Relay Applications for the Main & Transfer Bus Configuration

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Abstract

In 2012 Normann Fisher presented a paper that addressed the protection of “Unusual Bus Configurations”, taking a relatively theoretical approach. This paper looks at one of those configurations, the Main & Transfer Bus, also known as the Main & Aux Bus Configuration, and presents Portland General Electric’s (PGE) experience using multi-CT line relays and multi-winding transformer differential relays. Since 2011 PGE has upgraded the relaying on four 115kV and four 230kV Main & Transfer buses, including new relays for 19 line positions and 5 transformer positions.

The paper includes an over view of PGE’s past approaches to protection of the Main & Transfer positions, from the original electromechanical relays through some attempts to use single CT line relays, to the insight that Main & Transfer was simply just another type of two breaker configuration; one where one of the two breakers was shared with other positions.

Unlike other common two breaker configurations, such as ring bus and breaker-and-a-half, the currents associated with the substitution breaker may at times have nothing to do with the relay’s zone of protection while at other times the substitution breaker have all of the current associated with the zone of protection. The paper examines the switching sequence and the relay logic used to transition from using one input while ignoring the other, to using both inputs, to using just the previously ignored input.

PGE has implemented this using two different line relays and one type of transformer differential relay. Differences between relays and the associated limitations are addressed and the “work-arounds” developed to address some of the limitations are addressed.

Background

For many decades, Portland General Electric (PGE) configured major substations as Main and Transfer (M&T, also known as Main and Aux Bus). While PGE no longer constructs new M&T substations, the system includes several 230kV and 115kV M&T installations.

The M&T configuration is characterized by a Main Bus with one breaker per position (line or transformer), a Transfer Bus (or Aux Bus – general usage within PGE is to refer to the configuration as M&T but refer to the Aux Bus, henceforth this paper will also refer to the Aux Bus), and a breaker that connects the Main Bus to the Aux Bus, see Figure 1. Within PGE this additional breaker is referred to as the Bus Tie Breaker, some other owners of such systems refer to it as the Substitution Breaker. Where the M&T installation is at 115kV in a substation with two 230/115kV bulk power transformers there are two 115kV Main buses; the Bus Tie Breaker is located on a short section of bus between the two Main Buses with interlocked switches so that the Bus Tie Breaker can be connected to either Main Bus but the two Main Buses cannot be connected to each other, see Figure 1.

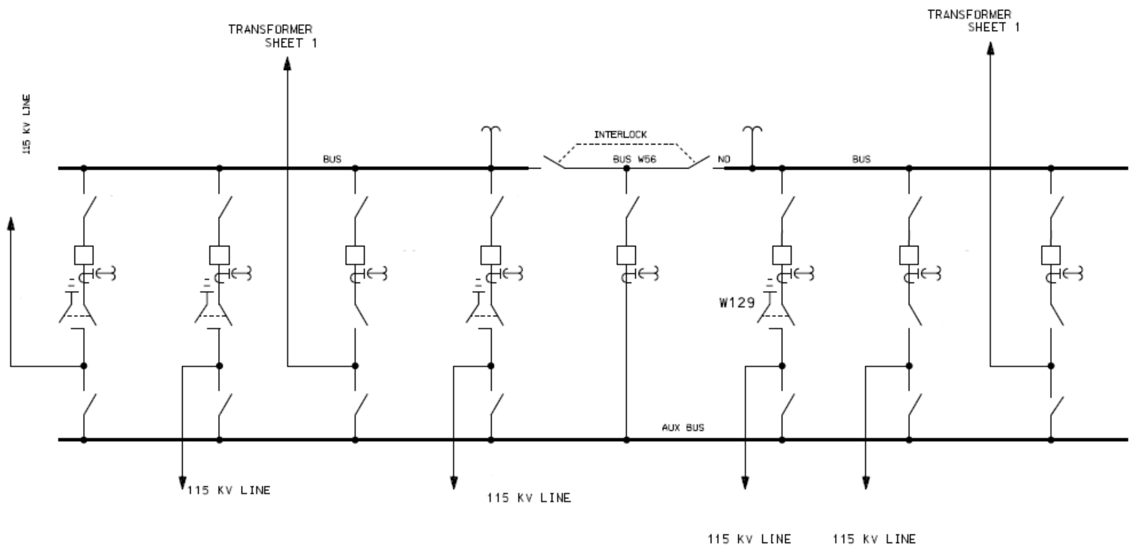

Figure 1

This configuration was seen as more reliable than straight bus (simple bus) while being less complex than either the ring or the breaker-and-a-half configurations when protection was provided by electro-mechanical relays with one trip contact per relay. Compared to the straight bus option, the M&T configuration allows any one breaker to be taken out of service for maintenance without needing to take the position normally associated with that breaker out of service. While a ring configuration would require one breaker less than M&T for the same number of positions, the tripping and reclosing circuitry would be more complex, requiring either auxiliary tripping relays or the use of diodes to allow two positions to trip a breaker without the trip propagating around the ring. At the time these stations were built, breaker-and-a-half would have had the complexities mentioned for the ring configuration, and also required the use of 50% more breakers. Given the trade-offs, the conventional wisdom of the day was that M&T was the optimum configuration when more flexibility was required than offered by the straight bus.

This author is aware of two approaches of applying relaying to the M&T configuration. One approach is what PGE did; use a Relay Transfer Switch (RTS) to switch the position relays between the normal breaker and the bus tie breaker. The other approach is to apply separate relays to the bus tie breaker. In the electro-mechanical relay days, the approach of applying separate relays to the bus tie breaker would require resetting those relays every time the bus tie breaker was used for a different position. Placing a transformer position on the bus tie would still have required transferring the relay inputs to allow use of the transformer differential relay.

Once numeric relays with multiple setting groups became available, the use of separate relays for the bus tie position became easier as a setting group could be dedicated to each line position. Transformer positions remained a problem as a different type of relay is used than for line positions. PGE knows that a large transmission provider in the area takes the approach of

separate relays for the bus tie breaker, but in general PGE's approach has been to use the RTS to switch which breaker is monitored and tripped by the line and transformer relays.

Prior to the implementation of the approach described below, switching a line position between the normal and bus tie breaker would result in both breakers in parallel with the protection connected to the CTs of only one breaker and having the ability to trip only one breaker. Then as the RTS was switched from the Normal to Bus Tie positions (or back from Bus Tie to Normal) there would momentarily be no protection for the position as the CTs and trip circuits were disconnected from one breaker and then connected to the other breaker. When a transformer position was involved, an additional step was required; the differential would first need to be disabled. In both situations, a bus fault during switching would have had a less than optimal protection response.

Intermediate History

In 1992 PGE's preferred relay vendor introduced a new numerical line distance relay that when paired with a 1993 dual breaker reclosing relay allowed the use of a distance relay with a single 3-phase CT input in dual breaker applications.

In 1999 said relay vendor released an update distance relay that included single breaker reclosing and then in 2003 a version was released that added line differential to the mix. In this time frame, the protection group at PGE worked out a scheme they felt met their needs; with two relays one could do synch check/voltage supervised close of one breaker and the other could do synch check/voltage supervised close for the other breaker. Reclosing of the second breaker would occur a fixed time after the reclose logic closed the first breaker provided the first breaker remained closed. All seemed well for the ring and breaker-and-a-half stations that were beginning to appear on the system.

In that same era, in 2001, the same relay vendor introduced a line distance relay with two 3-phase CT input as well as dual breaker reclosing. This new relay had hundreds more settings than the relays with a single 3-phase CT input and required some of the logic to be programmed by hand in a free-form logic area rather than simply entering settings. The vendor promoted this relay as the answer to the ring and breaker-and-a-half applications. At that point the PGE protection group was comfortable with what they had using the single 3-phase CT relays and took a pass on the new two 3-phase CT input relay.

In the meantime there were occasions to replace electromechanical relays in M&T applications. Some locations, where only a few positions were upgraded, were treated the same as always, the RTS switched the CT inputs and the trip circuit from one breaker to the other. Other locations, where all of the relaying was replaced, received a separate set of line relays on the bus tie breaker with each line's settings in a different setting group; transformer relays still needed to have CT circuits switched. Neither approach was considered a success. The RTS switching approach still had all of its drawbacks, and the separate relay approach introduced new complications, such as needing to remember to update the bus tie relays when a line position's settings were revised. When the line has transfer trip there also needs to be a means to transfer the communication circuit from the Normal Breaker relays to the Bus Tie Breaker relays.

As 2008 began, the general consensus in the group was that the M&T configuration was trouble, but otherwise the single 3-phase CT relays could cover it all and that new-fangled two 3-phase CT relay was just more trouble that it would be worth.

This author had joined the group at the end of 2006, and was unable to leave well-enough alone. During 2008, while contemplating a project that would go into service in 2009, the author was given the go-ahead to experiment with the two 3-phase CT relays on a ring bus application.

While studying the manual in preparation for that initial ring bus application, the author discovered an interesting group of settings. The standard application settings for the relay had the distance elements, plus other protection functions, using the combined CT input; the relay summed the two sets of CTs internally instead of a hard wired summation external to the relay in the CT wiring. But, there was also an option to tell the relay to use only one 3-phase CT input at a time and to control which of the two sets of CT inputs was to be used in relay logic. This seemed to be a solution to the vexing M&T problem. The question was could it really work.

Further work and experimentation with the relay showed that, yes, it could be made to solve the M&T problem. As a better M&T solution than anything tried up to that point, it was much easier to push the relay for ring and breaker-and-a-half applications as well. The relay manufacturer had never produced any application notes for the use of this relay in M&T applications; only as the "ideal" relay for traditional two breaker applications, ring and breaker-and-a-half, plus the occasional double bus-double breaker station. In hind-sight, if the manufacturer had produced a detailed application guide to the M&T installations, it is highly likely that PGE would have started using the relay many years earlier than it did.

Much has been written describing applications for this relay, and others similar to it, in conventional two breaker applications, and PGE now has many two 3-phase CT relays in those applications. On the other hand, very little has been written on "the other two breaker application", M&T. In the remainder of this paper, this relay, a related relay that adds line differential, and a transformer differential relay from the same product family are examined in the M&T application. As this is written PGE now has over 20 line or transformer positions in M&T stations protected with these relays. PGE's experience has shown these relays to be a significant improvement in the protection of M&T positions, albeit with a few teething problems.

Implementation

The key to making this application work were a few settings in the relay:

- NUMBK – the number of breakers in scheme
    - Ring, Breaker-and-a-half, and M&T all use NUMBK = 2
- ESS – the source selection.
    - Ring and Breaker-and-a-half use ESS=3
    - M&T uses ESS=Y
- LINEI – The source for the current in the protected line.
    - Ring and Breaker-and-a-half use LINEI = COMB, the internal summation of the two current inputs.

    - M&T uses LINEI = IW, one of the two current inputs; the current input associated internally with Breaker 1 in the scheme, the normal breaker.
- ALINEI – The alternate source for the current in the protected line.
    - For Ring and Breaker-and-a-half this setting is not available.
    - For M&T this is set ALINEI = IX, the other current input; the current input associated internally with Breaker 2 in the scheme, the bus tie breaker.

There is no combination of settings available that allows use of both breaker currents independently in addition to using the combined currents. To have the option of either breaker current individually or the combination of both (3 choices) would be more advantageous than the present options of COMB plus one current or both currents individually but not in combination.

Interestingly, in the line relay that also includes line differential, the currents used by the distance element are selected as described above, but the differential allows inclusion of either or both currents without limitation. The transformer relay from this relay family also allows dynamic inclusion in the main differential of each set of CTs independently of the other CTs. In that relay though, the Restricted Earth Fault (REF) configuration cannot be dynamically assigned. In the relays where CTs can be assigned to differential zones, it is done on a CT by CT basis, included or not included, unlike the distance elements where one is required to pick one normal configuration and one alternate configuration.

When this application was first considered, the approach was much like the prior implementations; either on the normal breaker or on the bus tie breaker, not both. It was, however, realized that another option existed; a switching mode where the relay does as much as it can with both breakers, the limitation on distance elements notwithstanding. In the initial consideration, use of the Normal Breaker was controlled by a logical condition of RTS in Normal, while use of the Bus Tie Breaker was controlled by a logical condition of RTS in Bus Tie. As the scheme developed, it was realized that for most purposes, the preferred logic for the use of the Normal Breaker was the logical condition of RTS not in Bus Tie and RTS not in Normal for the Bus Tie Breaker. With this change the position of the RTS between Normal and Bus Tie, indicated on the name plate as Off, effectively becomes a Both position.

As switching begins, placing the RTS into the Off position adds the Bus Tie Breaker to much of the logic. With the Off position becoming Both, the switching instructions were rewritten to make placing the RTS in Off the first step; in the older versions the Off position was to be avoided to the extent possible and moved through as rapidly as possible. With the RTS in Off, both logical states RTS not in Bus Tie and RTS not in Normal are true and both breakers will trip should a fault be detected.

The next step is finishing the switching and ending up with the relay looking at the new breaker currents and tripping that breaker. How to get there became a question. One route would be to switch the RTS and then open the outgoing breaker; the other would be to open the breaker and then switch the RTS. In the first case there would be a period when the breaker would still be closed but would no longer be considered for tripping. In the second case, all of the current would momentarily be through the breaker no longer being monitored; a fault at this point would be completely missed.

The solution to this was a logical “Switching Mode”. Switching Mode is programmed using a latch; placing the RTS into the Off position causes the relay to enter switching mode. The relay exits Switching Mode when the RTS is placed into either the Normal or Bus Tie position and the other breaker is opened. Exiting this way provides for a proper logical exit whether the sequence is completed or is halted and then backed out of. Using Switching Mode in this manner, the tripping of the second breaker is picked up at the beginning of the process, both breakers remain closed while the RTS is moved from Off to the final position, at which time the current selection is changed to match the RTS position, and then when the breaker being taken out of service is opened it is removed from tripping.

One downside to having the relay working with the currents of one breaker while there are two breakers in parallel is that the distance elements will exhibit underreach. The relay will measure the voltage resulting from the fault, but will only measure a portion of the current, increasing the apparent impedance to the fault. If the two paths, one through the Normal Breaker and the other through the Bus Tie Breaker, have the same impedance the apparent impedance will be twice the actual impedance. If the impedances are unequal, as they are likely to be, the lower impedance path will produce a more accurate impedance calculation; more accurate, but perhaps not much more accurate. During a complete switching evolution from Normal Breaker to Bus Tie Breaker and back to the Normal Breaker there will be time that the relay is using the CTs that produce the more accurate impedance and times that the relays will be using the CTs that produce the less accurate impedance.

This underreach was determined to be an acceptable risk based on two considerations; the prior scheme had the same underreach problem, as long as the fault didn’t happen while the RTS was in Off, and would only trip one of the two breakers; and the most probable location of a fault during switching is where the switching is being done, a close-in fault in the station. It was not anticipated that the potential underreach could be so severe as to fail to reach a close-in fault.

An Alternate Approach

In working with this application after the initial installations, it was noticed that there might be a “better” solution, certainly a different solution. One possible combination allowed by the relay logic is the use of COMB as the normal LINEI and IX (Breaker 2) as the ALINEI. There is not a similar condition with IW (Breaker 1) as the ALINEI setting.

If Alice were to apply the relay in *Wonderland*, she could then connect the Normal Breaker as Breaker 2 and define ALINEI as the normal condition while connecting the Bus Tie Breaker as Breaker 1 and define LINEI as the current to use when not solely on the Normal Breaker. In this world *Beyond the Looking Glass*, Alice would find that in making everything backward it all worked out better. With this approach the logic that selects the ALINEI current instead of the LINEI current would be RTS in Normal; RTS in Off or in Bus Tie would then use the normal COMB currents. During switching, while some of the current goes through each breaker, the use of COMB would eliminate the underreach problem describe above. The downside to this approach is that while the position is on the Bus Tie Breaker, the relay continues to include the Normal Breaker currents in the protection calculations. Any bogus currents into the relay while

the position is on the Bus Tie Breaker could potentially result in an undesired trip of the line. The presence of CT test switches at the relay allow a ready means of preventing any currents associated with testing around the Normal Breaker from reaching the relay while on the Bus Tie Breaker.

If PGE were now just beginning to apply this type of relay to the M&T configuration, this is the CT connection and selection logic that would be applied.

Line and Bus Voltages

If the connections and logic described in the previous section aren't sufficiently from Alice's world for the reader, consider the voltages. If there is any real clue that the relay manufacturer missed this application of the relay, it is the terminology around the voltages. For the line relays in this family, Line Voltage comes from the 3-phase voltage source used for the protection voltage and Bus Voltage comes from the 1-phase voltage source across the breaker from the Line Voltage. For synch check functions this isn't of much concern. But these relays also include settings and logical states for Dead and Live – Line and Bus.

It is necessary to keep firmly in mind, when considering this relay; the line is that which provides a 3-phase voltage. In the conventional two breaker applications the line is something composed of stranded conductors hung from insulators on widely spaced poles or other structures while in the M&T application the line is something often composed of aluminum pipe supported at close intervals on post insulators. On the other hand, in the conventional two breaker applications, the bus voltages come from portions of the system composed on aluminum pipe while in the M&T application the bus voltage comes from a portion of the system composed of stranded conductors. Everything reversed is normal, just like Alice found.

A Switch Mode Misadventure

The line relays used in this application have more inputs than the transformer differential relays. When the initial I/O allocation for the transformer relay was developed it was found that only one input could be allocated for the high-side RTS and one input for the low-side RTS; the line relays have inputs for RTS on Normal and RTS on Bus Tie while the transformer relays were only given RTS on Bus Tie inputs. It was decided that this lack of I/O would be addressed by using push buttons on the front of the relay to enter and exit Switching Mode. The switching instructions were written to include use of the push buttons. The Protection Group thought the situation was sufficiently addressed. It later became apparent that the push button solution was not an adequate solution.

The relays for one transformer had been placed into switching mode between the time the relays received their functional testing and when the relays were placed in service. Switching Mode was active and the transformer position RTSs (high- and low-sides) were in the Normal position. With the Bus Tie Breaker out of service, the inclusion of its currents in the differential calculation did not pose any problems. When one of the line positions was placed on the Bus Tie Breaker the stage was set for a potential misoperation. With relatively low normal load current on the Bus Tie Breaker the differential operate quantities remained below the minimum operate

threshold and the scheme remained secure. The line position on the Bus Tie Breaker was the normal source to one distribution station.

While that distribution was on the Bus Tie Breaker, a condition occurred where the differential relay saw about 240A on one phase and about 40A on the other two phases. The inclusion of this extra, unbalanced, current was sufficient to satisfy the negative sequence differential and the relay issued a trip.

For the line positions, the line relays directly trip the breaker(s) that are active in the scheme at the time, but for transformer positions the practice is to trip a lockout relay and let the lockout relay trip the breakers. In an M&T installation tripping of the Bus Tie Breaker is controlled by the transformer position RTS. Since there was a line position on the Bus Tie Breaker, its RTS was in the Bus Tie position and the handle captured. This ensured that the RTS for the transformer position was in the Normal position. In the Normal position the RTS blocks the transformer lockout from tripping the Bus Tie Breaker. Thus the transformer lockout tripped the Normal Breakers on both sides of the transformer position and the Bus Tie Breaker remained closed. The breaker failure logic was set up assuming that the document switching sequence would be followed. To allow for proper tripping throughout the switching process the relay performed breaker failure for the Bus Tie Breaker while in Switching Mode or with the RTS on Bus Tie. Switch Mode was active, breaker failure was initiated, and 10 cycles after the transformer was tripped, breaker failure was declared and the bus lockout was tripped.

Following that event it was determined that the I/O could be reallocated to free up inputs and allow both RTS on Normal and RTS on Bus Tie and the elimination of the push buttons.

Other Quirks

In addition to the selection of distance element currents and the line/bus voltage confusion mentioned above there are a few other places where this application requires working around the relay capabilities as it comes from the factory:

Restricted Earth Fault (REF)

The transformer relay has the capability of three REF zones, and each REF zone can be turned on or off in logic, but boundaries of zones are set when the relay is programmed. Each of the three REF zones is associated with one of three neutral CT inputs. Normally for an autotransformer the neutral CT would be wired to one of the inputs and one REF zone would be implemented. In the M&T application it is desired to not include the Bus Tie Breaker Currents unless the Bus Tie Breaker is in use for the Transformer position so different configurations need different REF zones; and multiple REF zones require the connection of multiple neutral CT inputs. In this application the single neutral CT is wired into all three inputs of the relay in series, allowing all three available REF zones to be used.

Given the fixed boundaries of the REF zones, it would be useful to have four zones to account for two configurations on the high-side and two independent configurations on the low-side.

With only three zones, the configuration where both the high- and low-sides are on their respective Bus Tie Breakers at the same time was considered improbable and was omitted.

Because the boundaries are fixed, it is necessary to turn off REF when Switching Mode is entered and then turn on the correct REF zone when leaving Switching Mode. While this means that an important transformer protection is unavailable during the switching operations, it is, however, protection against a fault type that is unlikely to be instigated by the switching operations.

Back-up Overcurrent Elements

PGE uses definite time overcurrents on bulk power transformers to trip for uncleared transmission system faults. The relay does not provide combined input elements, all are for a single CT input only. To provide working overcurrent elements through the whole switching process it is necessary to create them in logic by summing currents multiplied by status bits and then comparing that against the set point.

Reclosing

In the line relays, the manufacturer has defined reclose lockout as any condition for which the relay will not attempt a reclose; this can be that reclosing is blocked, the final shot has occurred, or the breaker was manually opened and logically removed from the lockout scheme. While that definition provides a very predictable outcome from the relay, it doesn't match how PGE operationally defines a reclose lockout.

For PGE a reclose lockout requires a relay trip followed by the relay not issuing a close command. In the general case, for a transmission relay this can be a result of reclose having been blocked or following the final reclosing shot. This is accomplished by defining reclose lockout as occurring either when the relay issues a trip with reclosing blocked or the relay transitions from reclose cycling to reclose lockout.

During the switching operations associated with moving a line position between breakers, it is likely that any fault occurring during the switching is a result of the switching. Reclosing for a fault likely to be in the yard, over the head of the operator performing the switching, is not desired. The first approach considered was to not initiate reclosing during switching. After a time delay the relay would indicate reclose lockout; that would produce the desired result if the relay's definition of reclose lockout matched our definition. PGE's solution was to allow reclose to be initiated and then use the relay's reclose supervision logic to keep the close command from being issued. The breakers will remain open and when the reclose supervision time expires the relay's internal logic will change from reclose cycling to reclose locked out and that will produce the transition that results in the desired reclose lockout signal to the SCADA system.

Conclusions

- The family of "Two Breaker" applications is larger than just those applications where both breakers are normally in service together.

- When contemplating relay for an application where the manufacturer has not provided application guidelines it is necessary to have a thorough understanding of the assumptions made by the manufacturer in the design of the relay. For example the use in these relays of "Line Voltage" to refer to the three-phase voltage source whether physically connected to the line or the bus.
- When implementing a new scheme such as this expect operational surprises as field conditions produce situations not anticipated during the scheme design.
- If the scheme relies on specific steps happening in a specific order, be prepared for those steps to happen in a different order.
- "Unconventional" relay applications can solve long standing protection problems.

Recommendations to the Manufacturers (if I may)

- Don't make assumptions about system configurations such as those that result in "Bus" voltages coming from the line and "Line" voltages coming from the bus.
- In any case where is it possible to include, or not include, a CT set (or a VT set) in a calculation, make the selection on a CT-by-CT basis rather than a normal-alternate type selection (see the distance current discussion above).
- When some features of the relay allow dynamic inclusion/exclusion of CT sets (or VTs), include that capability for all functions (see the REF discussion above).