Circuit-Breaker-Failure Protection: A Logical Design Path

Samuel Hogue, GE Vernova

Introduction

Circuit-breaker-failure protection is widely discussed, from requirements to implementation and testing. The general theory seems simple but quickly becomes quite complex when analyzed. Fortunately, IEEE, NERC, and many others have provided numerous examples of circuit-breaker-failure implementation, the issues that can arise, and recommendations for proper operation. All this information is substantial and can be overwhelming when choosing a design path. This paper presents a decision-based logic path that guides the reader from design constraints to the best-practice solution for their situation.

This paper begins with design constraints such as available fault current, circuit-breaker layout, and single-pole vs. three-pole tripping. Next is consideration of security, speed, and outlying conditions. Once this general design path has been determined, the next section determines the features of the circuit-breaker-failure protection scheme; these include timing, re-trip, remote trip, single vs. dual trip coils, and alarming. Lastly, this paper presents a real design implementation with considerations of external circuit-breaker-failure initiate, internal vs. external tripping sources, blocking the circuit-breaker-failure protection, the utility of knife blades and cut-out switches, and more. A full design path is presented along with specific guidelines on the needs and implementation of that design.

This paper employs microprocessor relays in the solution; electromechanical relays are not in the scope of this paper. Also, this paper does not consider single-sided energy applications like static VAr compensators (SVCs). Although the auxiliary (aux) contact methods described may be used on these devices, it is often not the optimal method of monitoring circuit-breaker failure for these types of equipment; in-depth options for these types of equipment will not be considered. Generator circuit-breaker-failure design and live-tank, circuit-breaker failure with respect to ground faults is not considered. All these circuit-breaker-failure applications have been thoroughly detailed elsewhere and references to these applications are at the end of this paper.

To begin, consider the three things that any circuit-breaker-failure system must have. First, it requires circuit-breaker-failure initiation or a method of arming the circuit-breaker-failure protection. Typically, this is a trip command. Second, circuit-breaker monitoring must be present. This is the part of the system that checks if the circuit breaker has opened successfully or it failed to open. Finally, circuit-breaker-failure outputs must perform the remedial actions necessary to clear a failed circuit breaker.

Configuration Considerations

There are circuit breaker parameters to consider in configuring an effective circuit-breaker-failure scheme. These include the following:

- Current source and available fault current
- CB status contacts
- Number of circuit breakers to operate
- Available communication
- Required scheme operating time

Current Source and Available Fault Current

Does this circuit-breaker-failure scheme have a single current source for the circuit breaker in question? If the circuit breaker has an isolated current source, it is advisable to include current-monitoring elements in the circuit-breaker-failure scheme. This is an overcurrent element that checks whether current is flowing through the breaker CTs after a trip command has been sent. Some relay schemes have currents from multiple circuit breakers summed into one current input in the back of the relay, such as breaker-and-a-half schemes. If this is the case, each separate circuit breaker does not have an isolated current source and this can cause the circuit-breaker-failure scheme to mal-operate during some conditions and possibly during testing. If no isolated current source exists for the circuit breaker, the simplest solution is to exclude current monitoring from the circuit-breaker-failure scheme. However, this is not the only solution. There are alternative methods that can be used to include current monitoring on a shared relay current input, but these can become complex to the point of causing more mal-operations than correct operations. Another thing that must be considered when using current monitoring on a shared current input is testing and operations. Is there a case where a field technician could inadvertently cause a circuit-breaker-failure operation while doing maintenance of a circuit breaker on a shared current input? Note whether current monitoring will be used in the circuit-breaker-failure scheme and continue designing the scheme.

Is there sufficient, available fault current for a current pickup element to register? There must be adequate available fault current through the circuit breaker and the CT ratio must be low enough that a current monitoring element will pick up and drop out for the circuit breaker in question. The relay manual should describe minimum pickup current necessary for the current elements. System-modeling software or a fault study will determine minimum fault current flow through the circuit breaker in question. Lack of fault current can also occur with high-impedance-grounded systems. If sufficient fault current is not available, it is advisable to use auxiliary contacts for circuit-breaker-status detection.

CB Status Contacts

Does the circuit-breaker-failure scheme have status contacts for the circuit breaker or switch in question? The circuit-breaker-failure scheme must include either status contacts for the circuit breaker or current monitoring for the circuit breaker. Although it must have either or, having both the current and status inputs will increase the security of the circuit circuit-breaker-failure system. However using both leads to an important security question that will be discussed further on, that is, should the circuit-breaker-failure system require both status and currents to operate, or should the circuit-breaker-failure system require status or currents to operate? Once it has been determined and noted whether the circuit breaker has status inputs available for circuit breaker failure, the setup can be continued.

Number of Circuit Breakers to Operate

How many circuit breakers does the circuit-breaker-failure scheme need to clear to extinguish the fault that the circuit breaker in question failed to clear? Answering this question leads to vetting the relay performing the circuit-breaker-failure scheme. Consider the following [1;2]:

- How many output contacts are necessary?
- What type of communication is required?
- Perform the circuit-breaker-failure scheme in a separate relay? (Use of a separate relay for tripping will be considered in a subsequent section)

Available Communication

Is there communication to each of the adjacent or remote circuit breaker(s) from the relay that is providing circuit-breaker failure? This can be a tricky question because the goal is to cover all the circuit breakers that the circuit-breaker-failure scheme needs to clear in the event that the circuit breaker in question has failed. Communications types vary from the copper wires of an output to the fiber and microwave necessary to trip a circuit breaker at an adjacent substation. If there is no form of communication to send a signal to a circuit breaker that must be tripped, how is that circuit breaker going to clear the fault? In some cases, like very long transmission lines without communications schemes, it is acceptable to rely on the remote-end protection scheme to trip the circuit breaker. However, it is always preferred to have the relay performing the circuit-breaker-failure protection send a trip signal to all the circuit breakers that need to clear if the circuit breaker in question fails.

Required Scheme Operating Time

How fast does this circuit-breaker-failure system need to trip? The design engineer should make the circuit-breaker-failure system trip as fast as possible without sacrificing security. There are some applications, like with EHV where critical clearing times need to be taken into consideration. Consult the planning group or system modeling group for critical clearing times if available.

Status Contacts

There are four circuit-breaker-status contact types, 52aa, 52a, 52bb, and 52b. The 52aa contacts open when the operating mechanism begins its motion to open the circuit breaker. The 52bb contacts close when the operating mechanism begins its motion to open the circuit breaker. 52a and 52b contacts are set to open and close respectively by the time the operating mechanism finishes its motion of opening the circuit breaker, typically towards the end of the motion or at the end of the motion. These might be set at the factory or might be field settable. In either case, it is important to time these contacts when considering the timing of the status change. If no timing is available, a good place to start is the rated interrupting time of the circuit breaker. Usually, 52b contacts are not represented in the circuit-breaker-failure logic but can be used instead of a 52a contact.

If 52aa contacts are available, use 52aa contacts in the circuit-breaker-failure design. If 52aa contacts and 52a contacts are available and current monitoring is not available, these contacts can be used together for faster speed. If 52aa contacts, 52a contacts, and 50BF current monitoring is available, it is advisable to use 52aa in conjunction with 50BF. If 50BF current monitoring is available and a mechanism failure causing a 52a to fail closed is unacceptable, simply use the 50BF current monitoring for the circuit-breaker-failure protection scheme.

Consider whether this circuit-breaker-failure design must trip single-pole circuit breakers or if the circuit breaker is a ganged, three-pole device. Most medium-voltage circuit breakers use ganged, three-pole operation. Single-pole operation is less common and is more design intensive.

Now that system layout has been determined, as well as which circuit breakers are included in the circuit-breaker-failure scheme, next is to configure the scheme logic. When determining the logic behind a circuit-breaker-failure scheme the most important considerations are speed, dependability, and security. The goal is to have the fastest speed and highest dependability possible without sacrificing security.

Logic

The following logic considerations are for a ganged, three-pole circuit breaker with either single or dual trip coils. This section presents three usable logic blocks and the security and speed for each of the suggested combinations.

52aa Logic Only

The 52aa logic is shown in Figure 1.

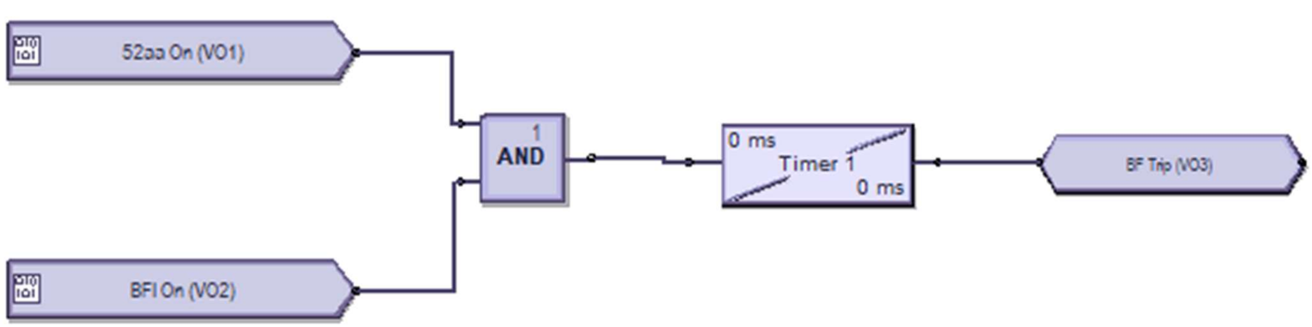

Figure 1. 52aa circuit-breaker-failure logic

52aa logic alone has the fastest trip time for the circuit-breaker-failure protection logic. However, it sacrifices a significant amount of security, making it much less advisable. If there is a flashover of the circuit breaker, the 52aa contact might declare the circuit breaker open and not issue a circuit-breaker-failure condition even though current is still flowing through the circuit breaker. This is a large dependability risk. If the design engineer chooses to use 52aa logic alone, they must consider system instability because of these risks. These questions must be considered and it is advisable to document the answers if the 52aa logic is chosen alone:

- What would happen if a circuit-breaker failure occurs and the circuit-breaker-failure protection failed to trip?
- Would circuit-breaker failure cause system instability?
- Would there be resulting protection trips, like thermal overloads, that would successfully clear the persistent fault or would it persist and cause unacceptable system damage?
- If the persistent fault causes other protection elements to trip, is the resulting outage acceptable or does the resulting outage lead to greater problems?

52a Logic Only

52a logic alone, shown in Figure 2, has the same concerns as the 52aa logic. It is slightly slower; the 52a contact status change is not at the beginning of the mechanism operation. The security matters described in the 52aa logic only section must also be considered for the 52a logic only case.

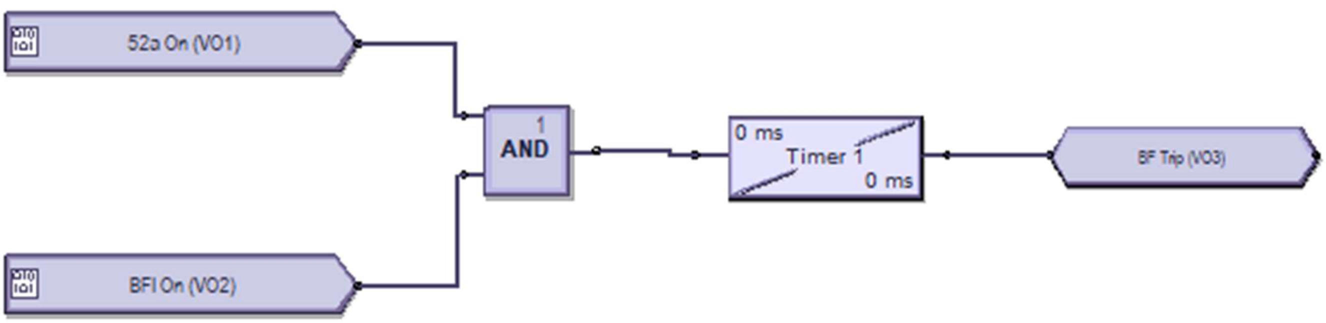

Figure 2. 52a circuit-breaker-failure logic

50BF Logic Only

The logic for 50BF element operating alone is shown in Figure 3. Typically, using only the 50BF logic is slower than the 52a logic. There are also sensitivity concerns with using only the 50BF logic. If the fault is a high-impedance fault then the fault current might not be large enough for the 50BF element to pick up. The circuit-breaker-failure protection will not operate, even if the circuit breaker itself has failed to operate. There is also the consideration of other protection on the system. Although it should be coordinated with other protection, there is a chance that other protection clears the fault before the 50BF element initiates a circuit-breaker-failure trip. This would mean that the circuit-breaker-failure protection does not sense the failed circuit breaker. The 50BF logic by itself provides a dependability advantage compared to the 52a/52aa schemes provided there is sufficient fault current available for the 50BF current detector to pick up. Overall scheme dependability can be improved by using a combination of the 50BF and 52a schemes.

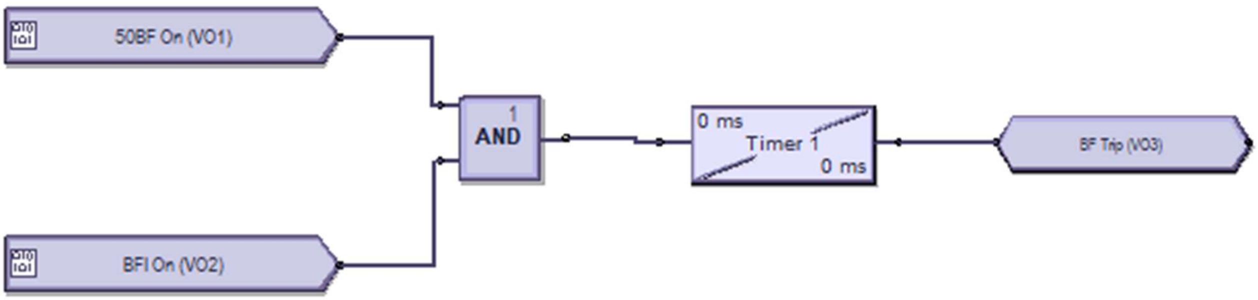

Figure 3. 50BF circuit-breaker-failure logic

Logic Combinations

Combinations of circuit-breaker failure logic make a robust solution. For the purpose of getting to a functional design quickly, only combinations of two circuit-breaker failure logics are discussed. More complexity can be added based on design preferences and the project requirements.

52aa and 50BF Dual-Timer Logic Combination

Use dual timers, a 50BF element and a 52aa status contact for the circuit-breaker-failure protection, as shown in Figure 4. This logic has the speed of the 52aa logic alone while reducing the security concerns of this logic. If there is a flashover or a contact failure such that a circuit-breaker-failure condition exists but is not reported by the 52aa contact, the 50BF contact will still sense and operate the circuit-breaker-failure protection. This scheme maximizes dependability and speed.

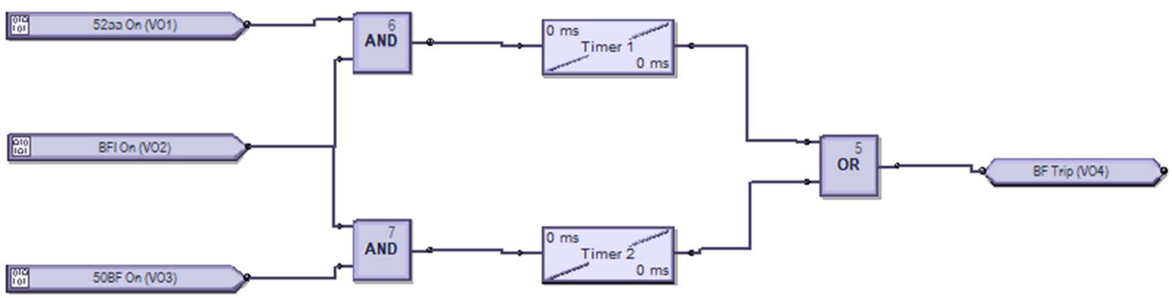

Figure 4. 52aa and 50BF dual-timer logic combination

52aa and 50BF Single-Timer Logic Combination

If a dual timer is not available and a single timer must be used, and a 50BF element and a 52aa or 52a status contact are available, choose the logic in Figure 5 for the circuit-breaker-failure protection. The speed reduction from the larger time requirement of the 52a or the 50BF element makes this design inferior to a dual-timer design. However, the dependability of the dual-timer design still applies, which makes this an acceptable design if the speed requirements are sufficient. Note that, in this design, the 52a and 52aa contacts are interchangeable.

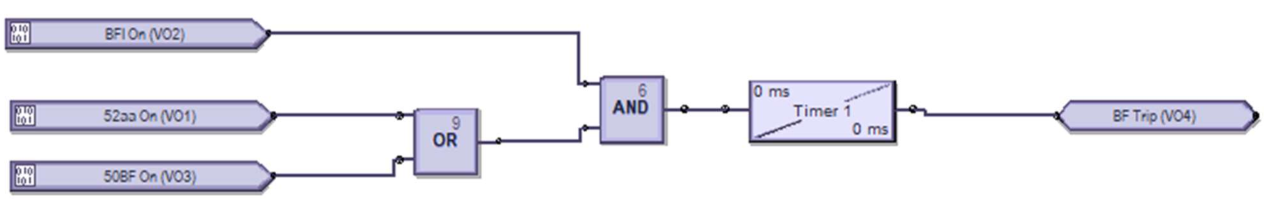

Figure 5. 52aa and 50BF single-timer logic combination

Alternate 52aa and 50BF Single-Timer Logic

An alternate 52aa and 50BF single-timer logic combination, shown in Figure 6, is biased towards non-operation. It does not offer improvements in speed and dependability. If the 52a contact or the 50BF contact fails to sense the circuit-breaker-failure condition, as described in their separate logic sections above, the scheme does not declare a circuit-breaker failure and does not operate. This scheme is not recommended unless it has been determined that a large bias towards non-operation is desirable and will not cause system instability. Choose this scheme only if it has been determined that the failures of both the 52a or 52aa logic and the failures of the 50BF logic is acceptable. This design may be chosen in a case where surrounding protection schemes cause a similar outage as the circuit-breaker-failure protection scheme and those surrounding schemes keep the system from becoming unstable. An example would be a two-breaker setup with a line in, line out, and a transformer tapped in the middle. If one of the breakers fails, the transformer overload and the remote end line protection might clear the same breakers as a breaker failure trip would clear. If no instability or transformer damage is caused by relying on these protection systems, then this logic may be used for the breaker failure protection.

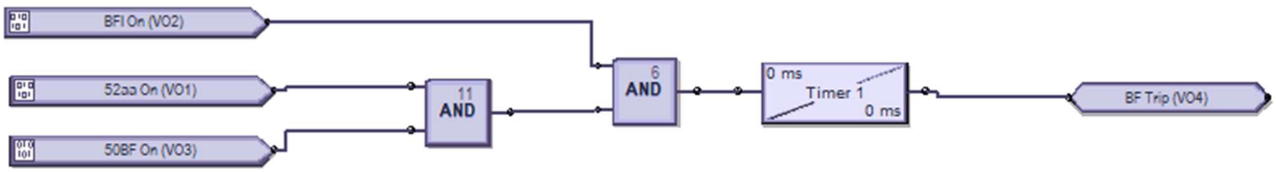

Figure 6. Alternate 52aa and 50BF single-timer logic combination

52aa and 52a Logic Combination Without the Use of 50BF

There are two logic combinations that can be chosen based on the availability of dual timers. These are shown in Figure 7 and Figure 8. The dual timers provide a speed advantage over the single timer as described in the 52aa and the 50BF logic combination section. These logic combinations add only a small security increase to the 52a-only and 52aa-only logic. This additional security is because of redundancy. If one of the 52 contacts fails open, the other 52 contact can still catch the circuit-breaker failure. Typically, this marginal gain in security is not sufficient to suggest this logic combination. Note that this combination might be chosen if the 50BF element is not viable for the circuit-breaker-failure protection logic; It is one way to increase security while decreasing failures when no 50BF element is available.

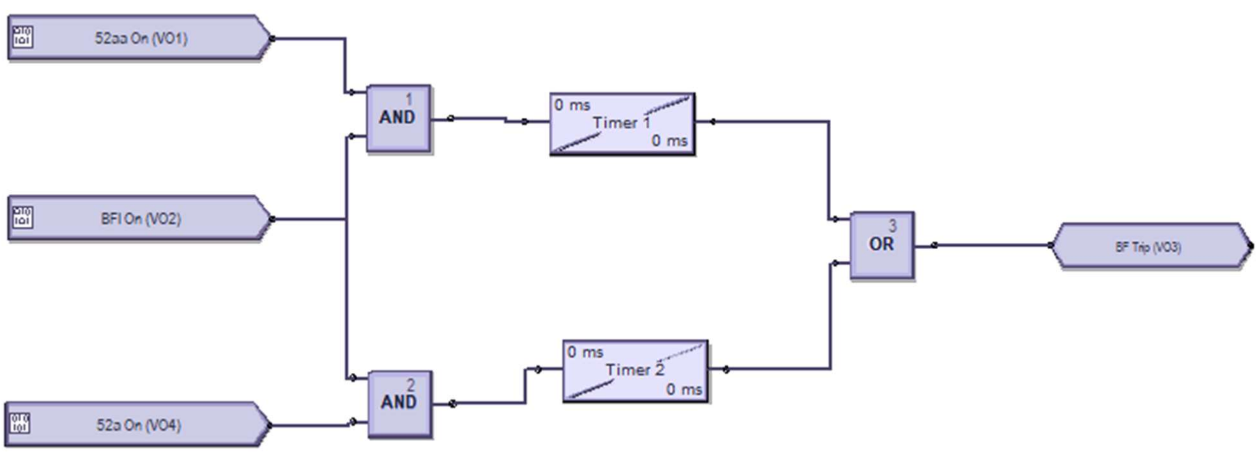

Figure 7. 52aa and 52a logic combination

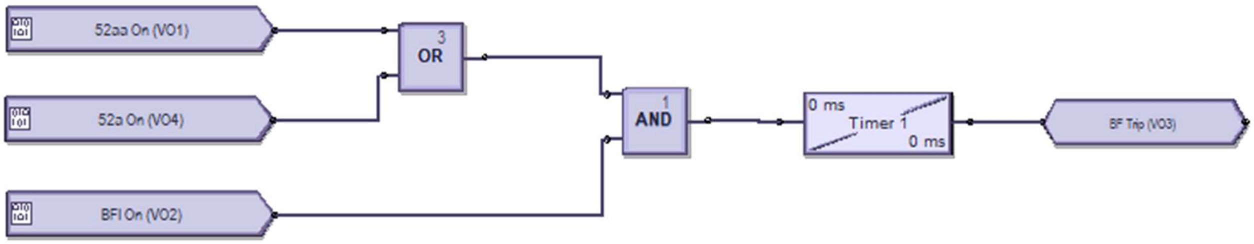

Figure 8. Alternate 52aa and 52a logic combination

Logic Considerations for Single-Pole Tripping

For single-pole tripping, apply the above logic blocks to each phase separately. Then, the outputs are all summed in an OR gate. Thus, there is one circuit-breaker-failure trip for all three of the phases as shown in Figure 9. A retrip timer can be added to each phase, as well. If there are two trip coils in each of the phases, one of the trip coils may be used for single-phase tripping while the other trip coil may be used for three-phase tripping. In this case, the three-phase trip activates each of the separate-phase, circuit-breaker-failure initiates.

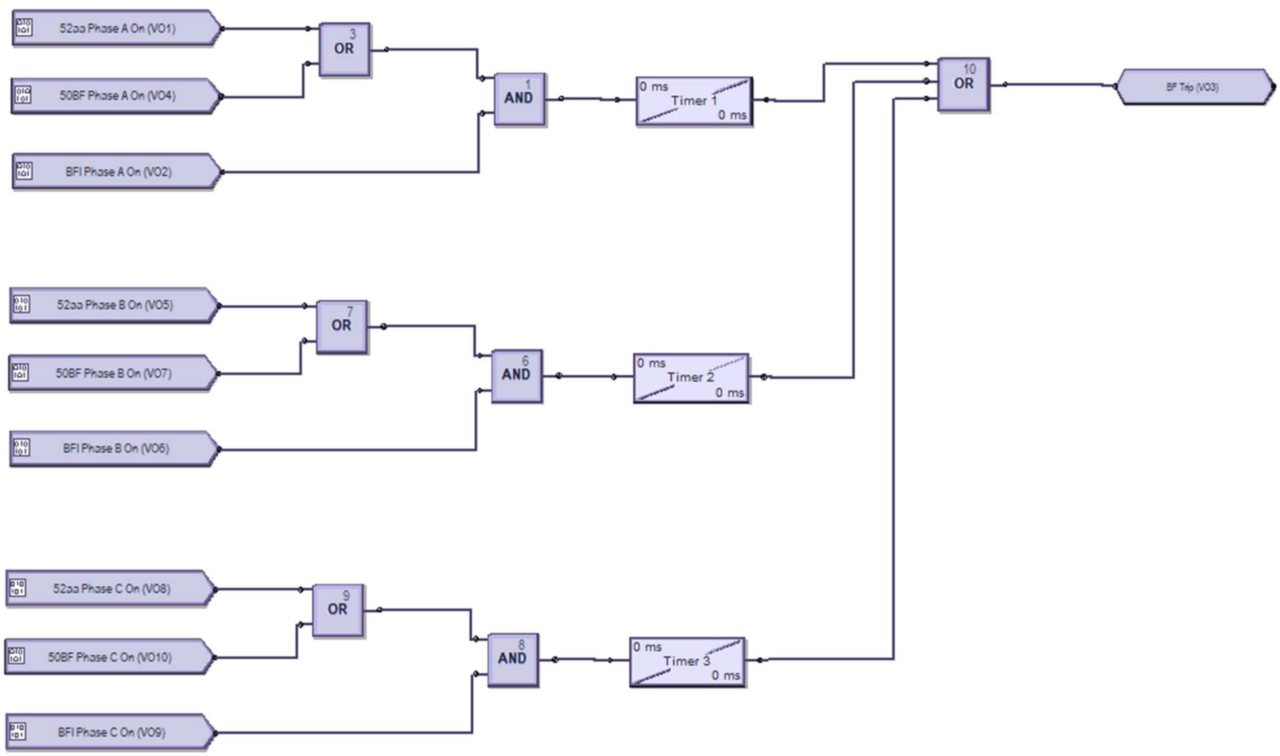

Figure 9. Single-pole tripping logic

Retrip

Now that a base of circuit-breaker-failure logic has been established, add retrip to the design. Circuit breaker failures can occur because the output contact of the relay used for tripping is either stuck or has failed to operate. Other circuit breaker failures can occur because of a burned trip coil. Retrip solves these problems without issuing a full circuit-breaker-failure trip. The ideal retrip logic is to use a separate output contact to retrip the circuit breaker. The logic for retrip is straightforward; it is the timing and the implementation of the output that needs to be considered.

As shown in Figure 10, from the circuit-breaker-failure initiate, BFI On, go through a timer and then to a retrip output function. There is no need for a check because re-tripping an open circuit breaker has a null affect. This can simply be added on to the base circuit-breaker-failure logic chosen.

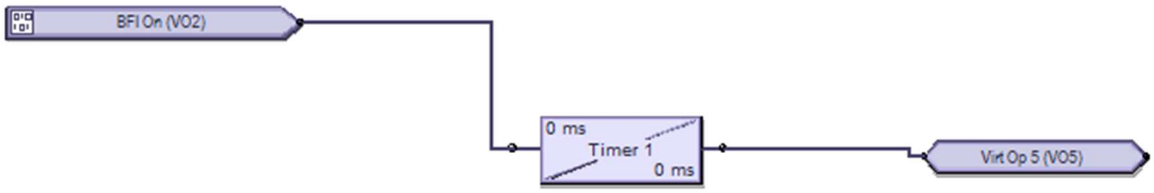

Figure 10. Retrip logic

Timing is an important part of the retrip function. The goal is to set the retrip timer to reactivate the relay trip outputs and the trip circuit of the circuit breaker in question. A stuck trip coil or a stuck relay output contact can cause a circuit-breaker failure; sometimes, cycling the output can solve this. Set the retrip timer so the circuit breaker retrips before the circuit-breaker-failure timer expires. If there are tight timing tolerances because of a small critical clearing time, the timer might need to be set as small as zero (removed entirely). If there is sufficient critical clearing time, then set this time longer. Because the purpose of the retrip is to cycle the output contact(s), a good starting point for the retrip time is the output contact pick-up time plus a small margin.

Implementation depends upon the circuit-breaker setup. Send a retrip if there are two trip coils and protection trips with separate outputs on each trip coil. If more redundancy is needed, trip with additional, separate, relay contact outputs. However, if the circuit breaker has a single trip coil, consider tripping with a separate output to that single trip coil. If the relay does not have enough outputs to use a separate contact then it can trip through the same output contact again (not preferred). The first of these suggestions is the most robust design and the recommended method because of reduced failure probability, increased redundancy, and separation of tripping circuits.

Logic Elements

This section examines the separate elements of the logic scheme, beginning with circuit-breaker-failure initiate, BFI. The points to consider are the following:

- What should initiate a circuit-breaker-failure protection scheme?
- What starts the monitoring if the circuit breaker failed to open?

Typically, any protection trip or non-operator-commanded opening of the circuit breaker should initiate circuit-breaker failure. This can be analyzed logically. If there are personnel on site with specific switching orders who trip the circuit breaker, and the circuit breaker does not open, there is no persistent issue that will cause instability. Thus, the situation is resolved manually. The onsite personnel can open the adjacent circuit breakers and deal with the failed circuit breaker using an emergency outage. Similarly, if the circuit breaker is commanded to be opened remotely by a properly designed supervisory system or by supervisory personnel, there is also no immediate danger to the system if the circuit breaker does not open, so the adjacent circuit breakers can be opened accordingly. However, when there is a dangerous condition (a fault) that is detrimental to the surrounding system and the circuit breaker fails to open, this is when the circuit-breaker-failure protection must have been armed and must operate. Therefore, any condition that could cause adverse effects to the system if the circuit breaker in question fails to open should initiate the circuit-breaker-failure protection.

The 50BF current element detects whether there is still current going through the circuit breaker after it is supposed to be open. Typically, this is an overcurrent element although an undercurrent element can be used as well by employing the opposite logic used in the overcurrent element. The overcurrent element can be a phase overcurrent element or a ground overcurrent element but typically it uses both a 50P phase overcurrent element and a 50N neutral overcurrent element. The phase overcurrent element is set just above maximum load and the neutral overcurrent element is set more sensitively. The neutral overcurrent element is set to the maximum imbalance current seen during high loading conditions plus a margin. If this value is not known, fault studies will show imbalance current and the 50N is set using the imbalance current from the fault studies. Then it is verified such that it will not pick up under imbalanced loading conditions. This setting gives security over accidental circuit-breaker-failure initiates. If the circuit-breaker-failure initiate input is energized or the circuit-breaker-failure internal logic inadvertently becomes true, these combined element settings provide additional security to make certain that there is a faulted condition with fault current greater than load and greater than a set imbalance level. If sufficient load is not available and security against BFI is not a concern, it is possible to choose a phase-overcurrent element 50P by itself and set to the minimum secondary current that the relay reads accurately. However, in most cases, this is not recommended because it decreases the circuit-breaker-failure protection system security. Subsidence current in CTs after a fault has occurred might keep a 50P that is set too low from resetting. Most manufacturers have algorithms and settings instructions that avoid this.

Critical Clearing Time

The power-system critical clearing time must be analyzed before setting the timers in the circuit-breaker-failure scheme. Calculating the critical clearing time has been discussed elsewhere using different methods and as such will not be discussed here. Critical clearing time is the maximum time a fault can exist in a power system before the system becomes unstable, loses synchronism, or experiences unnecessary damage to equipment [4]. However, if it is unknown when designing the circuit-breaker-failure protection, then it is important to use a fault study that considers the surrounding equipment. The study analyzes which piece of equipment is most susceptible to damage from the worst-case lingering fault. Often, this includes the adjacent substation if it is a transmission-line circuit breaker. Once the capability of the weakest equipment is known, a reasonable clearing time can be determined from the maximum allowable current, and duration of that current. This becomes a reasonable starting point for the time needed for the circuit-breaker-failure system to operate.

If the critical clearing time and a reasonable tripping time for equipment damage cannot be defined, the next best approach is to consider the minimum security necessary for the circuit-breaker-failure scheme. Minimum security gives the shortest clearing time. Then, compare this time to the critical clearing time (when available) and choose the shortest time.

Circuit-Breaker-Failure Timing

Many elements must work together for proper circuit-breaker-failure operation. Figure 11 shows a well-known timing chart that describes the relationships of the different timing components of a circuit-breaker-failure system. Manufacturer drawings and manuals depict specific time requirements for each component. For example, a breaker manufacture might state a 6 cycle clearing time for the breaker interrupt time within its breaker drawings.

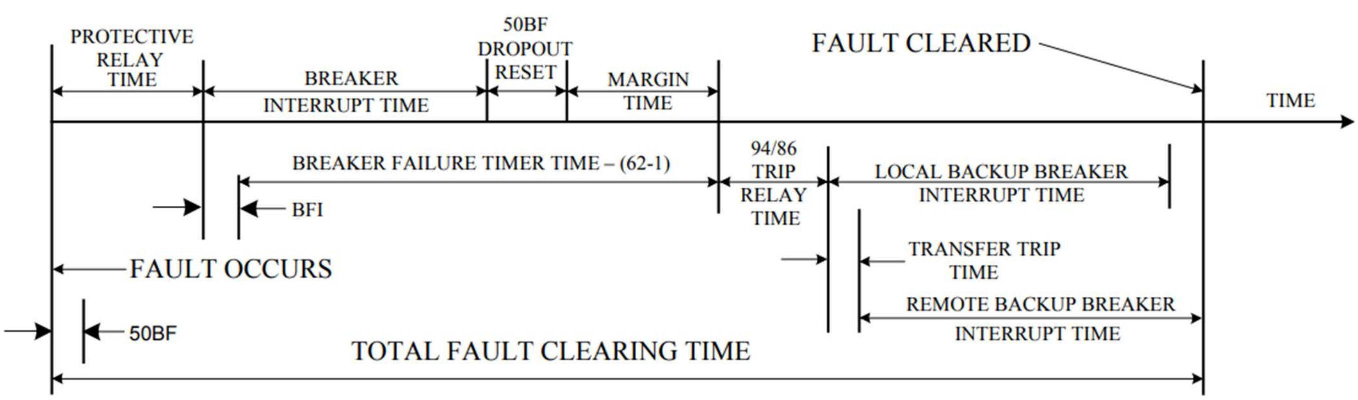

Figure 11. Circuit-breaker-failure timing

If a single timer scheme is used, the timer must meet all of the requirements shown. For example, if the circuit-breaker operate time is six cycles, the 50BF element dropout time is ¼ cycle, the BFI input change time is ¼ cycle, and two cycles of margin is used, the minimum circuit-breaker-failure timer (62-1) would be 8.25 cycles, or 0.1375 seconds at 60 Hz.

If a dual-timer scheme is used with a fast 52aa contact, then the timer for the 52aa contact differs from the 50BF timer. For example, because the 52aa contact opens when the operating mechanism begins its motion to open the circuit breaker, the margin time and circuit-breaker interrupt time must be considered—having only these two factors allow for a shorter timer.

Implementing Circuit-Breaker Failure

A major decision for circuit-breaker-failure schemes is where it resides. The location of the circuit-breaker-failure settings are determined by many factors. However, it is important for the designer to be prepared for numerous situations. The factors that determine which relay contains the circuit-breaker-failure logic include the following:

- Company standards
- Redundancy needs
- I/O availability
- Operational logic location

Follow the company standard to have separate circuit-breaker-failure relays. If none exists then consider redundant relaying for this circuit breaker; use the backup relay for the circuit-breaker-failure settings. When there is no redundant relay then use the primary relay for the circuit-breaker-failure settings.

Common-mode failure occurs when multiple relay functions fail simultaneously. Redundant circuit-breaker-failure protection can be designed and applied in multiple relays if this is a concern. Take care to applying the initiate and block logic between the redundant protection systems.

If the relay does not have enough I/O for the circuit-breaker-failure scheme then consider using an alternate relay if available. If an alternate relay is not available, then implement a separate circuit-breaker-failure relay. Alternatively, a one-to-many tripping device can be used, an 86 lockout relay, but this adds complexity to the blocking considerations discussed in further sections.

Also, consider the operational logic location. Because many of the mal-operations of a circuit-breaker-failure system are caused by field-personnel testing, the location of the circuit-breaker-failure relay is important:

- Near the protection and controls for this circuit breaker
- Easy to see and isolate (avoiding a mal-operation)

Optimize the location of the circuit-breaker-failure relay if possible or consider installing multiple, external, blocking mechanisms that are easily viewed when onsite.

Blocking

Blocking is a very important part of the circuit-breaker-failure scheme. Block the scheme during testing and during system operating conditions that render the breaker failure system harmful. For example, block the breaker failure protection if the associated breaker is undergoing maintenance thereby rendering the protection useless. If a bus is temporarily reconfigured such that the breaker failure protection is no longer tripping the necessary breakers, reconfigure the breaker failure protection outputs or block the breaker failure scheme temporarily. There are many ways to block a circuit-breaker-failure system. The oldest and most used method is to install external blocking mechanisms like a toggle switch or knife-blade cutouts. In schemes that use physical output contacts only, having a physical blocking mechanism on the output tripping contacts is sufficient. However, if the scheme uses a communications link instead of physical outputs, then the circuit-breaker-failure initiate system must also have a blocking mechanism, or the communications logic must have a blocking mechanism. This can either be a toggle switch or a knife blade cutout that goes to an input, or it can be an internal blocking mechanism like a pushbutton on the relay itself. Consider the de-energized relay state; make sure that the system is not communicating a circuit-breaker-failure enabled or circuit-breaker-failure trip while the relay is de-energized. Newer protection systems incorporate more protection schemes into fewer relays. Recent industry practice is removing as much copper wiring as possible. This leads to more circuit-breaker-failure blocking mechanisms being virtual instead of physical. However, even in these scenarios, it is helpful to have an external mechanism to block the circuit-breaker failure for lockout tagout reasons and to meet other operational needs. The two most important things to consider when designing circuit-breaker-failure blocking mechanisms are testing and isolation. This can also be compared as laboratory testing and field testing. Consider a circuit-breaker-failure scheme that clears six circuit breakers when it declares a circuit-breaker failure. In a laboratory, while testing the associated relay panel, it is easy to initiate a circuit-breaker-failure trip six times and test each output contact or test circuit-breaker-failure lockout relay (LOR) outputs to make sure that it trips all six circuit breakers. However, in the field, it is unreasonable to cause a six-circuit-breaker outage just to test a circuit-breaker-failure protection scheme. Therefore, system isolation is important. The circuit-breaker-failure scheme might need a blocking system that blocks all but one of the circuit-breaker-failure trips. Thus, each circuit breaker in the scheme can be tested without requesting an unnecessary and sometimes impossible outage. This requires two types of blocking in the scheme:

- Operational block
- Isolation block

An operational block removes the scheme in its entirety, and an isolation block prevents operation of portions of the scheme for field testing. If all the protection outputs for the circuit-breaker-failure system are physical, knife-blade cutouts can be used for isolation. However, if there are communications trips, isolation through logic is necessary. It is beneficial to have both virtual isolation and physical isolation in the circuit-breaker-failure blocking mechanism.

Typically, the operational block is a knife-blade cutout or a toggle switch that opens the circuit to the circuit-breaker-failure initiate input. This entirely blocks the circuit-breaker-failure scheme because it disallows initiation of the system. Typically, the isolation block is knife-blade cutouts on each of the outputs for the circuit-breaker-failure system. These cutouts isolate specific output trips for the circuit-breaker-failure system, which allows for proper system testing. If there is a one-to-multiple output configuration then these multiples should also have isolation switches. If the relay has one output that trips a LOR that goes to multiple circuit breakers, then for proper isolation requires the LOR outputs have associated knife-blade cutouts.

If there is any relay communication associated with the circuit-breaker-failure scheme, a virtual- or logic-blocking system for the circuit-breaker-failure protection must also be incorporated. This communications-scheme blocking can replace or augment the physical blocking system. When added to the physical blocking system, the operational block must command both the physical and virtual systems. Blocking-system uniformity is a design goal, both virtual and physical. However, this might not be possible if there are limiting operational requirements. Communication and a one-to-many case requires a combination of virtual and physical blocking systems for isolation blocking.

Additional blocking outside of the circuit breaker failure protection should be considered as well. Reclosing should be blocked if a circuit-breaker-failure trip occurs. Block remote supervisory closing depending on whether there is a process in place to handle a failed circuit breaker. Consider the other elements that could close the failed circuit breaker and whether to block these, as well.

Designing a circuit-breaker-failure blocking system is difficult. The design engineer must consider the needs of their field personnel and the standard practices of their customer or company.

Circuit-Breaker-Failure Initiation

Typically, a physical relay input contact is used for the circuit-breaker-failure initiation logic. This method allows for the external block in the circuit-breaker-failure implementation that was discussed previously. Any protective trip activates this input to initiate circuit-breaker-failure protection. Communications-based protection trips can go through an output to this input or can initiate a virtual input for circuit-breaker failure. If this input is in parallel with the trip coil of the associated circuit breaker, then take special precautions so that non-protective trips do not initiate a circuit-breaker-failure condition. Possible solutions are using separate trip coils, an entirely separate DC circuit, or a diode in the trip circuit.

Alarming

Alarming the circuit-breaker-failure system is important and necessary. Alarming and operational notification reduce the time to assess the cause of a larger outage. It is important to identify and address circuit-breaker-failure operation as quickly as possible. Operational needs, company standards, and specific site needs are inputs to alarm and notification design. Consider alarming on multiple tiers. The first tier of alarm and recording is locally. There should be at least one locally annunciated circuit-breaker-failure alarm and multiple, local alarm locations can be effective. Possible locations are the following:

- On the relay itself using a relay front-panel LED
- On the relay panel where the circuit-breaker-failure logic is located
- At a supervisory and control annunciator panel

The second tier of alarms is communications-based. If there is a remote-control room for operators, an alarm must go there so that the operators know of the circuit-breaker-failure operation. A remote substation in the circuit-breaker-failure operation must have a circuit-breaker-failure alarm. Specific company needs increase and decrease the alarming installations.

Additional Considerations

There are additional considerations for designing a circuit -breaker-failure scheme. These special cases include the following:

- Live tank circuit-breakers
- Generator circuit breakers
- Static VAR compensators
- Capacitor banks
- Reactor banks

These circuit-breaker-failure protection applications are noted in the References section [2, 3, 5].

Additional coordination considerations are the following:

- The limits of the equipment for which the circuit-breaker failure operates
- External overreaching zones that could trip before the circuit-breaker-failure protection
- Non directional elements that might trip before the circuit-breaker-failure protection

Evaluate the protection in its entirety once the circuit-breaker-failure protection has been designed.

Control Power

Loss of circuit-breaker DC should not affect circuit-breaker-failure protection . Consider the DC circuit that supplies the circuit-breaker-failure initiation logic and the tripping outputs—this should not affect the circuit-breaker-failure protection. As much as possible, use separate DC circuits for the circuit-breaker-failure protection system.

Adjacent Circuit Breaker not Ready

There are cases when an adjacent circuit breaker is not fit to open. One example is low SF6 gas in an SF6 circuit breaker. Typically, there is a multistage alarm for the SF6 gas level. At the critically low SF6 stage, the circuit breaker is unable to clear a fault. Although this falls into a separate protection category, it affects the clearing ability of the circuit-breaker-failure-protection. Therefore, consider this situation carefully when designing circuit-breaker-failure protection.

Reference Existing Guidance

It is important to understand, analyze, and follow the specific company circuit-breaker-failure design guide or conventions. Every company has unique system configurations and requirements. Therefore, it is important to analyze these current methods before implementing change.

Conclusions

This paper presented the basics of circuit-breaker-failure protection.

Circuit-breaker-failure protection and the logic presented in this paper will persist in the protection and controls arena. Proper understanding of basic circuit-breaker-failure protection logic and implementation ensures effective application and system protection. The methods of protection continually change as technology evolves and innovation produces more efficient and effective equipment. However, the basic problem of handling equipment failures has existed since the inception of the power system and continues on through time.

References

- [1] Xue, Yiyan, et al., “Review of The Breaker Failure Protection Practices in Utilities,” 2011, https://na.eventscloud.com/file_uploads/08459e40feec142e648207fe237f9108_xue_pap.pdf
- [2] "IEEE Guide for Breaker Failure Protection of Power Circuit Breakers," in *IEEE Std C37.119-2016 (Revision of IEEE Std C37.119-2005)* , vol., no., pp.1-73, 16 July 2016, doi: 10.1109/IEEESTD.2016.7509575.
- [3] Alla, Matchyaraju, et al., “Improvements in Generator Breaker Failure Protection During Low-Current Conditions”, 2020, https://esic.wsu.edu/documents/2023/10/western-protective-relay-conference-2020-improvements-in-generator-breaker-failure-protection-during-low-current-conditions.pdf/
- [4] Wang, Yunqi, “A Study on Critical Clearing Time (CCT) of Micro-Grids Under Fault Conditions”, 2016, https://doi.org/10.1016/j.renene.2016.04.029
- [5] "IEEE Guide for AC Generator Protection," in IEEE Std C37.102-2023 (Revision of IEEE Std C37.102-2006) , vol., no., pp.1-211, 28 June 2024, doi: 10.1109/IEEESTD.2024.10576672.