Review of The Breaker Failure Protection Practices in Utilities

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***Abstract*- Breaker Failure Protection (BFP) is widely used in transmission network as backup protection. The BFP design varies from Utility to Utility, and is influenced by Utility's past practices and their experience with electromechanical relays. The consequence of BFP mis-operation is usually severe, no matter it is false tripping or false no-tripping. It is a challenge to design a perfect BFP scheme that can achieve both security and dependability for various applications. This paper starts with the fundamentals of local and remote backup protection. The typical BFP schemes from three Utilities are followed as examples. A few mis-operation cases are presented to exemplify how the security of BFP was breached. After that, a number of aspects on how to improve the BFP scheme are explored with a focus on security side. The dependability and sensitivity of BFP scheme are also discussed for breakers associated with power equipment such as transformers and generators.**

I. Introduction

The power system relies on protective relays and Circuit Breakers (CB) to clear faults. For the safety of the public and the reliability of system operation, there shall be backup methods to isolate the fault if a relay or a CB fails to operate. It is common to deploy main and backup protective relays. But it is rare to install two CBs in series to handle single CB failure due to the formidable cost. However, dual trip coils are often used for high voltage CB.

The CB may fail to trip due to various reasons, such as trip coil failure, interrupting component failure, dielectric gas pressure low, etc. Faults must be cleared under CB failure conditions. In doing so all the adjacent CBs shall be tripped, which can be accomplished by the backup protection or by installing dedicated CB failure protection (BFP) for each CB.

A. *Backup Protection without Dedicated BFP Scheme*

The relays associated with each CB can be used to provide local or remote backup for the neighbor CBs. This type of backup may have problem in speed, sensitivity and coordination. For a fault in Fig. 1, if CB3 fails to trip while CB4 trips, the fault may be isolated either by local adjacent CBs 2&5, or by remote CBs 1&6. If there is no dedicated BFP, the reverse-looking relays of CBs 2&5 or the forward-looking relays of CBs 1&6 can provide local or remote backup respectively. Such backup for CB failure must have sufficient delay to coordinate with the primary protection and other backup functions, which may put system and equipment at risk.

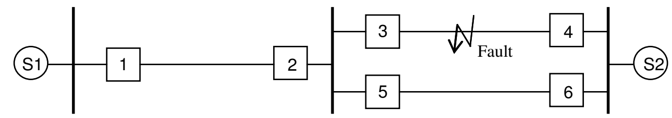

Figure 1. Backup protection in a transmission system

In addition to the speed problem, the sensitivity of such backup may also be an issue. For example, if the source S1 is a weaker source, the distance or overcurrent relays associated with CB1&2 may not be able to detect the fault due to the strong infeed current from strong source S2. Meanwhile, the sensitivity of the backup protection may be limited by the loadability requirements or the load unbalance. Another drawback of a remote backup is the extra outage to the load that is tapped on the line.

With all these disadvantages, this type of backup still has some merits. First, it needs no extra hardware. Second, if a station loses its DC supply completely, the remote backup may be the only way to isolate the fault. In one Utility, the distance zone 3 is used not only for time delayed remote backup, but also as tripping zone in Directional Comparison Block (DCB) scheme. By including the far-reaching distance zone 3 and sensitive ground overcurrent elements, the DCB scheme can provide high speed backup in case of complete DC supply failure in remote station. Third, this type of backup may provide a 'comfort cushion' in BFP design. Since the consequence of BFP mis-operation is severe, with local or remote backups in mind, a relay engineer may have more confidence to bias towards security on line BFP design and settings.

By using digital relays, it is convenient to add reverse-looking elements as local backup for CB failure. It has more sensitivity than the remote backup relays. But it adds one more step for protection coordination. Some Utilities have used the reverse looking element for backup, whereas some have not.

B. *Backup Protection by Dedicated BFP*

The dedicated BFP should be deployed when the protection speed and sensitivity cannot be compromised. The basic BFP logic is illustrated in Fig. 2. The more comprehensive BFP schemes are based on the same simple concept: if the CB fails to isolate the fault after receiving the trip signal for a certain period, the BFP scheme will actuate to trip all the adjacent CBs.

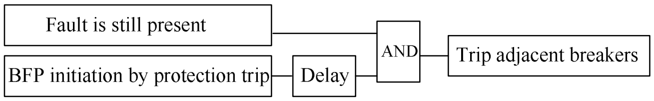

Figure 2. The basic BFP logic

A BFP scheme can be divided into three parts: the BFP initiation circuits, the fault & CB failure detector, and the output circuit. In general, any protection functions that trip the CB should initiate the BFP. The BFP relays of other CBs may also initiate the BFP. There may be exceptions on CB pole discrepancy tripping, Special Protection Schemes, transformer non-electrical protection tripping, etc., which are up to different Utility's practices. The manual open command should not initiate BFP since BFP is designed to isolate fault instead of load. Most BFP fault detectors are based on overcurrent relays and there are a number of variations on fault detector design in BFP scheme. For BFP output circuits, some Utilities would use lockout relays to prevent manual or automatic reclosing of the CBs tripped by BFP, some Utilities would not use lockout relays in order to facilitate quick restoration through remote control.

C. *The Requirements of BFP Schemes*

Since the BFP operation will trip a number of adjacent CBs, the consequence of its mis-operation is usually severe. In some cases, the BFP mis-operation was the starting point of cascading outage in the area. On the other hand, if the BFP does not operate to isolate the fault, the system is at risk too and some equipment such as generator and transformer could be damaged. Therefore, a good BFP design should be able to prevent mis-operation due to single component failure or single human error. It is desirable to achieve both security and dependability at the same time. However, the design preference for a Line CB may be different from that for a Bank CB, which is defined as breaker associated with generator, transformer, shunt reactor or shunt capacitor bank. The Line BFP may need to bias towards security while the Bank BFP need to bias towards sensitivity and dependability.

II. BFP PRACTICES IN UTILITIES

This section reviews the BFP designs in three Utilities from the implementation point of views such as the BFP initiation, fault detector settings, the BFP timer settings, tripping circuits, system restoration design, direct transfer trip (DTT), etc.

A. *BFP design in Utility-1*

1) *BFP Implementation*

In Utility-1, most CBs at transmission level have dedicated BFP scheme that is based upon a stand-alone digital relay for each CB. The relay also includes other control and monitoring functions such as Auto Reclosing, CB control, CB alarms, trip circuit monitoring etc. In the past several years, this Utility has extended the installation of dedicated BFP to subtransmission level at 69kV.

2) *BFP Initiation*

All protection devices/relays that trip the CB also initiate BFP except trips from another BFP Lockout relay operation. The BFP initiation signals from protective relays are hard-wired to the inputs of the dedicated CB Control and Failure relay.

3) *BFP Logic*

Residing in the dedicated CB control relay, the BFP logic includes the following three components: Current Detector (50P or 50G), CB Failure Initiation (BFI) and CB Failure Timer (t_{BF}).

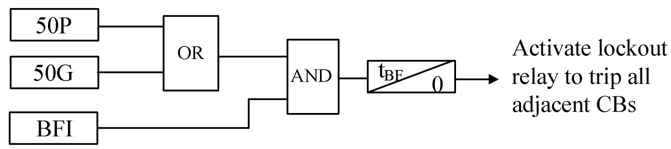

Figure 3. The Utility-1's BFP Logic

This simple BFP logic is inherited from EM relay design. As shown in Fig. 3, the BFP scheme is armed if the current detector (50P or 50G) is actuated and the breaker failure initiation (BFI) signal is presented. If these conditions persist after BFP timer expires, the BFP will pick up the lockout relay (LOR) to trip all the adjacent CBs. The typical t_{BF} setting is 7~15 cycles, which is up to the CB type and voltage level. If applicable, the LOR also initiates DTT signal to remote terminal and stops the blocking signal of DCB schemes. This Utility has DTT facilities installed for lines over 200kV, or for some generator interconnections. For lines below 200kV, the local relays are set to back up the remote CB. For example, a far-reaching distance zone 3 and sensitive ground overcurrent used in a DCB scheme can backup the failed CB in remote station if the blocking signal is absent.

4) *Fault Detector Settings*

This Utility used to bias toward sensitivity and simplicity on BFP fault detector settings. For most CBs, both 50P and 50G for BFP scheme were simply set to 1 Amp. Recently, this Utility is in a review process of this setting philosophy. A tentative Guideline is to use different overcurrent settings per fault study results. In doing so the Line BFP fault detector must have sensitivity to detect the minimum internal faults, and the Bank BFP needs to be even more sensitive to detect faults with low current.

5) *Re-trip Logic*

This Utility has just started to apply re-trip logic for new and retrofit projects. The dedicated breaker relay will trip its associated CB after receiving the BFI signal. To ride through the transients and disturbance of the relay input, the re-trip timer can be set at 1 cycle.

6) *BFP Trip Circuit*

If BFP operates, the breaker control relay will send contact output to LOR, which in turn trip and lock out all the adjacent

CBs. The LOR also has contacts for DTT signals and carrier stop signal. However, the LOR trip signal would not be used as BFI for adjacent CBs. In the case of the Bus Tie CB, the BFP output will hit the same LOR for the Bus Differential Protection to ease the number of inter-panel wirings.

B. BFP design in Utility-2

1) BFP Implementation

In Utility-2, currently not all transmission CBs have dedicated BFP schemes. In the past several years, it has been a policy to install dedicated BFP schemes on all new transmission CBs, and to add BFP in CB replacement projects where BFP is absent.

2) BFP Initiation

All protection devices that trip the CB also initiate BFP. The implementation logic for CB tripping and BFP initiation is always identical, whether it is accomplished by internal relay logic or physical device architecture.

3) BFP Logic

For most applications, the BFP logic resides in the dedicated CB control relay. However, this Utility has started to use the fully integrated BFP schemes in some projects, which is up to the bus configuration. I.e., instead of using CB control relay for BFP, the integrated BFP function of each zone relay is utilized. There are two types of BFP logics: Line BFP and Bank BFP.

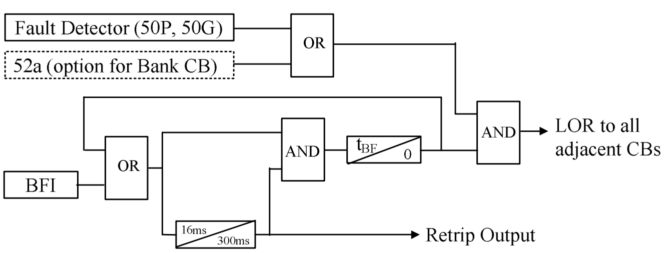

Figure 4. The Utility-2's BFP Logic

- Line BFP Logic

As shown in Fig. 4, the BFP consists of three parts: the Fault Detector (FD), the BFP Initiation (BFI) and BFP Timer (t_{BF}). The t_{BF} is typically set 8 cycles for the line CBs. The lockout tripping will occur if FD is actuated at the expiration of the CB failure timer.

- Bank BFP Logic

The Bank BFP is applied to transformer banks, reactor banks, condensers, etc. It is almost the same as Line BFP, except that it has additional CB auxiliary contact 52a in parallel with the FD to detect the CB failure, as shown in Fig. 4. The t_{BF} is typically set at 10 cycles for BFP, slightly longer than the typical Line BFP timer for security purpose. A separate BFI signal from the bank differential and non-electrical fault relays are designed to bypass the FD.

4) Fault Detector Settings

Fault detectors are set as sensitive as the primary relaying. Typically the phase fault detectors are set at 60% of the minimum internal 3-phase faults, and ground fault detectors are set at 50% of the minimum internal ground fault.

5) Re-Trip

Both the Line and Bank BFP schemes include the re-trip scheme that sends a redundant trip signal to the CB. A 1-cycle delay is added to prevent mis-operation by nuisance input due to transients or noises.

6) BFP Trip Circuit

The BFP operation will send lockout trips to all adjacent CBs and blocks their reclosing. For a substation with 1-½ and ring bus configurations, a dedicated DTT scheme is typically deployed. The Fig. 5 explains the necessity of DTT for such stations. In this example, if the line-1 protection at remote terminal is not sensitive enough to detect the faults on the transformer low side, the fault cannot be isolated by the local BFP if the middle CB2 fails. A DTT signal initiated by BFP will remove the remote source.

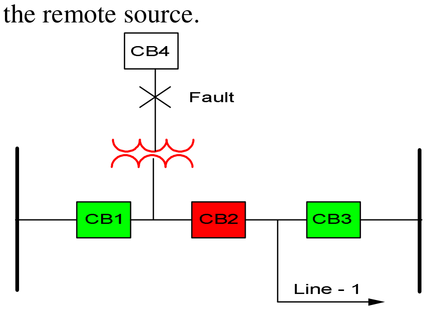

Figure 5. The need of DTT for a 1-½ bus configuration

C. BFP design in Utility-3

1) BFP Implementation

In Utility-3, all transmission CBs that are part of classified Bulk Electric System (BES) should have dedicated BFP installed. This is always accomplished by utilizing a stand-alone IED per CB or separate scheme per CB. The BFP will also be provided for HV and LV side CBs for a Dual Element Support Network Transformer and Bus-Tie CBs.

2) BFP Initiation Design

All primary protection devices that trip the CB also initiate BFP. In addition, trips from the other CB's BFP operation and the CB low dielectric trip (for Air blast, Oil or SF6-type CBs) also initiate BFP.

3) BFP Logic

The BFP logic resides in the dedicated CB control relay. As illustrated in Fig. 6, the logic includes the following three main paths, plus frame leakage protection trip and re-trip,

- Mechanical CB Failure Detection (62a Path)

The 62a CB failure path provides fast BFP when the CB mechanically fails upon fault detection. This path is supervised by a fast 52aa auxiliary CB contact, set to operate as soon as the CB mechanism begins to move. The typical 62a timer is 4.5 cycles or the measured 52aa response time plus 2 cycles, whichever is greater. If the FD remains picked up and the 52aa does not change state after the 62a timer expires, the CB is deemed failure, which leads to a BFP trip. In normal operation, it is important to ensure the 52aa auxiliary contact operates reliably within the design limit, in order to minimize the coordinating margin of the 62a timer setting.

- Electrical CB Failure Detection (62b Path)

The 62b CB failure path can handle the scenario where the CB may mechanically operate but electrically fails to interrupt the fault current. An example is CB contact flashover, where the auxiliary contact 52aa may be open, but the primary current continues to flow. The BFI signal is typically sealed-in for about 400 ms from the protective relay that initiates it. After 62b timer expires, the CB is deemed failure if FD still picks up. The 62b timer setting is based on the interrupting time of CB, overcurrent element reset time and coordination margin.

- Low Current CB Failure Detection (62c Path)

The 62c CB failure path is a last resort measure and used for instances where the fault level is below the pickup of the overcurrent detector. E.g. it is used in Special Protection Scheme or transformer applications. The 62c path is supervised by a regular 52a auxiliary contact in series with a CB selector contact in order to avoid inadvertent tripping when the CB is under test. The 62c timer is set to a standard setting of 500ms.

- Frame Leakage Protection (FLP)

Frame leakage protection is incorporated into the BFP scheme, and is provided for HV live tank CB and live tank CT. The FLP is based on instantaneous overcurrent relay with current taken from dedicated CT's installed at the bottom of live tank CB (or CT) to detect column flashover and to cover blind spots between the CT and the CB.

- The Re-trip

The BFP scheme also includes a separate re-trip output to provide redundant CB trip.

4) Fault Detector Settings

The Fault Detector (FD) of the BFP scheme includes High Set and Low Set overcurrent levels. The Low Set overcurrent is enabled after a settable delay to allow for coordination with CBs that utilize an opening resistor. In most cases, both the High Set and Low Set elements are set identically, sensitive enough to the available fault current. The setting is also intended to detect arcing and other faults within the CB. A typically setting is 1000 primary Amps. It is important to check that the setting is below 50% of minimum fault current.

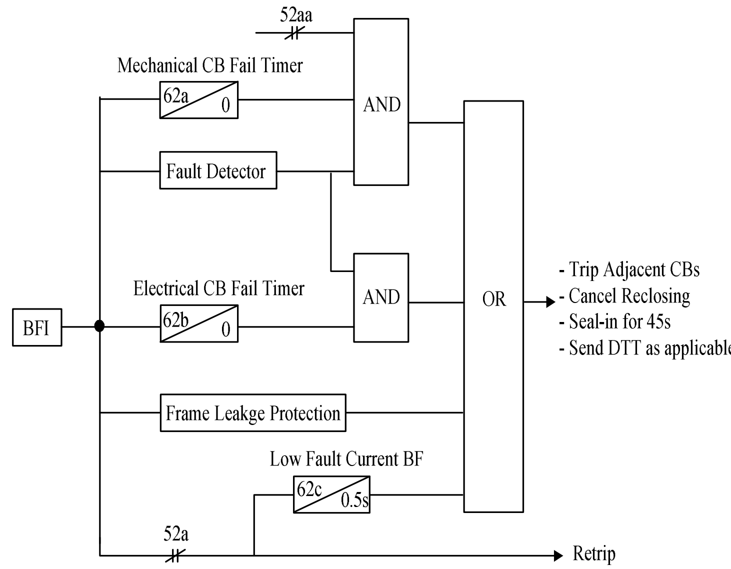

Figure 6. The Utility-3's BFP Logic

5) BFP Trip Circuit

The BFP operation will trip all adjacent CBs using an auxiliary relay and seal in this trip signal for 45 seconds. In addition, a DTT signal is sent to remote end as applicable. The seal-in trip signal cancels the automatic reclosing of all adjacent CBs. Through SCADA control, once the failed CB is isolated by opening its associated motor operated switches (MOS), the adjacent CBs can be closed manually. This BFP design has utilized the capability of modern IED relays to allow for quick restoration after a BFP operation.

III. CB FAILURE PROTECTION MIS-OPERATIONS

This section will review a few BFP mis-operations and the corresponding solutions to fix the problems. Most BFP schemes are intended to provide a reliable operation for a true CB failure condition. But in reality, the BFP schemes may be susceptible to the following situations:

- Unforeseen electrical characteristics of DC input circuits of BFI such as capacitive coupled transient, BFI contact bouncing, impact of ground faults in DC battery systems, switching transients, AC coupling with DC cables [5,6]
- Interaction of Microprocessor based relay scheme with legacy Protective relaying scheme
- Hardware problems
- Human errors

A. Mis-operation Caused by Legacy Circuit Design

A BFP mis-operation case was caused by the legacy protective circuit design after replacing the EM relay for BFP with an IED relay. In this case, a white light (W) was used to monitor the trip coil of the lockout relay (87BX1) for the bus protection. Since the IED relay use high impedance inputs for BFI, the BFP was falsely initiated in the case of loss of negative DC in the relay panel. A separate 87B contact should have been used for BFP initiation. But since the legacy relay does not have spare output, the solution was to move away the white light circuit.

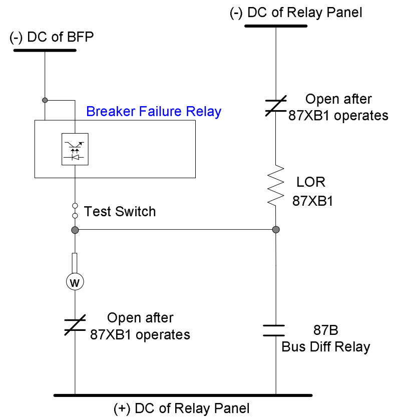

Figure 7. The BFP mis-operation case caused by circuit design

In a similar mis-operation case shown in Fig. 8-a, the relay trip circuit was monitored by a red light in the legacy scheme where a “Low-Low Pressure” normally-open contact 63MTPX was put in series with trip signal to initiate the BFP, in addition to the BFI through other inputs. Due to the red light monitoring circuit, whenever the “Low-low Pressure” was asserted, the BFP input would be activated through the red light branch. Because of the 63MPTX contact, the mistake was not found until mis-operation happened. The solution was to make modification as in Fig. 8-b.

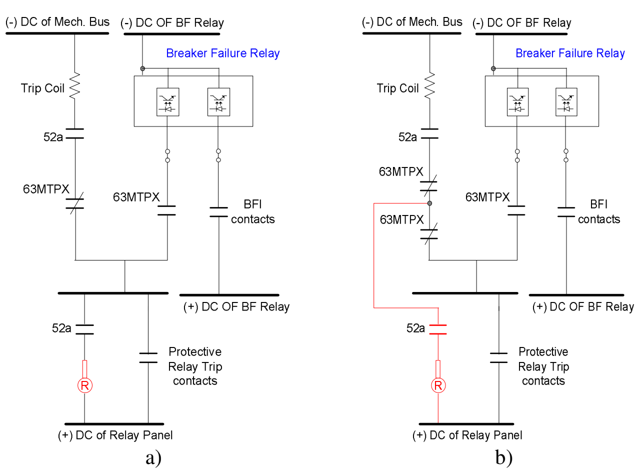

Figure 8. a) The BFP mis-op caused by circuit design. b) The fixed circuit

B. *Mis-operation Caused by Relay Output Contact Failure*

In another BFP mis-operation case, all the relays were digital and the BFP initiation circuit is as simple as shown in Fig. 9. The high speed hybrid output of the line relay was used to initiate the BFP. Due to the diode failure in the bridge rectifier circuit of the hybrid contact output, the BFP was falsely initiated. This hardware problem has been identified by the relay vendor.

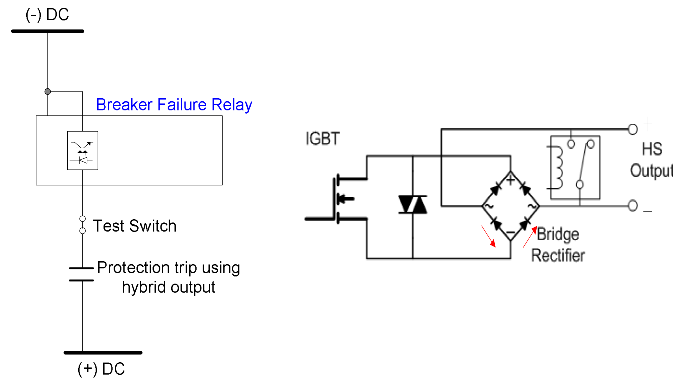

Figure 9. The BFP mis-operation case caused by circuit design

C. *Mis-operation Caused by Mysterious Input Activation*

Almost all the digital relays are using opto-coupler for digital input, which has very high impedance and is sensitive to small leakage current. There were a number of mis-operation cases that was caused by mysterious input activation during normal operation. One of the reasons is due to the capacitance between the long wires. The charges were accumulated over time and suddenly discharged when the DC negative was grounded. A small discharging current was able to activate the high impedance inputs. Another reason was the external interference signal or induced voltage when the cable shield was not properly grounded.

D. *BFP Mis-operation Caused by Human Error*

The human error caused a number of BFP mis-operations. In one case, the technician forgot to open the test switch for BFP initiation when he was doing the current injection test. In another case, the technician tried to use a jumper to simulate a trip signal but put the jumper to the wrong terminal that initiated the BFP. In a turn key project, due to the ambiguity of relaying interface, the BFP timer was mistakenly taken as re-tripping timer, which was set at 3 cycles.

E. *Mis-operation in a Generating Plant*

A generating station experienced a single-phase generator motoring event during a Generator Unit shutdown. The generator was driven by the network power as motor for 24 minutes. In this case, two 345kV CBs failed to open “A” phase and the CB pull rod failure was the root cause. The generator rotor experienced significant flux slot overheating during this event. The Unit was isolated finally by the operator.

In this station, there was no generator CB and the connection of the generator to the system is through two 345kV CBs at high voltage side of the step-up transformer. Since the Unit was coming off-line and also due to the high CT ratio, the current seen by the BFP relay was not enough to pick up the fault detector. The BFP had never operated. The CB auxiliary contact 52a was not included in the BFP logic. But even if it was included, the failure of the CB status 52a contact in this case would not allow BFP to operate.

For such application, the solution was to allow the generator reverse power protection to have two-stage operations to handle the worst situation. The first stage is to trip the unit breakers, with a delay of 2~5s. The second stage with a longer time delay (e.g. more than 30s) can activate the breaker failure lockout relay directly. The BFP overcurrent detector setting may also be reduced to the lowest level for these breakers.

F. Mis-operation due to BFP-Overcurrent Relay Failure

A BFP scheme using EM relays mis-operated during clearing of a circuit fault and it was found that the overcurrent relay of BFP scheme failed to drop out. The output contacts of the measuring unit were defective. The unit was replaced before the BFP scheme was put back to service.

G. Mis-operation due to Slow Breaker Auxiliary Contacts

In Utility-3, BFP mis-operated at a few locations due to slow auxiliary CB contacts. As shown in Fig. 6, if the 52aa auxiliary contact is slower than the 62a timer, or the 52a is slower than 62c timer, the BFP will output. The mitigation was to perform test at least once every 2 years to all the CBs involved in such BFP scheme.

H. Mis-operation due to Low Dielectric Trip

A BFP occurred due to SF6 gas density monitor relay operation. The operation was caused by rain water accumulation in the monitoring relay, not because of the actual low gas density. The drainage system of the relay was modified, the relay was dried and the breaker was put back in service later the same day.

IV. Methods to improve the Security of BFP

It is desirable to ensure both security and dependability of a BFP scheme. But from time to time a bias has to be taken in the scheme design. In general, the BFP design needs to bias towards the security due to the severe consequence of its mis-operation. However, the preference should be different when BFP is involved with power equipment such as generators and transformers. This section explores a few aspects that can possibly enhance the security of BFP.

A. The BFP Overcurrent Settings

Majority of BFP mis-operations were caused by false BFP initiation out of various reasons, including human error, inappropriate circuit design, hardware problem, etc. If this happened, the fault detector that uses overcurrent element would become the only defense line. If the overcurrent setting is lower than the load current, the mis-operation would become inevitable. On the other hand, the overcurrent setting has to be sensitive enough to ensure pickup for internal faults including high impedance faults.

Some Utilities use 1 Amp as across-the-board setting for BFP overcurrent element. The simplicity is the only advantage of this approach. But from system protection standpoint, it results in less security if there is no other means to supervise the BFP operation. Since BFP is a backup protection to isolate the fault, the overcurrent element should actually be a fault detector. In some line applications, the overcurrent setting could be set well above the normal load and be sensitive at the same time. Then why should it be more sensitive than needed? On the other hand, the 1A setting might not be sensitive enough for unit CB in transformer or generator applications. The point is: the overcurrent setting should be based on system study for each case instead of a universal value, especially when the overcurrent element is the only one in BFP fault detector.

For transmission line CBs, the setting of phase overcurrent should provide sufficient sensitivity for line end fault, such as 50% of minimum phase-to-phase fault current at line end. Hopefully it could be above the load but that is not the goal. It would be beneficial to have zero- and/or negative sequence overcurrent element in junction with the phase overcurrent element. By adding them, the fault detector sensitivity for unsymmetrical faults can be improved such that phase overcurrent element only needs to have sensitivity for internal 3-phase faults. The zero- and negative sequence overcurrent settings can be set above the maximum load imbalance, which is a easy way to achieve sensitivity for ground faults. In the applications that use single phase breakers, the zero- and negative sequence overcurrent element can be even more useful because it is unlikely that two or three single-phase breakers fail at the same time, so the phase overcurrent setting could be set higher.

The typical BFP time delay setting is 7-15 cycles that allows the CBs to interrupt the fault and give time for current detector to reset. Unless there is special system requirement, this timer should maintain sufficient margins for CB operation and FD reset. In addition, a longer delay for single phase ground faults may be considered in BFP scheme because the system usually have more tolerance to the ground faults, which is also the most frequent fault type. If the fault type can be reliably distinguished and a separate BF delay timer can be used and set longer for ground faults than for phase faults, the security of BFP could be enhanced.

B. Overcurrent Supervision by Disturbance Detector

If the phase overcurrent setting cannot be set above the load current to meet the sensitivity requirements, the overcurrent element itself may be supervised by a disturbance detector. The example logic is shown in Fig. 10.

Many digital relays have already included such disturbance detector that is based on the sudden change of the phase currents or the sequence component currents. The threshold of the current sudden change detection could be as sensitive as the relay cut-off current, such as 0.1A secondary. Since the sudden current change would not happen often, the disturbance detector can block the sensitive overcurrent element during normal operations but unblock it for any type of faults in the area. Once the disturbance detector picks up, it needs to be held for a while to coordinate with the slowest backup protection. For example, the off-delay timer t_{DD} in Fig. 10 may be set at 5~10s.

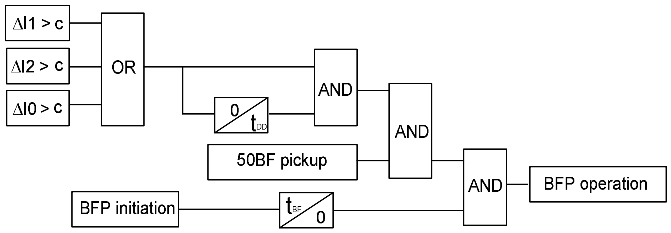

Figure 10.Use sensitive disturbance detector to supervise FD

C. *Overcurrent Supervision by Voltage Elements*

Another possible way to supervise the fault detector is to use voltage supervision. Similar to the disturbance detector, the combination of phase voltage, negative sequence voltage and zero sequence voltage may be used to supervise overcurrent elements in a BFP scheme, in order to make sure the BFP operation is only to clear the fault.

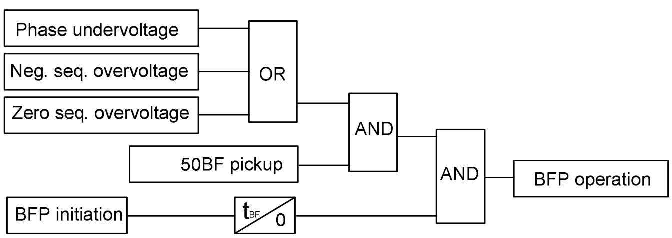

Figure 11.Use voltage elements to supervise FD

The voltage settings need to be sensitive enough to detect all the faults and try to avoid pickup by load. For example, the phase undervoltage setting may be set at 0.8 pu, the zero and negative sequence overvoltage setting may be set at 0.1 pu to avoid system imbalance. These values may be applied in most cases, but it is always necessary to verify the sensitivity. For some long line applications, the phase voltage drop due to phase-to-phase faults at the end of line may not be significant, such that phase undervoltage setting has to be raised to such a level that its capability as fault detector is compromised.

In transformer and generator protection applications, the voltage supervision shall not be used since the sensitivity is already a problem by using overcurrent alone in BFP scheme. An additional supervision will reduce the dependability of BFP.

To use voltage supervision, attention should be paid on the voltage source connections of the BFP relays. For example, in a one and half CB configuration, the BFP for middle CB needs to be able to see either bus voltage and determine which bus voltage should be used under different operational conditions.

D. *The Re-trip Function*

Almost every digital relay includes re-trip function as an option in BFP logic. But not every Utility takes the advantage of this useful function in typical BFP design. Apparently it looks redundant to send the trip signal once again to a failed CB. But in fact the re-trip function is mainly intended to reduce the severity of mis-operation caused by false BFP initiation. For example, if a relay tester initiated the BFP by mistake while the relevant CB is still in service, the re-trip scheme will be able to trip the CB before the BFP timer expires, such that adjacent CBs will not be tripped or even locked out by BFP. The mis-operation was not avoided by the mistake but the consequence is less serious with re-trip.

The re-trip function can also improve the security for applications that the CB has dual trip coils while there is only one high speed protection scheme. The general design will connect the primary relay to a trip coil and the backup relay to another trip coil. If the primary trip coil fails or the primary trip circuit has problem, the BFP initiated by high speed protection may be activated to trip all the adjacent CBs, since it is quite possible that BFP operates quicker than the other backup protections. The re-trip function can prevent BFP from operation if the second trip coil or trip circuit works properly.

Since re-trip is the output directly from relay input, cautions have to be taken to handle input transients. The high impedance inputs of digital relays are susceptible to DC transients, AC induced disturbance, and noise [5] [6] etc. This is similar to the problems of using digital relay inputs for transformer sudden pressure tripping, Bucholz tripping, inter-tripping schemes, etc. Hopefully the relay vendor may come up with some solutions to deal with this issue, such as described in [6] etc. But for a BFP re-trip function, a delay of 1~2 cycles can be added to avoid false pickup by input transients. After all, the speed requirement is not stringent on re-trip, as long as it can trip the CB and allow the BFP timer to reset.

If the CB has dual tripping coils, the re-trip function can send trip command to a second trip coil to enhance the backup protection. From this perspective, the re-trip also enhance the dependability of overall protection scheme. The re-trip output and CB failure output should always be separated and go through separate test switches even if there is only one trip coil. The re-trip should not be a lockout trip and it may or may not block the auto-reclosing. If the reclosing is not blocked, there is a chance to reclose the line CB automatically if the CB is tripped by mistake.

E. *The BFP Circuit Design*

The BFP initiation circuit design is important to prevent mis-operations. First, the test switch is a must for every BFP initiation signal if a separate BFP relay is used. To facilitate relay test, any protective scheme that is initiating BFP shall have test switch(s) on its own relay panel instead of the BFP panel. Second, a separate fused DC circuit should be assigned for BFP such that it is not mixed with other DC supply for protection or CB control. Third, special attention should be paid to the high impedance inputs of the IED relay. The normal relay output contact is safer than the hybrid output or the static output for BFP initiation. The cable for BFP initiation signal should be shielded and grounded at both ends.

If the signal cable is long, a resistor can be added in parallel with the high impedance input to handle the discharge of the wire capacitance. A de-bouncing timer (8ms-16ms) can be set for the high impedance input to avoid pickup by noise and transient disturbance.

F. *The Single-Pole CB Applications*

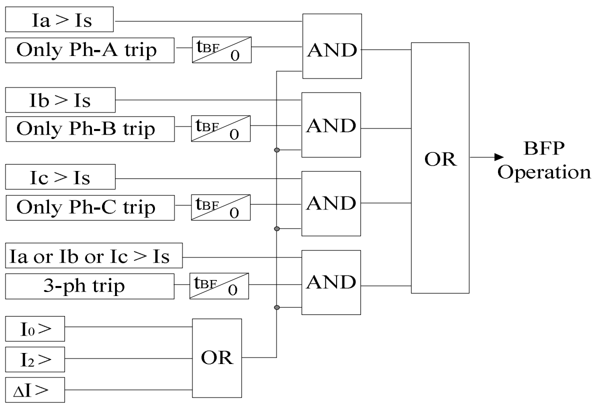

Figure 12.The BFP for 1-pole application

For single pole trip and reclosing applications, the BFP for single phase fault and multi-phase fault must be separate, as illustrated in Fig. 12. The zero/negative sequence fault detector or current sudden change detector could be used to enhance the security of BFP. A separate BFP timer that has longer delay may be used for the single phase ground fault.

G. *Separate CB BFP vs. Integrated BFP functions*

By using microprocessor-based relays, the BFP can be either accomplished by a separate CB relay, or through the integrated BFP function of the zone protection relay for line, bus, transformer, etc. The Fig. 13 & 14 compare these two designs for a 1-1/2 bus configuration. To utilize the integrated BFP, there could be less relays and less external wires so the security is enhanced. The dependability is also improved since the BFP redundancy is naturally realized. However, for a ring bus or 1-1/2 bus configuration, each zone relay must be able to bring in the CT inputs separately so the current detector can tell which CB fails. The traditional design of many utilities was to sum the currents outside the relay for line and bus protection, which is one of the reasons that they prefer to using separate CB relay for BFP.

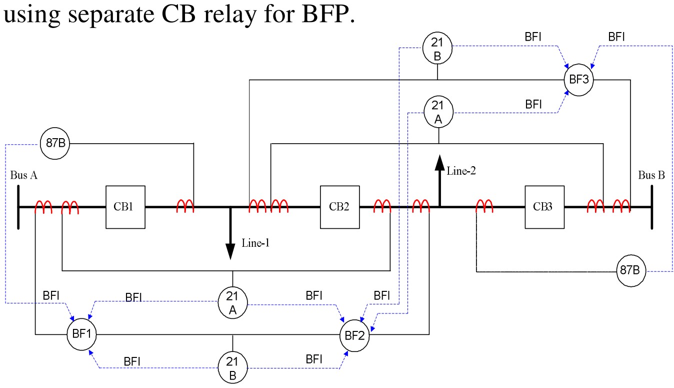

Figure 13.Use CB control relay for BFP

There are two ways to utilize the integrated BFP. One is called the fully integrated BFP scheme that every zone relay will incorporate an internal BFP function, as illustrated by an example in Fig. 14. The other way is called partially integrated BFP, in which some relays will still send trip signal to the zone relay that has BFP function. For example, when high impedance bus protection is included, it has no BFP function such that the trip signal has to be sent out to other zone relay to initiate BFP. The fully integrated BFP has the real benefit for security enhancement, while the partially integrated BFP may complicate the scheme. The GOOSE might be used as BFI to waive the hard wire, but it also brings a challenge for the field technicians to perform the test.

For now, it looks easier to use a separate CB relay to standardize the CB control and protection for all kinds of bus configurations and to maintain historical design. However, with the prevailing of multifunctional line relays and low impedance bus relays, it is foreseen that more and more Utilities will consider the fully integrated BFP schemes in the future.

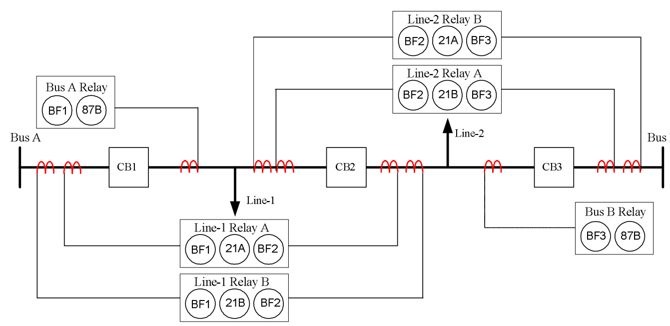

Figure 14.Use BFP fully integrated BFP

V. Dependability of the BFP

As a backup protection, the dependability of BFP must be guaranteed. Most BFP designs and applications do not have problem to meet this requirement. However, there were cases that BFP failed to operate due to hardware failure or because the fault detector failed to see the fault. The designer needs to carefully evaluate these possibilities and the impact to the system.

A. *Redundant BFP*

Since it is extreme contingency that CB failure and the associated BFP failure happen simultaneously, the redundancy of BFP is not required to meet the system planning standards [7]. However, for some critical applications, the BFP redundancy can be considered to increase the dependability of the overall protection scheme. After all, the cost of BFP scheme is relatively low. The fully integrated BFP can provide redundancy easily. But if the separate CB relay is used for BFP, another BFP relay should be added for redundancy. It is also preferable to have redundant DTT as part of the BFP redundancy.

B. BFP for the Bank CB

The BFP scheme for the Bank CBs should be treated differently from that for Line CBs. The Bank CBs are those associated with transformers, generators, reactors, condensers, and capacitors. Due to the equipment impedance and also high CT ratio in some cases, the fault current seen by the BFP relay could be low. For capacitor banks, if the CB or circuit switcher fails to trip due to a few capacitor pack failure, the primary current may not be higher than the normal such that the who capacitor bank may be burned if CB fails. In a Generating Station, the generator could be damaged if BFP fails to operate. Therefore, the dependability instead of security is the major concern for Bank BFP.

In order to increase the sensitivity of BFP fault detector, not only the phase current detector should be used, the zero~ and/or negative sequence current detector are needed too to increase the sensitivity of fault detection. And, as a last resort, the CB status auxiliary contact can added, It is known that the CB auxiliary contacts are not so reliable, but there is no better option to resolve the sensitivity issue by BFP scheme itself. For security, an extra delay could be added to the scheme for CB status condition, as shown in Fig. 15.

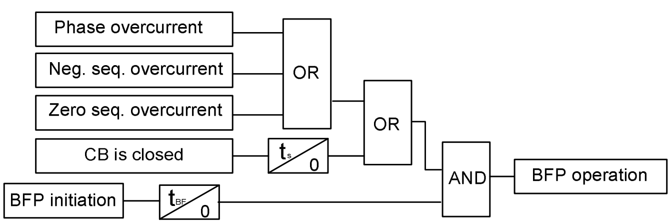

Figure 15. BFP Logic for Bank CB

For generator protection, it is also recommended to consider other back up protections that can handle the worst scenario in which both CB and BFP fail. For example, if the generator protection sees reverse power or negative sequence current for a certain period of time, the breaker failure lockout relay can be activated directly by generator protection.

VI. Conclusions

The CB Failure protection is an important defense line for power system stability and reliability. In this paper, a few BFP schemes currently used by Utilities are presented. These typical BFP designs are rooted from some considerations such as simplicity, security, dependability, historical practices, lessons learned, etc. They may or may not be exemplary design for others. The statistics shows that most BFP mis-operations were false tripping instead of false no-tripping. So the BFP design may need to be bias towards security even though it is desirable to achieve both security and dependability at the same time, and to keep simplicity in implementing and maintaining it. A good BFP design should avoid BFP mis-operation due to single component failure or human error. This paper explores a few aspects to enhance the security of BFP, such as BFP's fault detector settings, BFP circuit design, fault detector supervision, re-trip function, etc. Some BFP supervision logics are proposed as options for Utilities and relay vendors to consider. In the end, the dependability of BFP must be ensured, especially for the CBs that are associated with power equipment such as transformer, generator, reactor, capacitor banks, condensers, etc. Since the sensitivity of the general BFP fault detector in such applications could become a problem, it would be a wise approach to treat the transmission Line BFP design and the Bank BFP design separately.

References

[1] IEEE Guide for CB Failure Protection of Power CBs, IEEE Std. 37.119-2005.

[2] IEEE/PSRC Substation Protection Subcommitee WG K5, "Ancillary Protective and Control Functions Common to Multiple Protective Relays", http://www.pes-psrc.org.

[3] H. Altuve, M. Thompson, J. Mooney, "Advances in CB-Failure Protection", Proceedings of the 35th Western Protective Relay Conference, Spokane, WA, October 24-26, 2006.

[4] B. Kasztenny, M. Thompson, "CB Failure Protection – Standalone or Integrated With Zone Protective Relays", Proceedings of the 35th Western Protective Relay Conference, Spokane, WA, October 24-26, 200.

[5] B. Nie, S. Lam, F. Karchemskiy, E. Taylor, S. Nilsson and S. Vasilic, "Sensitive Relay Inputs – Contributing Factor to Major Power Outage", Proceedings of the 35th Western Protective Relay Conference, Spokane, WA, October 24-26, 2008.

[6] B. Kasztenny, V. Muthukrishnan, T. Sidhu, "Enhanced Numerical CB Failure Protection ", IEEE Transaction on Power Delivery, Vol. 23, No. 4, October 2008

[7] NERC System Protection and Control Task Force, "Protection System Reliability - Redundancy of Protection System Elements", November 2008, http://www.nerc.com/docs/pc

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