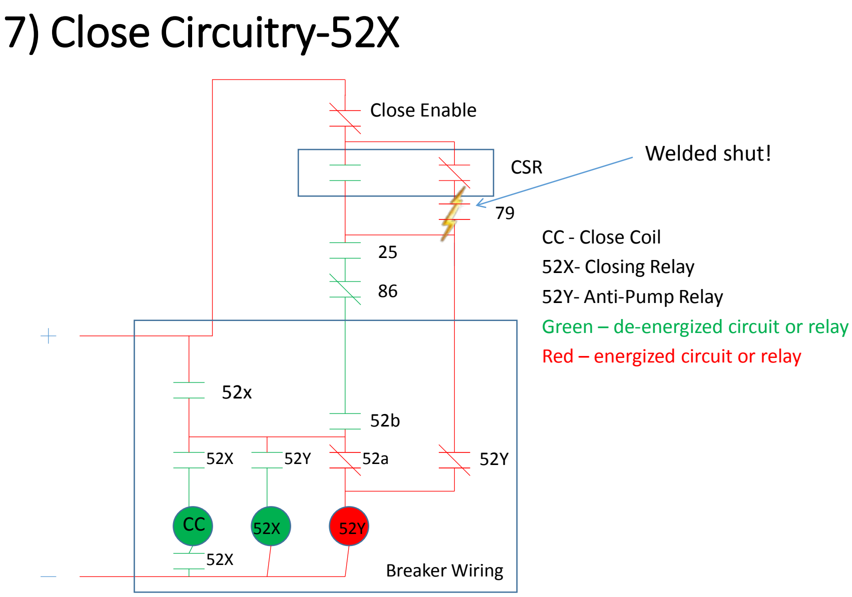


Step 6: The 52Y contacts change state due to the Anti-Pump relay (52Y) being energized. The open 52Y contact de-energizes the Closing Relay (52X).

6) Close Circuitry-52Y



Step 7: In the final step of the reclosing cycle, the de-energized Closing Relay (52X) opens all the 52X contacts. The opened 52X contacts de-energize and isolate the Close Coil (CC). The figure below shows that the closed 52Y contact would keep the Anti-Pump relay energized even if the 79 contact were welded shut. The closed 52Y contact prevents any breaker pumping the remainder of the closing process. The closed 52Y contact would also keep the Anti-Pump relay energized if the CSR contact 1 was closed due to the breaker control handle being held closed by a technician or by SCADA. If the 79 contact was open the Anti-Pump relay (52Y) would be de-energized during this final step of the reclosing cycle.



Anti-Pump Testing

It was determined that the anti-pump testing was done out at the breaker cabinet. The testing did not confirm the correct wiring from inside the control house. A new anti-pump test procedure was developed and discussed with the field crew. The new procedure was three steps:

1. Close breaker with CSR or 79 contact. (Hold the CSR or 79 contact closed during entire test)
2. Open and close test switch for sync check (25) contact
3. Apply trip to breaker trip coil.

Note: The breaker should trip open and remain open. The anti-pump relay should remain energized as long as the CSR or 79 contact is closed.

Operations

Discussed the possibility of failed anti-pump wiring and remotely turning off close enable switch prevent breaker pumping into faults. Reviewing the number of times and how recent the remote end breaker had been tripped prior to closing in the local breaker to determine if a fault is still present.

Biographical Sketch

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Joe Livingston graduated from North Dakota State University in Fargo, ND with a BS in Electrical Engineering in May 1993. He has worked as a Transmission & Distribution Planning Engineer and Relay Engineer for Minnesota Power from 1990-1997. Joe has been employed at Great River Energy since 1997 and is currently the Principle Protection Engineer. He is responsible for both the maintenance and the analysis of operations of GRE's protection systems. Joe is currently the chairperson of the System Protection Practices Group for the North American Transmission Forum.