

Lesson Learned

Relay Design and Testing Practices to Prevent Scheme Failures

Primary Interest Groups

Transmission Operators (TOPs)

Transmission Owners (TOs)

Problem Statement

A single-phase-to-ground fault occurred on a 230 kV three-terminal feeder. All associated circuit breakers initially tripped. The line automatically reclosed at one end, re-establishing the fault. Although the protection schemes were fully redundant, because of the occurrence of two protection equipment failures, which were unrelated to each other, no tripping occurred after the automatic reclose. The fault evolved to a multi-phase-ground fault and persisted for a total of 58 seconds eventually clearing by backup ground protection on two 500 kV lines. Breaker failure protection was not initiated during this event.

Details

Upon the automatic reclosing of the 230 kV breaker, 230 kV circuit electromechanical Line Relay 1 initiated a permissive trip and a direct transfer trip to the remote terminals of the faulted line. However, there was no local tripping via this scheme. The auxiliary tripping relay did not operate, which prevented tripping of the line terminal breaker as well as the initiation of the breaker failure schemes associated with this breaker. After investigation of the Line Relay 1 tripping scheme, a loose connection in the trip auxiliary relay coil cutoff contact string was identified, preventing coil energization of the auxiliary tripping relay.

Although it could not be proven that the 230 kV circuit legacy microprocessor Line Relay 2 main tripping contact closed when the 230 kV breaker reclosed into the fault, event records indicate that the relay sent a permissive trip and a direct transfer trip to the remote-end substations in approximately 0.5 seconds, suggesting that the main trip output contact closed as designed. In addition, event records show receipt of a transfer trip from the intermediate substation. Both the main trip output of the legacy microprocessor relay and the receipt of transfer trips from the intermediate and remote-end substations are wired to actuate the same type AR auxiliary tripping relay in the Line Relay 2 scheme. However, this auxiliary tripping failed to operate. As with the Line Relay 1 scheme, operation of the AR auxiliary relay in the Line Relay 2 scheme is designed to trip the line terminal breakers and initiate their associated breaker failure schemes.

Corrective Actions

The following corrective actions were implemented:

- The TO evaluated appropriate existing procedures for opportunities to align periodic relay testing with planned transmission outages to perform circuit breaker trip testing. Inclusion of breaker trip testing in conjunction with relay testing may result in a greater probability of identifying loose connections in the tripping circuitry.

- Separate contact strings for the Line Relay 1 line trip auxiliary relays were rewired such that the three 52a contacts from each pole of each breaker are now connected in parallel rather than in series. This configuration provides a more reliable trip circuit.
- The legacy microprocessor relays used in Line Relay 2 were replaced with modern microprocessor relays.
- The modern microprocessor relay contacts have been connected to trip the line circuit breakers independently of the auxiliary tripping relays, which allows segregation of the breaker trip from the breaker failure initiate signal.
- The use of the modern microprocessor relay also allows the removal of the 52a contacts from the Line Relay 2 auxiliary tripping relay coil circuit, eliminating a potential failure mode of the protection scheme.

Lessons Learned

- A key element to this event was the breaker failure initiate (BFI) signal originating from the auxiliary trip relays. A local breaker failure scheme should protect against potential failures of the auxiliary relay circuitry to the greatest extent possible.

Three options for a more reliable design are:

- Use a separate contact from the protective relay to provide the BFI signal.
- Use a dedicated auxiliary relay for BFI if a separate contact is not available on the protective relay.
- Connect the protective relay trip contact directly to a breaker failure relay input if the breaker failure relay will accommodate a voltage input.
- Analysis of the auxiliary trip circuit after the event revealed the following opportunities for design enhancement:
 - Evaluate whether 52a contacts in series with the trip auxiliaries is a necessary configuration. If not, avoid use of the 52a contacts.
 - Where 52a contacts in series with the trip auxiliary relays are necessary and where independent pole breakers are used, connect the 52a contacts in parallel rather than in series.
- Consider including the following for the periodic functional testing of protection circuits:
 - If functional tests fail to detect open circuits or other defects in any portion of the protection circuit, these defects could prevent either the tripping of the required local remote breakers (as applicable) or the initiation of breaker failure.
 - Verification that primary elements of the protection scheme generate trip output(s), as applicable, to the associated trip auxiliary relay, directly to the breakers, or both.
 - Verification that the required breakers do, in fact, trip as a result of a trip output(s). This verification should be performed during the functional testing if possible.

The protection system for the 230 kV line consists of two completely independent and redundant protection systems referred to as LR1 and LR2 (see Figure 1). The protection systems are configured as a direct under-reaching transfer trip/permissive overreaching transfer trip system, using instantaneous Zone 1 and timed Zone 2 coverage. The LR1 system utilizes electromechanical relays, and the LR2 system utilizes legacy microprocessor relays. Each protection system utilizes separate direct current sources, separate current transformer/potential transformer devices, separate trip coils, separate communication systems, and separate breaker failure schemes.

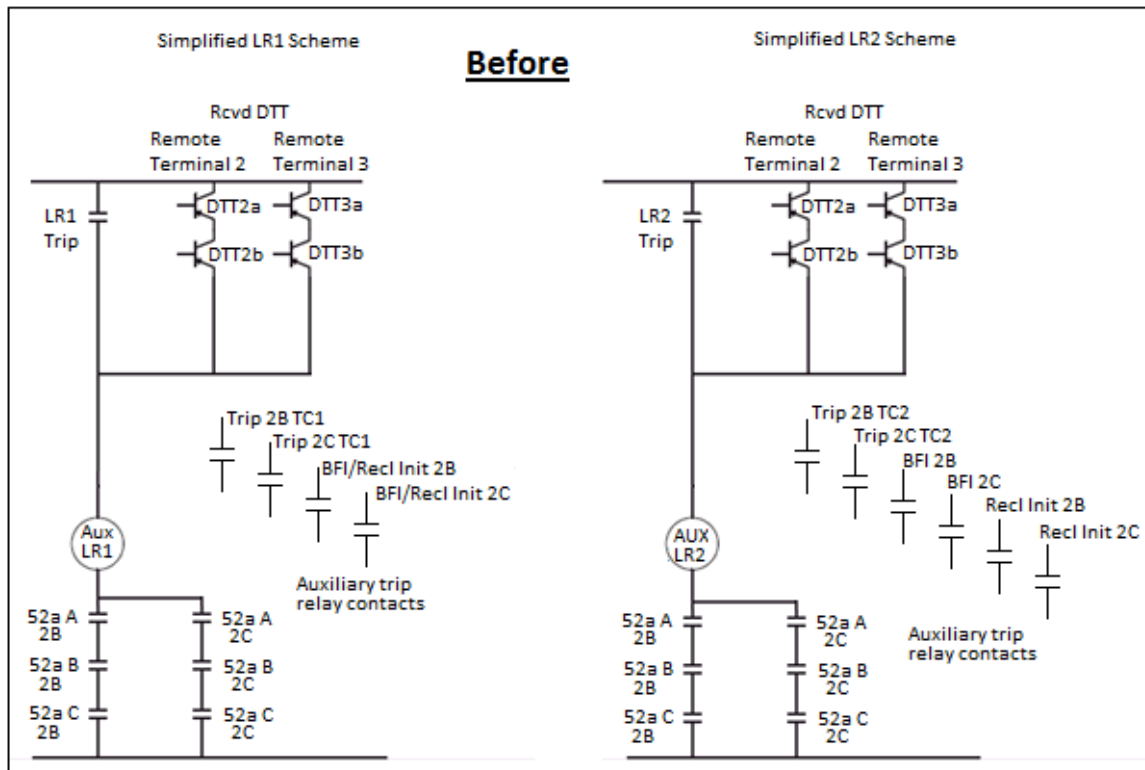


Figure 1

The wiring changes that were made to improve the reliability of the breaker tripping circuitry are illustrated in Figure 2.

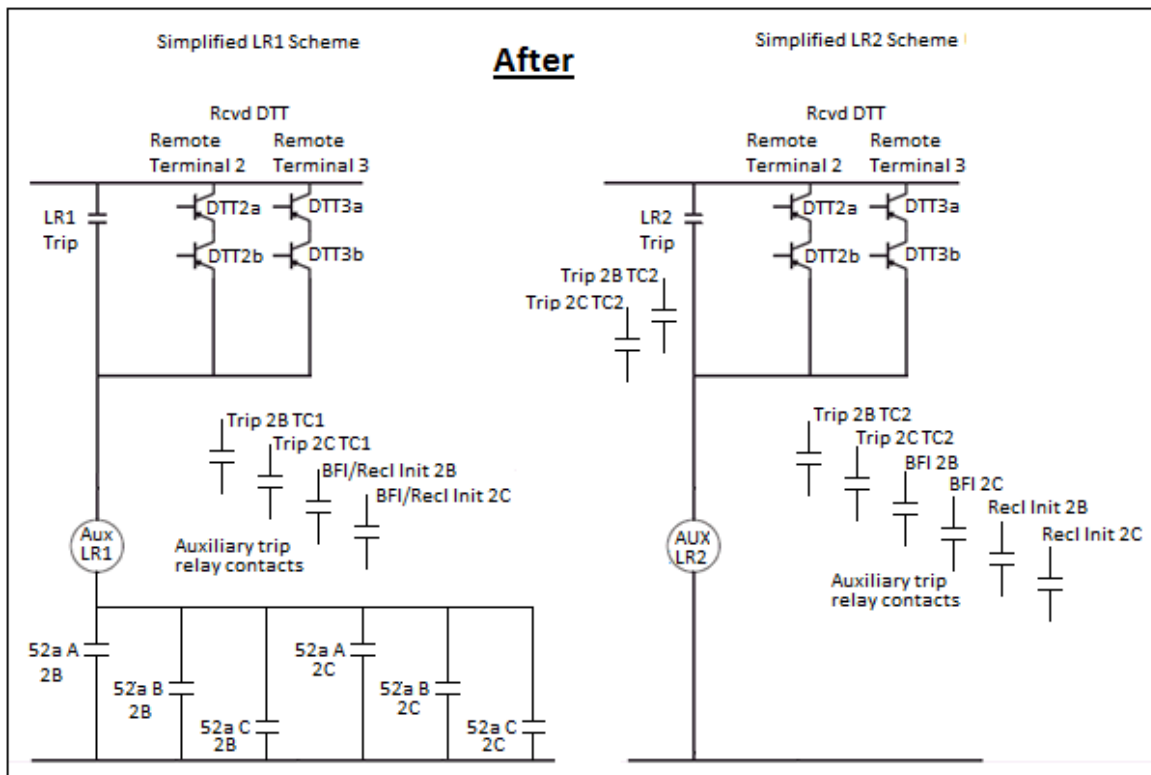


Figure 2

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Source of Lesson Learned:

ReliabilityFirst

Lesson Learned #:

20150902

Date Published:

September 15, 2015

Category:

Relaying and Protection Systems

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