Summary of Revision, IEEE C37.119-2016, Guide for Breaker Failure Protection of Power Circuit Breakers

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***Abstract*— This summary paper covers principles of breaker failure protection and changes and additions that comprise IEEE C37.119-2016, Guide for Breaker Failure Protection of Power Circuit Breakers. The scope is expanded to include breaker failure protection of generator unit breakers. In addition to breaker failure initiation from fault conditions, initiation from automatic or manual tripping and closing devices that detect potentially damaging non-fault conditions is included. Column ground fault protection, breaker differential protection, and tandem breaker protection schemes are added. Different utility philosophies about how to apply breaker failure protection including ways to avoid single points of failure are discussed.**

***Index Terms*—BFP (breaker failure protection), BF (breaker failure), BFI (breaker failure initiate), BFR (breaker failure relay), 50BF, circuit breaker, fault.**

I. Background

Workgroup K5 of the Power System Relaying and Control Committee (PSRCC) has revised IEEE C37.119-2006, *The Guide for Breaker Failure Protection of Power Circuit Breakers*. This summary paper describes changes and additions to the guide, now referred to as IEEE C37.119-2016. A new clause describes protection of the power system from generator unit breaker failures. This protection is initiated not only from fault conditions, but also from automatic or manual tripping and closing devices that detect potentially damaging non-fault conditions. Descriptions for column ground fault protection, breaker differential protection, and tandem breaker failure protection have been added. Examples of how utilities apply BFP in ways that minimize the impact of single points of failure within the protection system are provided. Different utility philosophies about how the BFP interacts with local and remote control, automatic reclosing, lockout, and restoration functions are discussed.

II. Introduction

Local breaker failure protection (BFP) is added to protection systems to improve their overall performance during the occurrence of failures of the power circuit breaker itself or of associated components such as trip coils, DC control circuits, or auxiliary relays.

A distinction is made in the guide in Clause 4 between local BFP and remote backup protection. Remote backup is accomplished by a protection relay at the remote substation(s). Protection at the remote substation has no knowledge of when the local breaker is commanded to open by the local protection relay. On the other hand, local BFP is initiated by local protective relays in the same substation as the breaker being monitored by the local BFP. When a breaker failure occurs, the local BFP trips other adjacent local breakers to isolate the breaker that did not open. Pros and cons are discussed between these two methods. It is shown that local breaker failure protection is much more sensitive and selective than remote backup protection. The amount of time delay will be higher using remote backup protection vs local BFP, it may cost more to do local BFP, and there may be a complexity of settings and maintenance as the power system continues to change, etc. The guide recommends users to look at sensitivity, selectivity and speed requirements.

Clause 5 of the guide discusses all kinds of breaker failure modes covered by Breaker Failure relaying. There are two main failure modes of a breaker; failure to trip, and failure to clear. Some BFP schemes cover additional failure modes such as loss of dielectric material/pressure, loss of energy in its mechanics, and contact flashover.

III. BFP Schemes

A. Scheme Varieties

Clause 6 of the guide discusses a variety of BFP schemes. Common components of BFP include:

- Breaker failure initiation (BFI) by a breaker trip signal such as a protective relay that has operated to trip the breaker.

- Determination that the breaker has tripped successfully by monitoring the reset of an overcurrent element (50BF) that responds to each measured phase current (50P) and possibly the sum of these phase currents (50N), monitoring change in the state of the circuit breaker auxiliary contacts (52a, 52b, or 52aa), or some combination of these methods.
- A timer
- Some means to trip and block closing of adjacent breakers
- Optional: A separate output contact to issue a re-trip signal to the circuit breaker before issuing a breaker failure output with sufficient margin such that successful opening of the circuit breaker will prevent an undesired breaker failure trip output.
- Optional: A teleprotection channel to key a direct transfer trip and block reclosing of remote circuit breakers.

Advantages, disadvantages and cautions of each of the BFP schemes are explained throughout this clause.

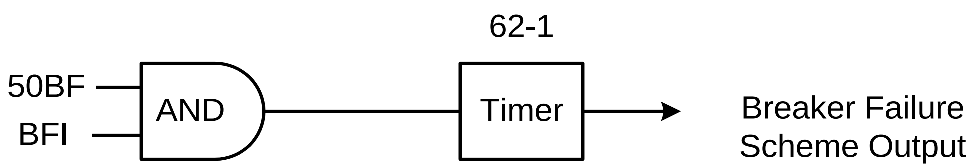

Fig. 1 Basic breaker failure protection logic

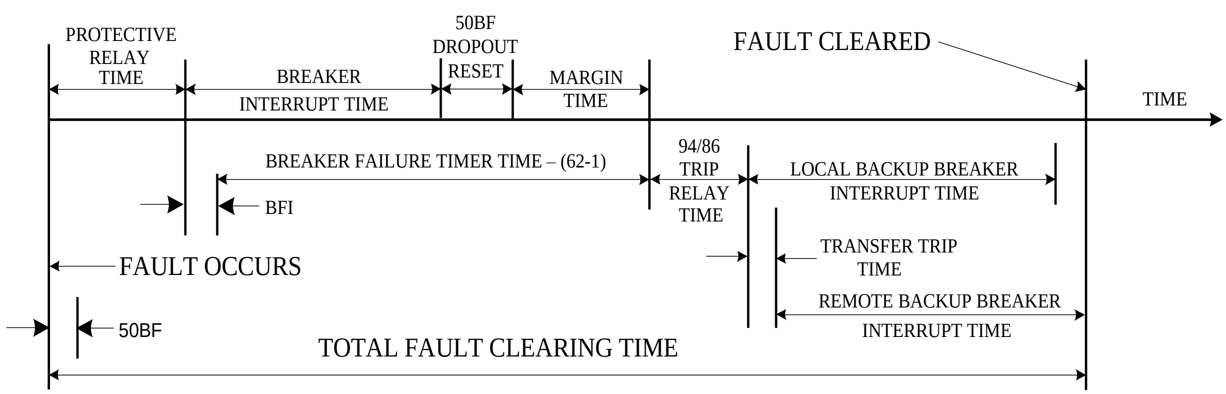

Fig. 2 Fault clearing timing chart

Basic BFP: The basic BFP scheme shown in Figure 1 is a very common scheme in the utility industry, which provides a basic understanding of how the scheme works with a protective relay. A fault clearing timing chart, shown in Figure 2, is included to assist the understanding of this basic scheme. The scheme consists of an overcurrent detection element supervising the initiate signal that triggers a timer. The timer output, if not being reset, trips adjacent breakers via an 86BF lockout or a 94 auxiliary tripping relay.

Basic BFP with re-trip logic: This is a variant of the basic BFP. A second separate timer is used to send a re-trip to the main breaker.

BFP scheme for dual breaker arrangement (ie. Ring bus or breaker and a half): This is a variant of the BFP scheme where the timer is initiated by a BF initiation signal. The timer output then is supervised with overcurrent to trip the adjacent breakers.

BFP scheme based on 50BF pickup time: The overcurrent pickup is only enabled after the initiating timer times out. Both the overcurrent element and the breaker failure initiating signal need to be picked up to trip adjacent breakers. An enhancement to this scheme can be added by a control timer to provide increased security.

BFP scheme with a 2-step timing arrangement: Essentially, the overcurrent is separated to identify the type of fault.

Different fault types will drive different timers to allow for different operating times. Multiphase faults generally have faster timer settings than single phase faults.

BFP scheme with initiation seal-in logic: This scheme improves dependability if the protection relay drops out before the breaker failure timer runs out.

BF timer bypass scheme: This scheme bypasses the BF timer if prior knowledge of the breakers' capability of operation (close or open) is known. For example, a low gas pressure condition will disable or bypass the standard BF timer delay and trip the adjacent breakers faster when the protective relay initiates the breaker failure scheme.

BFP scheme with minimal current: Most of the schemes that use overcurrent supervision logic require some level of fault current. Sometimes there is insufficient fault current to trigger the BF current detector. This scheme provides an alternative input using breaker auxiliary contacts (driven by the breaker mechanism) in parallel with the overcurrent input. It is also mentioned in this scheme that adding a seal-in to the BFI input is not recommended as it increases the risk of misoperation. An additional lockout status can be used as part of the scheme to reduce the risk by adding seal-in logic when it is necessary. The modified scheme is presented in the guide.

The Guide describes other complex BFP schemes that include a dual timer BFP with fast breaker auxiliary contact and current detector reset check scheme; a triple timer breaker failure scheme; and a single-phase tripping BF with retrip scheme.

B. Basic breaker failure with re-trip logic

Re-trip is a separate output contact from the breaker failure relay, which is intended to prevent undesired breaker failure operations and consequent loss of adjacent circuit elements for certain causes such as human error during relay testing, false initiation of BFP from DC transients induced on control circuit wires, and failure to trip due to loose or shorted breaker trip circuit wiring or non-functioning trip coils. Re-trip logic is designed to issue the re-trip signal to the breaker with sufficient time margin such that the successful opening of the breaker due to the re-trip signal will cause the 50BF element to drop out (and the 52a contact to toggle open) before the breaker failure timer expires.

Rarely, some utilities add a time delay (62-2 of Fig. 3) to the re-trip circuit. This helps identify, by observation of a slower breaker trip time (slower, due to the delayed re-trip output), a failure to trip by the first trip coil circuit. When the breaker failure scheme has internal sequence of events recording, the information can be used to determine whether the breaker operation occurred by the re-trip circuit or by tripping on the initial fault detection, and this might be used to inform maintenance personnel that a breaker inspection may be necessary even if the breaker has successfully opened. For this scheme the re-trip time-delay-on-pickup setting (62-2) needs to be coordinated with the breaker failure timer (62-1) for its effectiveness. Fig. 3 illustrates the addition of re-trip logic. Most utilities set the 62-2 timer to zero time. The dotted line illustrates an alternative connection of the re-trip timer to the output of the AND gate, which some manufacturers might implement for additional security.

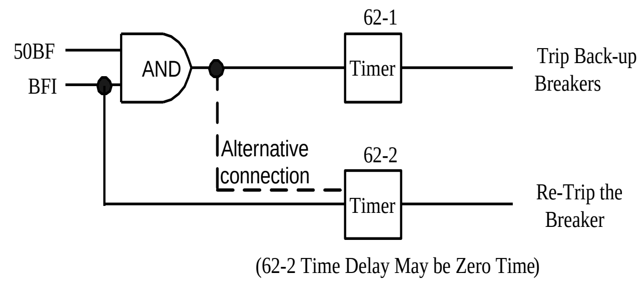

Fig. 3 Breaker failure re-trip

IV. Protection System Component Failures

A. BFP Detailed Design Examples

New Clause 7.6 has been added to the guide to provide details on how the design of BFP schemes applied to different breaker arrangements or protection philosophy can best support reliability. The North American Electricity Reliability Corporation (NERC) posted a standard authorization request (SAR 754) addressing power system performance despite single points of failure within the control and protection system. In 2009, NERC identified several wide area outages resulting from single protection device failures. A technical paper titled "Protection System Reliability, Redundancy of Protection System Elements" [1], was produced. Similar outages have occurred since then.

Clause 7.6 illustrates how utilities have provided separately fused control power to redundant relays, each operating on separate breaker trip coils. These best practices are of interest because short or open circuits in DC control power supply cables are credible failures, and there are many circuits to keep separated when applying redundancy. For dual breaker arrangements such as ring bus or breaker-and-a-half, there are two local line terminal breakers, each with two separate trip coils, each common to two protective zones (one on each side of the breaker) and where each zone has redundant primary relays. The choice to deploy any particular method affects the application and concept of the re-trip function provided by the BFP.

Fig. 4 (Figures 29 and 30 of the guide) provides a schematic representation of the separately fused circuits that comprise each method. One method shows each primary relaying system operating on separate trip coils with separate breaker failure initiation in a different circuit. Another shows primary relays with a limited number of outputs (legacy electromechanical devices) driving auxiliary relays to initiate breaker failure. Two separate initiate inputs to the breaker failure relay are used to maintain galvanic isolation in a different method.

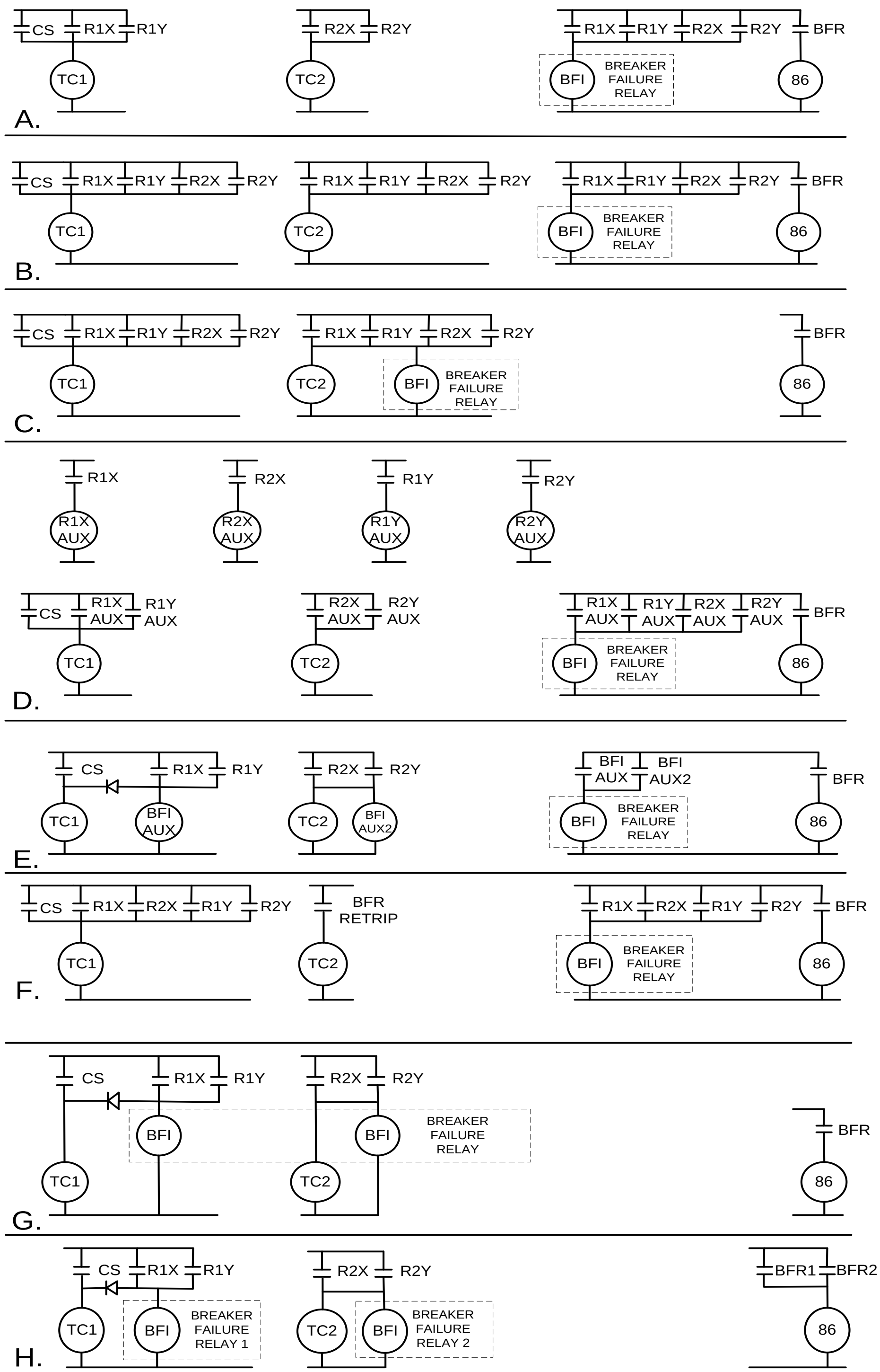

Fig. 4 Methods to initiate BF for circuits X and Y on each side of a breaker

Another example shows how two separate breaker failure functions (or relays) might be applied as a single aggregate BFP where the BFP function is integrated with the primary protection function. In another practice, each primary relay operates separately on both trip coils with a separate initiate or with the breaker failure initiate input in parallel with one of the trip coils. Finally a method is illustrated where both the first and second primary relay systems operate on one trip coil and separate contacts from each primary relay initiate the breaker failure scheme in a separate circuit with the breaker failure re-trip function being relied upon to trip the breaker using the second trip coil.

The pros and cons of each method are discussed including description of how the BFP might interface with legacy equipment and how initiation from manual tripping is typically prevented. With each of these best practices, it is important to recognize that no single component failure can disable both the primary breaker tripping AND the breaker failure backup tripping. An example of a breaker failure scheme is provided that shows interface of the BFP circuits with legacy type electromechanical relays.

B. False BFI due to accidental DC battery grounding

Positive and negative buses of DC battery supply systems for protective relaying are typically ungrounded, with high-impedance center-tapped grounding through light bulbs or a ground monitoring circuit in the charger. If either bus (lead) suffers a ground fault, the dc supply to protection systems is sustained, but the ground potential suddenly shifts by half the battery voltage.

There have been cases where BFI signals in power plants or substations are conveyed from primary protective relays to breaker failure relays by long wiring runs, with significant capacitance to ground. When a DC ground fault occurs, the cable capacitance couples the shifted ground voltage to the BFI input. Relays with high input impedance and a response threshold below half of dc supply voltage would seal in and initiate a false backup trip.

Battery grounding is a common single-contingency failure, and BF protection schemes need to be secure when it happens. It is unlikely that BFI will be falsely energized if any of the following measures are applied:

- Selecting a relay with a BFI input design that responds only above half of the maximum battery voltage.
- Selecting a relay whose binary inputs are compliant with IEC 60255-26, Measuring relays and protection equipment – Electromagnetic compatibility requirements, with specific reference to Clause 7.2.7, Power frequency immunity on DC binary inputs [7].
- Minimizing cable run length and capacitance.
- Utilizing a data communications-based means for conveying the BFI signal between buildings – a serial status transfer protocol implemented via the serial ports of many modern microprocessor-based protective relays, IEC 61850-8-1 GOOSE binary points on optical Ethernet LAN, or equivalent data connection [6].

V. SPECIAL BFP SCHEMES

A. Generator breaker failure protection

The application of breaker failure protection to breakers associated with large synchronous generators is very different from transmission substation applications. Events of prolonged motoring of generators due to a stuck breaker that was not isolated by a properly designed breaker failure scheme are not uncommon.

While considerations unique to generator applications are discussed in C37.102, IEEE Guide for AC Generator Protection [4], in many cases, the person responsible for designing the breaker failure protection system for the high-voltage breakers may not be a generator protection expert and therefore, not familiar with this document. This situation has become more prominent with the division of ownership and operational responsibility between generation and transmission assets brought on by reregulation of the electric utility industry. For this reason, the working group felt that a clause should be added to C37.119 to ensure that all persons charged with designing and setting breaker failure protection systems are familiar with the unique requirements for a dependable breaker failure system for generators.

While transmission breakers are normally tripped by short circuit protection where significant current is usually available, most of the protective elements associated with a generator are for detecting abnormal operating conditions and not for detecting short circuits. Many of the conditions that can cause severe damage to the generation system are not accompanied with high currents. Further, remote backup via overreaching elements cannot be relied upon to supplement the breaker failure scheme. Thus, the breaker failure protection scheme must include a means to detect failure of the breaker to open that does not rely on detection of current through the breaker.

To add this clause to the guide, it was necessary for the working group to ask the IEEE Standards Association to expand the scope of the guide beyond failure to clear power system faults. The scope was expanded to include performance failures of the power circuit breaker other than fault clearing failures such as failure to operate, either tripping or closing. Note that, for the first time, failure to close during synchronizing is now covered.

The new clause provides a list of application considerations that are somewhat unique to generator applications. It goes into considerations of CT locations, breaker and bus arrangements, open breaker flashover protection, and generator failure to close protection.

For example, open breaker flashover is most likely to occur just prior to synchronizing or just after the generator is removed from service, when the voltage across the generator breaker contacts approaches twice its nominal value as the generator voltage slips through 180 degrees out-of-phase with the power system. The guide describes special logic that can be added to the breaker failure scheme to address this hazard.

A hazard that is unique to generator breakers is potential damage to the generator and prime mover caused by slow closing during synchronizing. If the breaker fails to close in the time expected, the generator can slip past the angle of safe closure and be severely damaged if an out-of-synchronism close should occur. Here is a unique application where the breaker failure system is used to detect a failure to close event and isolate the breaker to prevent a faulty synchronization. A new clause describes in detail the application of this scheme.

When starting up a generator, it should be carefully synchronized to the power system to minimize the mechanical and electrical stresses to the turbine-generator set. Such stresses can be the result of differences in speed (slip rate), voltage, and angle across the open synchronizing breaker in the instant before the breaker closes. If the differences are large, severe transient torques will occur to snap the generator rotor and prime mover into phase with the power system. Also, transient currents can be in excess of the three-phase bolted fault current that the windings are designed for. The result of a faulty synchronizing event can be twisted or broken shafts, turbine blade fractures, or failed windings.

A generator is typically brought on line with its voltage matching the system, and its speed slightly faster than the system. This will ensure that the generator will inject a small amount of power into the system, to prevent operation of protection schemes that detect various abnormal operating conditions, such as reverse power, loss-of-field, out-of-step, or over-excitation. The synchronizing system is designed to cause the synchronizing breaker's main contacts to make at the instant when the angle difference across the breaker is as near zero degrees as possible, within the Safe Close Angle region shown in Fig. 5 [*Figure 27 of the guide*]. Thus, the synchronizing system must take into account the slip rate and rated closing speed of the breaker, and give the close command at a calculated time in advance of actual synchronism, before the angle difference reaches zero.

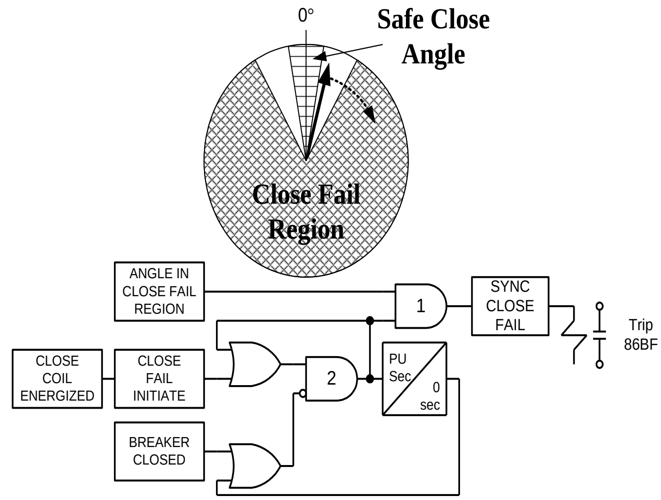

Fig. 5 Synchronizing breaker failure to close tripping logic

However, if for any reason the breaker mechanism is slower than expected, the generator rotor angle will advance beyond the Safe Close Angle and into the Close Fail Region. Depending on how long it takes for the breaker to actually close, the angle can increase to a point that severe damage can be expected if the contacts eventually do close. To prevent this possible out-of-phase close, the breaker failure protection system can be used to isolate the synchronizing breaker, such that the system side of the breaker has been de-energized, and the generator safely closes onto a dead bus.
Breaker failure to close protection system logic is shown in Fig. 5. Similar to other breaker failure scheme logic there is an initiate condition (indication that the breaker has been commanded to close), and a supervising condition (indication that the breaker has actually closed.) The supervising condition is the angle difference between the generator and the system, which will be zero if the close is successful.

The CLOSE FAIL INITIATE input is asserted by the presence of a voltage signal at a point in the close circuit nearest the close coil. Should the close be delayed long enough, the ANGLE IN CLOSE FAIL REGION input asserts, satisfying AND gate 1, resulting in a SYNC CLOSE FAIL output, which trips the synchronizing breaker 86BF lockout relay.

CLOSE FAIL INITIATE is sealed in until the breaker closes, or the window of opportunity timer expires. The window of opportunity timer is provided to disarm the scheme for the case where the breaker actually closes, but the BREAKER CLOSED indication (52a contact) fails to change state. Without this timer, the scheme would be armed and a BF trip could occur when the generator comes off line.

B. Series (tandem) breakers

There are two conditions for which system planners may recommend installing two breakers in series for the purpose of meeting applicable planning criteria following a breaker failure contingency. The first occurs when a breaker failure would result in unacceptable system performance due to tripping two adjacent critical transmission elements. The second occurs when the critical clearing time to maintain stability is shorter than the minimum breaker failure clearing time that is achievable. In both cases, placing two circuit breakers in series will address the concern. However, the protection system design may differ depending on which condition drives the need for the series breakers.

When the series breakers are needed to prevent tripping adjacent critical transmission elements, it is not permissible to overlap the protection zones for the two critical elements. As a result, a separate bus differential protection is needed to detect faults in the zone between the two series circuit breakers as shown in Fig. 6 *[Figure 20 of the guide]*. The protection for the two critical elements could trip both series breakers simultaneously, in which case there is no need to initiate BFP for either series breaker from the protection systems on the two critical elements. However, it is necessary to provide BFP for each series breaker to be initiated by the bus differential protection. Alternately, the protection systems for the critical elements could trip only the series breaker adjacent to the element. In this case, the BFP for each series breaker would be initiated by both the bus differential protection and the adjacent transmission element protection.

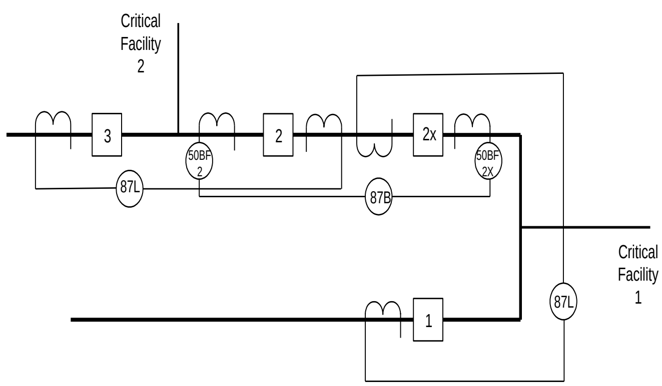

Fig. 6 Tandem breakers scheme

When the series breakers are needed to provide fault clearing in less than the critical clearing time, it is necessary to design the protection systems to avoid the need for BFP on the two series breakers. Overlapping the protection zones of the two adjacent elements around both series breakers achieves this objective by eliminating the need for a separate bus differential and BFP as shown in Fig. 7 *[Figure 21 of the guide]*. In this case it is permissible to overlap the two zones and trip both series breakers for a fault detected on either transmission element. In this case, as long as one breaker operates correctly, the critical clearing time is achieved; thus, BFP for the series breakers is not necessary. This arrangement is not acceptable when the concern is tripping two adjacent critical elements, since it does not provide the selectivity needed to avoid tripping both elements for a fault between the two circuit breakers accompanied by one of the tandem breakers failing.

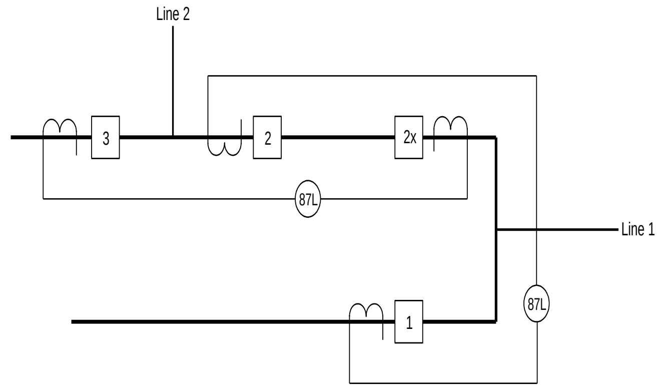

Fig. 7 Tandem breakers scheme without BFP

C. *Column ground protection*

The use of live tank circuit breakers introduces additional protection considerations for providing overlapping zones of protection and detection of ground faults on live tank circuit breakers and associated CT columns. A live tank circuit breaker is a current interrupter operating at line voltage, which requires CTs to be contained in a separate stand-alone column adjacent to the breaker. With this arrangement, it is not possible for the protections on each side of the breaker to overlap one another. This results in a "blind" zone on or between the live tank breaker and the free-standing CT, which can be detected by the protection for an adjacent element on only one side of the breaker. As a result, a fault in the blind zone will not be cleared. The most likely fault in the blind zone is a column to ground flashover; thus, column ground fault protection is added to promote fault detection and clearing.

The live tank breaker interrupters (one per phase) are physically mounted on the top of an insulated column. The CTs for the breaker are on top of an adjacent insulated column in a separate housing. Additional CTs are mounted around the base of the breaker and CT columns for the purpose of measuring ground fault current. In the event of a failure or short circuit of the primary of either the breaker column or the CT column to ground, an overcurrent relay supplied from the column base CTs will detect the fault. One design is to have the CT column secondary current and the breaker column CT secondary in parallel on each phase and summed into the overcurrent relay input, as shown in Fig. 8 *[Figure 19 of the guide]*. The output of this relay would directly operate the 86BF lockout relay coil, bypassing the BFI input of the breaker failure relay. The 86BF relay would trip and lockout all circuit breakers and initiate DTT for elements adjacent to the failed breaker or CT column.

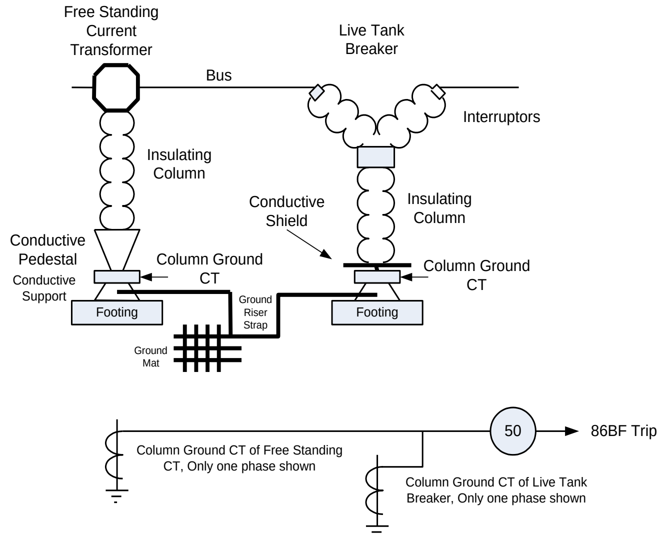

Fig. 8 Column ground fault protection

D. Breaker differential protection

Breaker differential protection is an option that may be used to detect circuit breaker internal faults, which may not be correctly diagnosed if the fault occurs when the main contacts are open, there is no visible damage, and the fault is cleared by primary protection devices before breaker failure relay pickup. If the operator does not have a breaker failure target or alarm, then the time needed to identify the faulted breaker may be unreasonably long, resulting in a lengthy outage until equipment is placed back in service. In the worst case, the operator may test the faulted breaker, resulting in a dangerous and catastrophic failure.

Current differential protection elements, supplied from CTs on each side of the breaker, are useful for accurately detecting faults that occur within circuit breakers. Such protection can operate quickly and independently of primary protection applied on adjacent elements, and bypass the breaker failure timer to immediately declare a breaker failure output.

Use of breaker differential protection varies across the industry as a result of differing operating and dispatch practices. This scheme provides useful information; however, it requires an extra relay scheme with associated cost and maintenance. An alternative to using a differential element is sensing the logical condition that protection on both adjacent zones has picked up.

VI. SETTINGS OVERVIEW

Typical breaker failure schemes include a phase current detector element and an operate timer. In addition, they may also include a ground detector current element. Fig. 1 [Figure 2 of the guide] shows a current detector operating a timer. In some schemes, the current measurements are only activated when the assigned breaker is requested to trip and the breaker failure timer has timed out. When the breaker has successfully operated and cleared the fault, the current will go to zero in both the phase and ground current detectors.

In order for a breaker failure scheme to operate as designed, the current detectors need to be set sensitive enough to respond to any fault condition. There are a few applications in which use of sensitive current detectors may not be adequate where the protective relays are designed to operate for fault and abnormal operating conditions that draw little or no current through the breaker. In these cases, the current detector in the breaker failure scheme will be limited by the minimum sensitivity of the breaker failure relay (BFR), and the scheme may need to be supplemented with non-current sensing inputs, such as breaker position status.

Setting the circuit breaker failure logic operate timer long enough to permit successful fault clearing by the circuit breaker and including a safety margin will reduce the possibility of scheme misoperations.

Criteria for setting the current detectors typically depend on system strength and bus configuration. Generally, it is desirable to set the current detectors above maximum load to reduce the possibility of the current detectors from being picked up under load for non-fault conditions. On the other hand, in many cases, the maximum load current is significantly higher than the minimum fault current and the breaker failure current pickup setting may have to be set below the maximum load level.

Further, the guide describes fault detector setting for breakers as part of multi-breaker configuration, generator connected breakers where protection is applied for non-fault conditions, and fault detector setting practices of some utilities.

For three-phase tripping applications, a ground current detector in the breaker failure scheme can typically be set with greater sensitivity than the phase elements to provide additional sensitivity for faults involving ground.

If either the phase or ground breaker failure current detector cannot be set sensitive enough to facilitate tripping for all faults, then a scheme based on 52a breaker auxiliary contact may be required as presented in the guide. On the other hand, this breaker failure scheme is otherwise discouraged as the breaker auxiliary contacts are considered to have low reliability relative to the rest of the breaker failure scheme and may lower the overall security of the breaker failure scheme. To improve dependability an alternative scheme that “ORs” the current detector with the breaker auxiliary contact could be used instead to sense whether the breaker has operated successfully.

The guide also describes an effect of subsidence current on the current detector dropout timer.

Minimum breaker failure time delays are applied for all fault types to enhance system stability, limit equipment damage, improve coordination of overlapping protection schemes, and improve quality of supply by minimizing the duration of power system voltage dips. The guide further documents the criteria for setting the breaker failure time delay.

The total clearing time of the BFP scheme is the summation of the following quantities (as applicable):

- Relay operate time
- Relay output time
- BFR input recognition time
- Breaker failure timer
- Breaker failure output operate time
- Auxiliary and lockout relay operate times
- Communication delay time
- Backup breaker operate time
- Adequate margin

The guide discusses a possibility of setting different breaker failure timers for the different types of faults. For an example, the breaker failure timer for three-phase faults may be set lower than for single-line-to-ground faults as the three-phase faults are more severe and may need to be cleared faster.

The guide also discusses settings considerations for a control timer in a breaker failure scheme based on current detector pickup time. The control timer is utilized to increase security by limiting the window of time for producing a breaker failure output. The control timer setting for the scheme should be carefully considered on circuits that have high-speed sync-check reclosing because of the possibility of producing a BF output if a primary protective relay trip contact fails closed.

VII. Communications-Based Breaker Failure Protection

Communications are used for breaker failure protection to send a direct transfer trip (DTT) signal to a remote line breaker(s) in the event the local breaker fails to trip. This enables high-speed remote clearing for faults that would otherwise be cleared with time delay. DTT also avoids fault situations that may not be detected by remote protection because fault contributions are small.

The communication channel could operate over various communication mediums such as leased telephone lines, power line carrier, microwave, or fiber optic paths. It needs to be dependable during fault conditions to enable the DTT signal to be received correctly. Equally important, this channel needs to be secure and to not cause incorrect spurious DTT because it is designed with no added supervision.

The guide also documents the development of IEC 61850 and other network-based methods, which is targeted to reduce the costs and improve the efficiency of integrated substation protection and control systems by replacing the hard wiring between the IEDs with high speed peer-to-peer Ethernet based communications. This type of communications is sensitive, time critical, and is highly reliable, and therefore, it can be applied for breaker failure.

For example, peer-to-peer communications-based breaker failure protection can be either designed:

a) As a function in an IED that initiates the breaker failure protection when it receives the trip signal from the relay protecting the faulted power system equipment. This, essentially, emulates a traditional stand-alone breaker failure relay.

b) As a built-in function in the protective IED (for example, a line relay) that detected the fault and issued the trip signal.

VIII. Testing Overview

Because a breaker failure scheme is critical to the protection system, its testing is very important. At the same time, caution needs to be exercised during testing to avoid an accidental scheme operation, causing an unnecessary outage to generation or customer loads.

Testing of the breaker failure scheme also includes the testing of the relays that initiate the breaker failure function. It needs to be regularly performed for all of the relay technologies, whether electromechanical, solid state, or microprocessor.

The test process checks the pickup value of the current detector. Other tests include verifying the breaker failure timer that is typically 6−12 cycles, and verifying the reset time of the current detectors.

During commissioning testing, the complete functional test of the breaker failure relay is performed with its whole scheme and each breaker failure initiate input is verified. The ultimate circuit performance is proved by testing the ability of the lockout relay, which is typically operated by the BFR output contact, to trip and block close all breakers around the failed breaker and initiate a DTT to the line's remote end if so designed.

The guide outlines the following items that should be considered when testing the BFP schemes.

- Isolation switches are required to allow maintenance and testing of the scheme.
- Auxiliary tripping relays may be considered while designing the BF schemes for less invasive testing process.

- Although it is possible to test a BF relay with its corresponding breaker in service, a better practice is to isolate the breaker to reduce the possibility of an erroneous trip output.

- A thorough review of drawings is necessary to determine all possible BF initiation sources and trip paths.

Unless enabling BFP trip outputs for trip checking, they need to be isolated whenever test current is passed through the BF relay current coils and/or whenever the relays that provide a BFI signal are being trip tested.

A full set of commissioning tests is recommended prior to placing a new BF relay in service, including initial testing per the manufacturer's recommended initial test procedure; applying relay settings provided by the protection engineer and testing current detectors and timers accordingly; and mechanical inspection of electromechanical models for broken/damaged components, tight connections, and contact gaps/wipe as applicable.

The guide further documents testing considerations for specific breaker failure schemes such as in multi-breaker applications and commissioning testing considerations for the overall breaker failure scheme.

IX. Conclusion

Quality breaker failure protection is critical to the high reliability that is expected from a transmission network. Recent events have influenced the need to provide examples of how to best apply the BFP to meet expectations and overcome single points of failure. The guide is now more comprehensive and includes generator breaker failure protection and other special schemes. Awareness of best practices when applying BFP are critical to those planning, designing, setting and maintaining, commissioning or operating any transmission grid.

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[2] IEEE, PES, PSRC, workgroup I-19 technical paper, "Redundancy Considerations for Protective Relaying Systems".

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[3] *IEEE Guide for Breaker Failure Protection of Power Circuit Breakers*, IEEE Std. C37.119-2016, July 2016.

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[1] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[5] *IEEE Guide for Protective Relay Applications to Transmission Lines*, IEEE Std. C37.113™

[6] *Communication networks and systems for power utility automation, Part 8-1, Specific communication service mapping (SCSM), mapping to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3*, IEC 61850-8-1 Ed. 2.0 2011

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