Evolution and Experience: Breaker Failure Protection

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Abstract

Breaker failure protection has evolved in its implementation from remote backup, to local backup using discrete relays, to being an integral part of the main protection in microprocessor relay schemes. This paper reviews breaker failure protection and the schemes that are being implemented in the industry based on some of the work currently being done in working group K2 of the Power Systems Relaying Committee. Some of the pitfalls in applying breaker failure protection are discussed as well as issues associated with timer settings, initiation elements, and breaker failure relay / reclosing relay coordination.

Introduction

This paper is the result of the work working group K2 of the Power Systems Relaying Committee has done in developing the document PC 37.119 “Guide for the Breaker Failure Protection of Power Circuit Breakers”. At this writing the document is in the process of being submitted for balloting. The following people were members of the Guide for Breaker Failure Protection of Power Circuit Breakers working group:

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When a fault occurs on a power system, protective relays identify the fault and trip the breakers necessary to clear the fault. In some cases, due to equipment problems, the fault is not cleared. Backup systems are called on to isolate the fault from the system. These backup systems can be classified as remote backup or local backup depending on where the backup devices are located. Let's look at the system in figure 1.

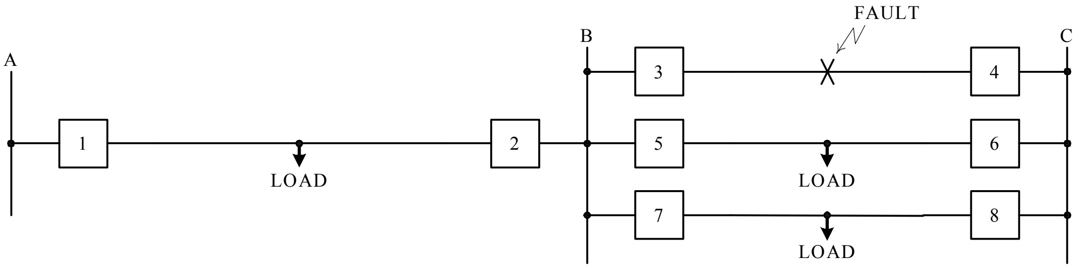

Figure 1 - Remote Breaker Clearing

A fault occurs on the line between breakers 3 and 4. Breaker 4 clears properly, but breaker 3 fails. Relays at breakers 1, 6, and 8 have overreaching elements that sense the fault and after some time delay, typically about 0.5 seconds, operate and clear the fault. This, of course, also interrupts the service to customers on lines 1-2, 5-6, and 7-8. But the fault is cleared and damage to the line and breaker are minimized. This is called remote breaker clearing, or remote backup. There are several disadvantages with remote backup protection. First, all of the tapped load on the unfaulted lines is lost. Second, the reach on the relay at breaker 1 needs to be set long enough to see the fault on line 3-4. This may pose problems. Third, the long time delay of the relay at breaker 1 necessary for coordination will lead to slow clearing and possible system instability.

Suppose now, that there was another relay at breaker 3 that detected the breaker did not clear the fault. This relay could issue trip commands to breakers 2, 5, and 7 to isolate the fault from the sources. In doing so the loads being served from the non faulted lines would still be served. This is called local back up protection. Breaker Failure Protection is a form of local backup protection.

Basic Breaker Failure Scheme

A basic breaker failure scheme is shown in Figure 2.

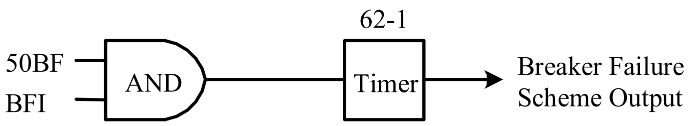

Figure 2 Basic Breaker Failure Scheme

The timing for this scheme is shown in figure 3.

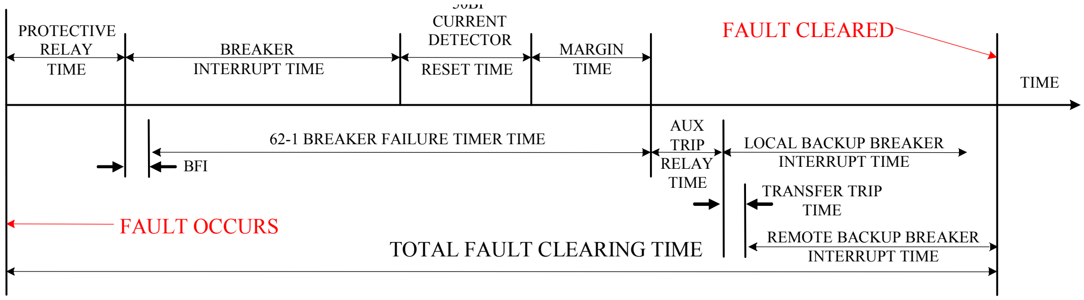

Figure 3 - Fault Clearing Timing Chart

There are three components to the breaker failure scheme: the current detector (50BF), the breaker Failure Initiate (BFI), and the timer (62-1). A protective relay detects a fault and issues a trip to the breaker. At the same time, the relay sends a breaker failure initiate (BFI) input to the breaker failure scheme. Current flow through the breaker picks up the current detector (50BF) and the "AND" is satisfied. The breaker failure timer (62-1) starts. If the breaker is operating properly, the current will cease to flow before the breaker failure timer times out. The current detector (50BF) drops out and the timer resets. If the breaker does not clear the fault, the breaker failure timer times out, and the breaker failure scheme operates. The output of the breaker failure scheme can do several things: Trip all the adjacent sources that supply fault current to the failed breaker, attempt re-trip of the failed breaker, activate direct transfer trip, and block reclosing of the failed breaker and adjacent breakers.

Let's take a closer look at two of these components: the current detector (50BF) and timer (62-1).

Current Detector

The purpose of the current detector is to determine if the system has continued current flow after the breaker was called upon to operate. It's important for the current detector to pick up for minimum fault current conditions. Current detectors are non directional instantaneous relays that monitor phase, ground, and residual current, or any sequence component of these currents. Phase current detectors are set above the maximum load current for the following reason. If the phase current detector was set below load it would be picked up under normal load conditions. There is a risk that during trip testing, the breaker failure scheme may not be disabled and breaker failure operation may occur.

The ground current detector should be set sensitive enough to detect the minimum fault with margin that the protection on the breaker is set to detect. The ground overcurrent pickup setting should be set high enough so that fault detector dropout will not be delayed by dc current decay present in ct circuit, which often occurs following a breaker operation or ct saturation.

If either the phase or ground breaker failure current detectors cannot be set sensitive enough to ensure tripping for all faults that initiate tripping of the breaker, then the 52a auxiliary contact should be used. A scheme employing a 52a auxiliary contact should be used only when required as these contacts are considered to have low reliability relative to the rest of the breaker failure scheme. Their use lowers the overall reliability of the breaker failure scheme.

Breaker Failure Timer

The breaker failure timer should be set so that the breaker has a chance to clear the fault and the current detector resets before it times out. The timer setting should take into account protective relay, auxiliary relay, and breaker operate times, as well as allow for the current detector (50BF) dropout time and adequate margin. The total breaker failure time should also be less than the transient stability time. It should also be set less than the time which damage to major pieces of equipment may occur, and less than the time major customer processes may be affected. Stability requirements usually dictate the setting be between 10 to 30 cycles. On occasion this may be as low as 7 cycles. Equipment damage typically occurs after 30 cycles. Customer processes typically the same. Since the scheme doesn’t start until the protective relay call for a trip, there is no need to provide additional delays to coordinate for faults outside the protective relays zone.

As can be seen in figure 2 the total clearing time for the breaker failure scheme is the sum of the breaker failure initiate pickup plus the breaker failure timer time plus auxiliary trip relay time plus local backup breaker time. If a remote source has to be removed then transfer trip time needs to be added to get the total clearing time. This total clearing time has to be less than the transient stability limit time.

Critical switching time for stability is the most often the limiting factor in determining the maximum total clearing time permissible. Critical switching time is dependent on many factors: severity of the fault, loading on the system, mass of the generators, and type of fault. Three phase faults must be removed faster than phase to phase faults which need to be removed faster than single line to ground faults. Using this knowledge, some schemes have multiple timers with different settings for different types of faults.

Circuit Breaker Failure Modes

Breaker failure protection schemes become enabled when protective relays initiate the tripping of a circuit breaker and the breaker does not interrupt the fault current. Breaker failure can be caused by a variety of situations:

Failure to trip – Failure to trip occurs when breaker contacts do not open after the trip circuit has been energized by the protective relay. This could be caused by a short or open in the trip circuit wiring, or a short or open in the trip coil. It could also result from a mechanical problem in the breaker.

Failure to clear – In this case the breaker contacts open but the arc is not extinguished and current continues to flow. This could be cause by a mechanical problem, or a dielectric problem (contaminated oil, loss of vacuum or low gas pressure). This scenario is quite different than failure to trip because the breaker auxiliary contacts (52a and 52b) change state indicating the breaker has opened when it in reality didn't. This is why the auxiliary contact position may not be a true indicator of the breaker position.

There are other instances that a breaker operates incorrectly, but are not classified as breaker failure. These should be considered in the system design. Examples of these are: Loss of dielectric, contact flashover, and failure to close.

Breaker Failure Schemes

The Guide for Breaker Failure Protection of Power Circuit Breakers, PC37.119 contains many schemes for breaker failure protection. Here are a few:

Since the operation of a breaker failure scheme is a last resort. One should make every attempt to let the breaker open on its own. One way to do this is with a Re-Trip circuit which gives the breaker a second opportunity to trip before a breaker failure is declared. For breakers with two separate trip coils, the circuit can be made to function if one trip coil fails to function properly. The re-trip logic can energize the second trip coil and open the breaker before a breaker failure condition is declared. Figure 4 shows a re-trip scheme:

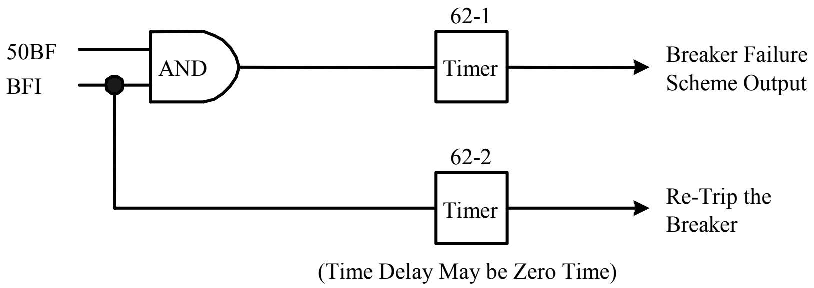

Figure 4 - Breaker Failure Re-trip

The re-trip time delay on pickup setting (62-2) must be coordinated with the breaker failure timer (62-1). The operating speed of the output contacts used for re-trip should be accounted for in the overall time delay settings, since slower speed output contacts may be used for re-trip activation. The operating speed of the breaker should also be considered in arriving at the margin between re-trip (62-2) and breaker failure timer (62-1) settings. For inherently slow clearing breakers, the coordination between re-trip and breaker failure timers should be considered, and additional system stability and protection coordination studies may be required if the breaker failure timer is to be extended.

The re-trip design logic is generally independent from the breaker normal tripping scheme activated following fault detection. When the relay has sequence of event recording, the information can be used to determine whether the breaker tripped via the normal path or through re-trip. If the breaker tripped via the re-trip path, then the main trip circuit could be checked in the next maintenance interval.

Re-trip logic may not be desirable in some cases for security reasons. For example, the re-trip logic may be viewed as more of a risk for a false trip than an improvement to reliability in applications with redundant protection schemes. Re-trip logic that may react to transients or temporary dc grounds must be avoided. The contact change-of-state recognition time should be greater than the length of any expected dc transient. A one quarter cycle delay should be sufficient. The pickup level of an input circuit should also be high enough to be secure for a battery ground situation. An input pickup level greater than one half the battery voltage is recommended.

In strong systems and in power plant switchyards where very short critical clearing times are a major concern, adequate reset time for the 50BF current detector may not be easily achievable when using the scheme shown in Figure 2. A slightly different scheme is shown in Figure 5. The current detector is enabled only after the 62-1 timer has timed out. The theory is that current detector pickup time is generally shorter and more predictable than dropout time; which is especially true with electromechanical relays. Also, if the breaker has normally interrupted the current by the time the 62-1 timer times out, then the reset time of the 50BF is not an issue. Eliminating the 50BF reset time significantly reduces the margin requirements. If the breaker fails to interrupt the fault current, the 50BF is allowed to pickup and produce a breaker failure output.

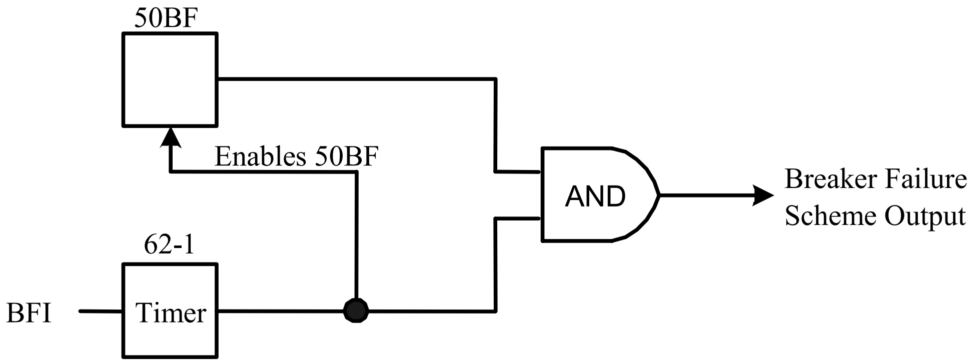

Figure 5- Elimination of 50BF Reset time.

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Regardless of current detector dropout issues, the logic shown in Figure 5 has an advantage in multi-breaker line protection schemes, such as ring bus and breaker-and-one-half schemes, where current in one breaker may be insufficient to pick up the current detector until the other breaker trips. This logic permits the breaker failure timer (62-1) to start timing with only the BFI input, eliminating the delay that might occur if the current detector input (50BF) were also required to start the breaker failure timer, as in Figure 2.

An enhancement to this scheme, shown in Figure 6 is a control timer, which increases security by limiting the window of time for producing a BF output to a short period following a BFI signal.

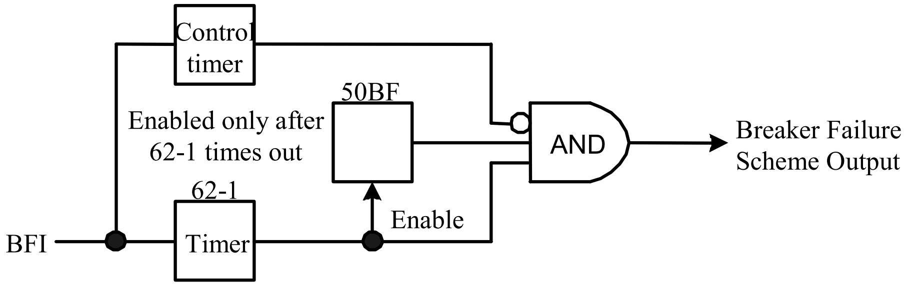

Figure 6- Addition of control timer

The control timer setting for the scheme shown in Figure 6 must be carefully considered on circuits that have high-speed sync-check reclosing. This is due to the possibility of producing a BF output should a line relay trip contact fail closed.

For example, consider a line terminal with a BF relay having the scheme of Figure 6. The breaker failure timer is set at 7 cycles and the control timer is set at 36 cycles. The phase current detectors are necessarily set below load so that the BF relay senses all fault conditions seen by primary relays (minimum fault current below maximum load). The same terminal has a sync-check relay set to close in 15 cycles following a breaker trip, if the bus and line voltages are in-phase.

Now, consider the situation that would occur if a line relay on this terminal failed with its trip contacts closed. This stuck contact would provide a BFI input to the breaker failure relay, which starts both the breaker failure and control timers. After three cycles, the breaker trips successfully, but the BFI signal continues due to the failed line relay contact. Fifteen cycles later, the breaker recloses via the high-speed sync-check, restoring line load through the breaker. By this time the BF timer has expired and there is current in the breaker, but the control timer has not yet expired. Thus an erroneous breaker failure output is produced, tripping the backup breakers on the bus section and disrupting the transmission system.

A proper control timer setting would coordinate with the sync-check reclosing time delay, and thus limit the window of opportunity for a breaker failure output. In the specific case above, a control timer setting of 13.5 cycles would have prevented the erroneous breaker failure output while still providing enough margin to produce a needed breaker failure output for an actual breaker failure condition. A proper setting of the control timer would result in the line breaker tripping to lockout instead of locking out the entire bus from an erroneous BF output.

It is necessary to be thoroughly familiar with the method used by a particular breaker failure relay manufacturer, along with knowledge of the scheme in which the relay is placed, when setting this control timer.

There are good reasons to use the Breaker Failure Initiate Seal-In function provided on modern breaker failure relays. Some high-speed relays do not seal-in the trip output, and fault conditions can evolve with time such that the trip output may not be present for the full breaker failure relay time delay. Modern breaker failure relays can use either one of two seal-in scheme configurations.

The first scheme, shown in Figure 7, requires that the current detector be picked up continuously for the breaker failure timer (62-1) to time out. Thus, the current detector (50BF) must continue to be energized even if the initiating relay (BFI input) momentarily resets. The breaker failure timer must have sufficient margin to allow the reset of the current detector for normal breaker clearing.

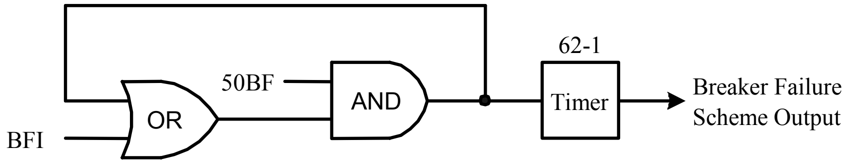

Figure 7 - Breaker Failure Seal-In

The second scheme does not enable the current detector until the breaker failure time has elapsed, as shown previously in Figure 5. For multi-breaker bus arrangements, such as breaker-and-one-half, ring bus and double-breaker double-bus configurations, the current distribution through the breakers can be substantially different. In this scheme, the BFI seals-in independently and starts the breaker failure timer (62-1) without regard to the initial current level through the breaker. Thus, after the first breaker trips and the breaker failure time has elapsed, there is enough current in the failed breaker to pick up its current detector and immediately provide a breaker failure output. The breaker failure time delay is not dependent on the slow or intermittent pickup of the current detector.

Transformer and generator faults, and faults in harmonic filters, may not be of sufficient magnitude to pick up a breaker failure current detector (50BF). Figure 8 shows a breaker 52a contact that has been added in parallel with the 50BF input. With this addition, the scheme will operate properly for low-magnitude faults because both the dropout of the 50BF current detector and the opening of the 52a breaker auxiliary contact are necessary to interrupt the 62-1 breaker failure timer. However, breaker auxiliary switch contacts should only be used when absolutely necessary. While operation of the auxiliary switch might properly indicate that the breaker mechanism has operated, it is not sufficient indication that the circuit breaker has interrupted the fault current.

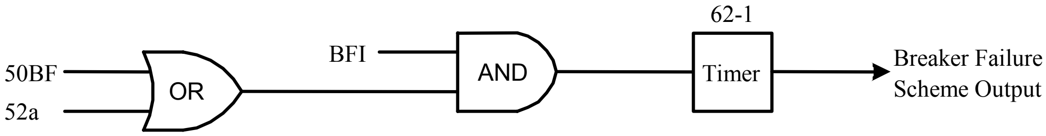

Figure 8 - Minimum Fault Current Scheme

Many other schemes such as; multiple timers, fast 52aa contacts, coordination with single phase tripping breakers , and bypass schemes are discussed in the guide.

Design Considerations

Breaker failure schemes are normally activated by the protective relays or systems used for equipment protection such as bus, line, transformer, or capacitor. The overall performance and proper operation of the local breaker failure protection scheme is critical in terms of isolating the problem and preventing cascading affects elsewhere in the system.

Breaker failure schemes are employed wherever failure of a breaker to operate or interrupt has an unacceptable impact on the system. It traditionally has been applied on the high voltage system and is increasingly being applied at all voltage levels. The breaker failure scheme may require the use of a communications channel for the tripping of local or remote breakers.

Some of the factors influencing the proper operation of the breaker failure protection involve the design of the breaker failure scheme. Typical design considerations for breaker failure protection schemes include:

- Scheme operation should only occur when expected and desired.
- Scheme operation should be independent of the types of failures detected in the breaker. For example, the failure mode of the breaker trip coil (either failed open or shorted) should not affect the scheme's ability to detect the failed breaker and to properly isolate it from the power system.
- Scheme operation during loss of the direct current (dc) source to the failed breaker.
- Sufficient overlapping of protection and isolation switches to allow maintenance and overall testing of the scheme.
- Proper application of auxiliary tripping relays, when applicable.
- Selection of properly rated inputs and outputs when the breaker failure is integrated as part of the equipment protection package and when user selectivity in rating is provided.
- Proper application of dc circuits and avoidance of mixing supply sources.
- Minimizing the impact of dc transients.

An independent breaker failure system should use a dc source that is different than the dc source used for the breaker control or bus differential scheme. Care should be exercised to avoid mixing of dc sources to minimize the impact of floating sources activating the breaker failure scheme unnecessarily; however, it is not necessary to use a separate station battery to supply the breaker failure system. The dc source for each of the breaker failure, breaker control, or bus differential schemes should consist of a separate fused dc circuit. The use of properly rated diodes or failure circuits independently will minimize exposures to mixing of the dc sources. The possibility of inadvertently tying dc sources together is reduced when the breaker failure function is integrated as part of the protective relay; however, both the primary and secondary relays should have this function included so that loss of one relay does not also disable breaker failure.

It is recommended that the breaker failure protection dc circuit be protected with a circuit breaker rather than a fuse. The breaker failure dc circuit should be monitored to detect loss of the dc supply. The impact of transient voltages on relays with internal power supplies should also be evaluated in the application of the dc source for breaker failure relays.

The bus configuration may support sharing of the dc source for multiple breaker failure relays provided that the dc source is properly selected. The design should be such that a single component failure does not result in the loss of the ability to trip and the breaker failure protection not being available.

The breaker failure design can include a "re-trip" circuit, or "re-trip" logic in the case of microprocessor devices. The re-trip function is intended to give the breaker a second chance to open prior to the breaker failure scheme timing out. A properly designed breaker failure scheme should alarm the maintenance personnel that a breaker operation occurred by the re-trip circuit as opposed to normal opening of the breaker.

The selection and application of breaker failure auxiliary tripping devices is also critical, particularly during commissioning stages or during maintenance intervals when scheme verification needs to be performed without tripping energized equipment. The scheme testing procedures and design should allow for the auxiliary tripping relay coil to be energized with the trip isolation switches open without damaging the auxiliary relay. Otherwise, care should be exercised to insure complete isolation of the auxiliary tripping relay coil to avoid its failure during testing.

Factors impacting the overall performance of the breaker failure scheme should be carefully examined prior to the design and implementation. The design should minimize the use of auxiliary components where possible, as these devices introduce additional failure points and time delays in the scheme. For example, one should use a dedicated set of breaker auxiliary contacts instead of using an auxiliary relay to multiply contacts that are already in use.

A breaker failure scheme may be initiated by receipt of a direct transfer trip (DTT) signal for various reasons. For example, when DTT is part of a the line protection or where DTT is used to quickly remove faults on line reactors, capacitors, or transformers that are on the line, the local breaker failure scheme may be initiated by a DTT signal from the remote terminal. When transfer tripping is used to activate breaker failure, proper isolation of the local transfer trip receivers should be incorporated to prevent inadvertent breaker tripping and breaker failure initiation during routine maintenance of the DTT transmitters at the remote substation, or when the communication circuits used for DTT are being tested.

A breaker failure scheme should not be designed such that manually opening a breaker activates the breaker failure scheme. Protective devices for the equipment connected to the breaker will active the breaker failure scheme should an insulation failure occur during a manual operation.

The breaker failure design should also consider the following where applicable:

- Any protective relay operation should activate the breaker failure scheme.
- Blocking reclosing of all tripped breakers.
- Effects of single pole tripping on breaker failure scheme operation.

Element in Multifunction Protective Relay

Intelligent Electronic Devices (IED's) including intelligent multifunction protective relays are the most common devices in today's new installations of substation protection and control systems. Intelligent multifunction relays typically include a set of primary protection functions required for the protection of the primary system equipment as well as multiple additional protection or non-protection elements that expand their functionality. The drawback to employing the breaker failure function in a multifunction device is the loss of independence of the breaker failure scheme from the primary or backup protective relays. Therefore, when applying breaker failure protection as part of an existing primary or secondary relay, the issue of commonality must be recognized and its effect on the application must be evaluated.

One of the most common additional built-in functions present in multifunction relays for the protection of feeders, transformers, motors, or transmission lines is breaker-failure protection. It can vary significantly in the level of complexity, ranging from a basic single timer to multiple timers and elements.

Following inception of a fault, one or more main protection functions or devices will operate and issue a trip signal to the fault interrupting device. If the fault condition has not been cleared following a set time delay after the trip initiation, the breaker failure protection will operate.

The BFP element can be configured to operate for trips triggered by protection elements within the relay or via an external protection trip. The latter is achieved by allocating one of the relay opto-isolated inputs to 'External Trip', or breaker failure initiate.

Care should be taken when applying breaker failure protection included in multifunction relays to ring bus, or breaker and one half bus configurations. Often times current transformers from both breakers feeding the protected line will be paralleled at the input to the relay. Should one of the breakers fail to clear the fault in this configuration, it will be difficult to tell which of the breakers is faulty. A larger portion of the bus will have to be cleared to isolate the failed breaker. With several lines exiting a ring bus, each with it's associated multifunction line protection controlling multiple breakers, the problem becomes more complex.

To review this issue and others associated with non traditional elements in multifunction relays, the PSRC has established a new working group to investigate the issues and write a report to the PSRC.

Communications is Breaker Failure Schemes

Communications are used to trip the remote breaker when the local breaker fails to clear the fault. These communications are in the form of a Direct Transfer Trip (DTT) signal passed on by a local transmitter to the remote receiver. The communications path can be powerline carrier, audio tone, microwave, or direct fiber. As the name implies, direct transfer trip has no supervision. Therefore, the channel must be very secure. To increase the security of the channel, it's customary for users to provide dual independent channels for transfer trip. Outputs contacts of the receivers are connected in series.

The integrated substation provides another approach to providing breaker failure protection. In UCA 2.0 or IEC 61850, hard wiring between IED's is replaced with high speed peer–to-peer communications. IED's report status changes to each other. Generic Object Oriented Substation Event (GOOSE) messages can be sent between IED's reporting relay operation and breaker status. The associated IED's receiving the message, use the contained information to determine what appropriate protection response is for a given state. It can be used for breaker failure protection to initiate a distributed breaker failure protection function or to trip the adjacent breakers.

The performance of such a scheme is described as follows: The relay will detect a fault condition on the protected line and will issue a trip signal in order to clear the fault. This can be a GOOSE message. The bay controller that implements the distributed breaker failure function will subscribe to this message, and as soon as it is received will start the breaker failure timer. If the breaker fails to trip, the breaker failure function will indicate a breaker failure and will send a GOOSE message to the substation LAN to trip adjacent breaker in order to clear the fault.

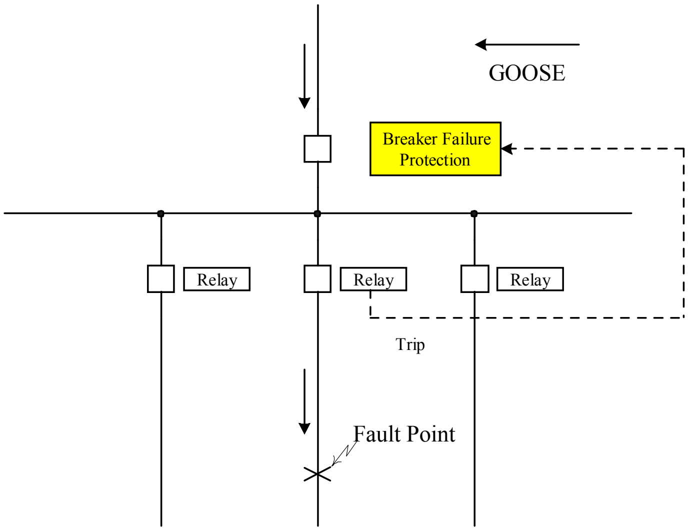

Figure 9. Distributed Breaker Failure Protection

Breaker Failure Relay Testing

Considering the necessary control actions performed by breaker failure outputs, users must be very careful when testing these schemes. Results of erroneous Breaker Failure (BF) tripping include dropping local loads, interrupting multiple transmission paths, tripping remote breakers with the possibility of dropping tap loads, and tripping or causing instability in generators. However, due to the importance of these schemes and the possible catastrophic consequences should the scheme fail to operate, initial and periodic testing is recommended.

The guide reviews several guidelines to follow when testing a breaker failure scheme.

The breaker failure scheme is part of the overall protection for the system. The circuit breaker could be called on to operate by many different protections: Primary bus protection, secondary bus protection, primary line protection, and secondary line protection. Testing of the breaker failure scheme can be done in concert with the other protections using synchronized testing via GPS capability in test equipment.

Conclusion

Several conclusions can be drawn from the discussion:

1. Breaker failure should only occur when desired.
2. Breaker failure timer setting should allow for adequate margin between back up breaker clearing and system critical clearing time.
3. Multiple timers can be used when critical clearing time is very short. Longer timer settings can be used for line to ground and phase to phase faults, and shorter timer settings can be used for three phase faults.
4. Current detectors should be used whenever possible due to the unreliability of breaker auxiliary contacts.
5. Retrip options should be used to give potential failed breakers a last chance to clear the fault before the entire bus is cleared.
6. Phase current detectors should be set above load to insure no operations during breaker failure scheme testing.
7. Seal-in circuits can be used to insure breaker failure scheme does not drop out prematurely.
8. Care should be exercised when applying breaker failure scheme to ring bus and breaker and one half schemes.

More information will be available when the guide is published next fall.

Bibliography

An Appraisal of Remote and Local Back-up Relaying, L.F. Kennedy, A.J. McConnell, AIEE Transactions, Vol. 76, pp735 - 741, October 1957

An IEEE PSRC Report , “Summary Update of Practices on Breaker Failure Protection”, *IEEE Transaction Power Apparatus and Systems*, Vol. PAS-101, No. 3, pp 555-563 , March 1982

Darlington, A. N., Patrick, T. W., “Experience with Local Breaker Failure Protection”, Georgia Tech Protective Relay Conference, May, 1973

Elmore, W., H Li, H., Westinghouse Electric Corp., “Breaker Failure Relaying”, *Silent Sentinels*, RPL 80-1, June 1980,

IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Addition

IEEE Committee Report, “Local Backup Relaying Protection”, 69TP 602-PWR, *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-89, No. 6, July/August 1970

Li, H. *Protective Relaying Theory and Applications*, Backup Protection, New York: Marcel Dekker Inc, 1994, pp.303-316.