Improving Breaker Failure Protection
for Generator Applications

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Abstract—The failure of a generator breaker to open often cannot be detected with traditional overcurrent schemes. Many tripping conditions of a generator breaker do not occur in conjunction with sufficient currents to allow reliable detection. Normal shutdown of a unit may include a sequence of events that makes it critical to detect that the generator breaker has failed to open properly. Potentially damaging motoring conditions may be experienced by the generator tied to the system through a failed breaker when the shutdown sequence is incomplete. Typically, the 52a breaker status is added in parallel with the overcurrent element in the breaker failure scheme to allow tripping based on breaker status in addition to overcurrent. While this may improve the scheme dependability significantly, it leaves a hole in the protection for a specific type of failure and introduces the opportunity of overtripping for other failures of the mechanical auxiliary switch and cabling. To avoid situations that may potentially cause costly damage requiring lengthy repairs or situations where avoidable system disruptions occur because of overtripping, the breaker failure scheme needs to reliably and securely detect the generator remaining tied to the system following a breaker open command without relying on the breaker status indication.

This paper examines the design and implementation of a breaker failure scheme using a synchronism-check element in addition to the traditional overcurrent element. In this scheme, a failed generator breaker is detected by sensing the lack of slip between the unit and system that should be present if the unit separated properly. A review of current industry guidelines for breaker failure system design is used as a starting point. The paper then describes the improvements realized by the new scheme.

I. INTRODUCTION

Breaker failure protection is an important component of comprehensive system protection. Given tight stability margins and the opportunity for equipment damage during fault current conditions, a breaker failure scheme is needed to avoid delayed fault clearing from backup and remote overreaching protection elements. The impact of a breaker failure operation can be severe, however, and great care must be taken to avoid a misoperation of the scheme. A dependable scheme is important to prevent damage to high-value electrical assets. A secure scheme is important to prevent significant disruptions to adjacent power system components. Reliable detection of a breaker that has failed to operate when called upon that balances both dependability and security is key to the protection system.

Traditionally, the state of the breaker is determined by one or both of two methods, electrical or mechanical. Electrical detection involves the detection of current flowing through one or more poles of the breaker. Mechanical detection relies on the physical status of an auxiliary contact (or contacts) that follows the action of the breaker contacts by way of a cam physically linked to the breaker mechanism. For reasons that will be discussed, electrical detection is the preferred method and is traditionally used in breaker failure schemes. Still, there are some applications where sufficient measurable current may not be present but detection of a failed breaker is required and action must be taken in a timely manner. One example is transformer protection that has no local breaker and relies upon a direct transfer trip (DTT) scheme to trip. The sensitive differential or sudden pressure elements could initiate a trip for a fault with currents below the threshold of sensing for the remote breaker failure relay. In these instances, mechanical detection has typically been added in parallel with electrical detection. While the addition of mechanical detection does extend the functionality of the scheme beyond normal fault current conditions, it is not an optimum solution because it introduces an additional point of failure that can have serious impacts.

II. BACKGROUND

Traditional breaker failure schemes initiate a timer based on a detected trip signal. Current detection is used as a supervising element either during the timing process or at the expiration and subsequent output of the timer. Current detection is used as an indication that the breaker has not opened or successfully interrupted current [1]. System configuration and time criticality dictate whether the current supervision is continuous (Fig. 1) or only at the expiration of the timer (Fig. 2). An instantaneous overcurrent (50) element is used to detect the presence of current above a set threshold. To add security to the scheme, this current threshold is typically set for a value indicative of a fault in the primary zone of protection and is often above normal load current seen by the breaker. This excludes scheme operation where a fault is not present. Breaker failures to open under load or no load are not usually considered time critical. There may be a separate scheme to detect this condition, or it may be left to operation personnel to detect and correct.
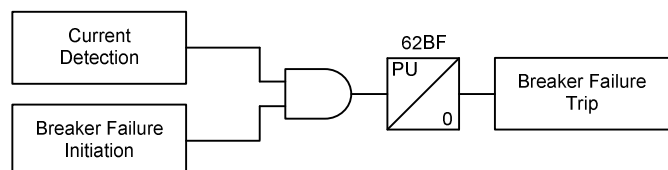

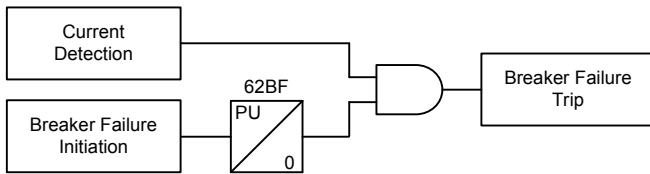Fig. 1.   Continuous Current Supervision Breaker Failure

Fig. 2.   Current Supervision at Timer Expiration

The application of breaker failure protection on a generator breaker requires an additional detection method beyond fault current detection. A large steam turbine generator shutdown requires a carefully crafted chain of events to occur in order to minimize possible damage or increased wear on the machine. The generator breaker is typically tripped by a protective relay detecting a reverse power condition. This is known as a sequential trip operation. The purpose of sequential trip is to ensure that the steam valves have actually closed and the turbine is no longer driving the shaft. This ensures that the turbine generator will not accelerate to excessive speed after it is disconnected from the power system.

If the generator breaker fails to open as expected, the machine can be subjected to a motoring condition. While not instantaneous, this motoring condition has the potential to cause serious damage in a short period of time. Allowable motoring time for steam turbines is typically in the 30- to 60-second range [2].

The current involved in a motoring condition is dependent on the type of prime mover but, in all cases, is much less than the levels for which a fault detection scheme would typically be set. A steam turbine, for example, has a typical motoring power range of 0.5 to 3.0 percent of generator rating [2]. Assuming that the current transformer ratio (CTR) is chosen such that the secondary current is 5 A at 100 percent of generator rating, the current seen by the breaker failure relay for an antimotoring trip can be as low as 250 mA. In many cases, the CTR is chosen so that the secondary current is considerably below 5 A at 100 percent of the generator rating, making the relay current even lower.

To overcome this, mechanical indication of the breaker status is added to the breaker failure scheme, as shown in Fig. 3. The breaker failure scheme can open additional breakers to effectively isolate the motoring generator in a timely manner to avoid damage.
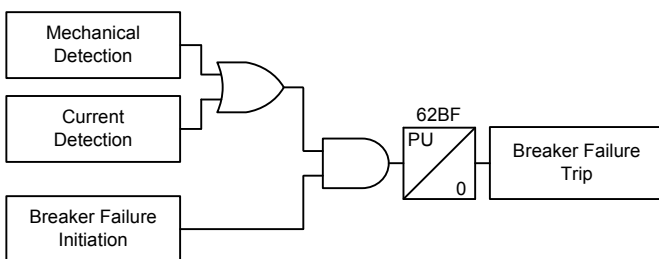

Fig. 3.   Mechanical Breaker Detection Added

The mechanical indication is provided from one or more of the breaker auxiliary contacts. The breaker auxiliary contacts are typically provided from a rotating cam that is directly linked to the breaker mechanism. Contacts that have the device number 52a are provided that follow the state of the breaker (open when the breaker is open). Reverse contacts (52b) are also provided (closed when the breaker is open). Several contacts are usually provided and used in other parts of the protection and control scheme, such as local and supervisory control and data acquisition (SCADA) indication. Current flowing through the trip coil is usually interrupted by a 52a contact to limit potential thermal damage to the breaker trip coil and current interruption damage to relay tripping contacts.

III.   Description of Deficiency

The addition of the mechanical breaker indication to the traditional current-based breaker failure scheme offers, in theory, the solution to no current or low current breaker failure detection. However, the mechanical indication through the breaker 52a auxiliary contact is not infallible. The indication is from a mechanical representation of the breaker status and is part of the element being monitored for failure. A breaker failure may involve a failure of the mechanism to move the contacts apart sufficiently to open the connection, while the auxiliary cam may move normally. In this case, the breaker failure to open would go undetected by the breaker failure scheme, leaving the generator vulnerable to motoring. Conversely, if the 52a contact fails to open correctly, a false failure can be indicated, resulting in an unnecessary backup trip, even though the main contacts have successfully interrupted the current.

In most instances, a significant run of cabling is required to send the 52a indication to the breaker failure scheme. This cable also presents a possible point of failure for the scheme. Much like the mechanical linkage described previously, if the cable is damaged (either open or shorted), the same problems described for auxiliary contact failure will occur. The failure of this mechanical indication can result in an overtrip or a failure to trip of the scheme, depending on the mode of failure.

IV.   Synchronism Check as a Solution

A modern microprocessor-based synchronism-check (25) element is normally used to supervise the closing of breakers near a generator. Not to be confused with the automatic synchronizer device that matches the incoming generator speed and voltage and initiates closing at the slip-compensated advanced angle, the synchronism-check element prevents the breaker from closing if the two sides of the open breaker are not within a set band of angle difference [3]. The synchronism-check element supervision of the breaker closing offers an independent verification that the electrical systems being tied together are within a range to avoid any damage or

adverse effects to the system or electrical equipment. Synchronism check is widely used on breakers across the transmission system and is not limited to generator breaker applications.

In modern microprocessor-based relays, the synchronism-check element has the ability to calculate slip between the two sides, in addition to the angle. Slip is the movement of the angle of one system relative to the other and is measured in hertz. The magnitude of the voltage signals used in the measurements for slip and angle must fall within upper and lower limits set to describe healthy levels on either side of the breaker.

In its traditional application, synchronism check is only important when closing the breaker and is typically turned off or blocked for a closed breaker condition. With the breaker closed, the two compared signals are in perfect synchronism because the signals that they read are from the same point in the electric power system. Turning off the synchronism-check function for a closed breaker was important in electromechanical schemes, where time was required for the permissive contact to travel to its reset position. Turning off the relay when the breaker opened helped ensure that a synchronism condition was properly qualified, with the relay permissive contact actually moving from an open position to a closed position when the breaker opened and then allowing the subsequent close. Modern microprocessor-based relays do not have the inherent reset time of the electromechanical relay and, with the flexible logic available, can be time-qualified if required.

When reviewing expected synchronism-check operation in various positions on the electric grid, significant slip is only expected when the open breaker separates two independently operating systems. For transmission breaker positions, an angle difference can be detected because of the electrical distance between the systems separated by the open breaker. But in a normally connected grid condition, this angle is not expected to be moving. For a generator breaker, however, the generator can be considered an independent system when not connected to the grid. The synchronism-check relay should see slip between the system and the generator bus as the generator is moved to tie on to the system and as the generator is isolated from the system after opening.

With the knowledge that slip between a generator and the system should be present for the two conditions stated previously, the presence of slip can be used as a reliable indication of the generator separating from the system. Furthermore, the absence of slip can be used to identify a failed breaker condition when added to the traditional breaker failure scheme. The synchronism-check element serves as an independent view of the breaker status and is superior to the mechanical 52a indication of the breaker position. Breaker indication from this element bridges the gap of traditional current-based breaker failure schemes for low current motoring conditions that cannot reliably be detected. It also provides superior security because it avoids false operation of the scheme for a failed, shorted 52a auxiliary contact or cabling to the breaker failure scheme.

Because the impact of an operation of the generator breaker scheme can be serious, additional security can be added to the logic by adding related elements that can be used to differentiate a normal separation event from a failed breaker event. In addition to a check for a measured slip frequency by way of the synchronism-check (25) element, an angle window threshold can be used to only allow the scheme to operate if the measured values from the two sides (generator and system) remain within a fixed value. A generator remaining tied to the system should theoretically have no angle separation between measurements on either side of the breaker. An indication of an angle difference can be used to prevent operation of the scheme without regard to slip, which effectively adds security to the protection.

In addition to slip and angle difference, voltage qualification should be done to turn the scheme off if either of the measured voltages falls below the level considered healthy for the normally operating system. This effectively adds security to the scheme by eliminating the possibility of operation when the breaker separates properly and the voltage on the generator side begins to decay.

V. IMPLEMENTATION CONSIDERATIONS

The new breaker failure scheme is shown in Fig. 4. The traditional current-based breaker failure timer (62BF-1) is initiated by all protective trips that are accompanied by an overcurrent (fault) condition. It is supervised by current-based breaker status indication. A separate breaker failure timer (62BF-2) is initiated by all protective trips that can occur with low current (abnormal operating) conditions. To maximize security, this timer is supervised by three elements to indicate that the breaker has not opened: no slip, no angle difference, and no voltage difference. This second timer replaces the function of the 52a mechanical detection of breaker failure to open. Using a separate timer further increases security by allowing a longer time delay than is traditionally associated with clearing a fault from the power system. Implementation considerations of the new scheme are discussed further in this section.
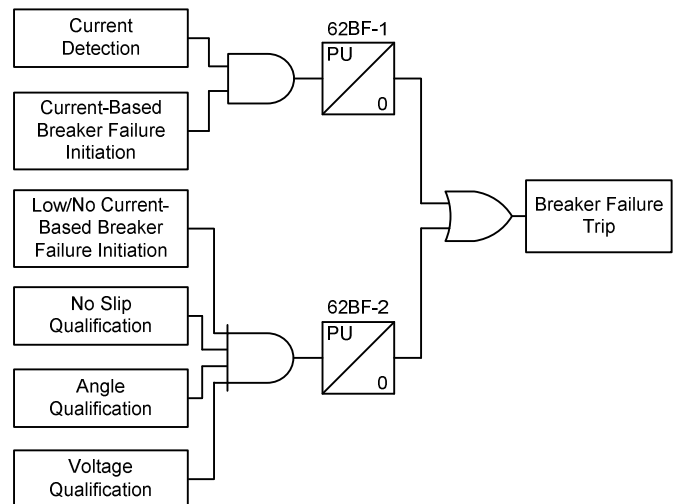

Fig. 4.   New Synchronism-Check-Based Breaker Failure Scheme for Generator Breaker Application

A. Breaker Failure Initiate Considerations

The addition of a synchronism-check element to an existing breaker failure scheme should be thought through sufficiently. Current-based indication of the failed breaker remains important for conditions where tripping is called on for a fault condition and fast clearing is required to minimize damage. Current detection remains a critical component of the breaker failure scheme. The synchronism-check indication is primarily for detection of a failed breaker when current is too low to measure reliably, namely during the unit shutdown process after the unit has been unloaded and the breaker has been tripped. The failure of the breaker to open at this time will lead to motoring of the unit, with relatively small currents involved.

The type of elements initiating the synchronism-check-based scheme should be considered for appropriate signal duration. In most instances for traditional breaker failure schemes, the tripping element initiating the breaker failure timer stays asserted until the condition is cleared by the opening of the breaker. In instances where the trip initiating the breaker failure is pulsed, a timer with an appropriate dropout duration can be used to extend the initiate beyond the breaker failure timer and allow current detection to control the operation. For the synchronism-check-based scheme, a pulsed trip signal from the shutdown process should also be extended or latched until the breaker is confirmed to be open.

B. Breaker Failure Timer Considerations

Breaker failure time delays are typically set to balance damage or adverse effects to the system with security. Damage to a unit due to motoring is not instantaneous and occurs over time, depending on the type of prime mover. While speed is important, the time-delay settings can be extended for the synchronism-check breaker failure detection relative to the current-based breaker failure detection.

C. Voltage Signal Monitoring Considerations

The voltage transformer (VT) signals become very important to the proper functioning of the scheme and should be monitored. The three-phase voltage signal for the generator side of the breaker(s) can be monitored by the loss-of-potential (LOP) logic in the relay. However, failure of the single-phase synchronism-check voltage inputs can cause the scheme to fail to operate because the voltage on one side of the breaker would incorrectly be determined to be dead. The scheme is inherently secure for a failure of a VT signal.

There are two methods possible for detecting a failed VT signal. One is to simply monitor the voltage healthy bits from the synchronism-check element and alarm if the voltages are not healthy while the breaker is closed. The second method is to build a voltage balance (60) element in programmable logic to compare the two voltage signals used by the synchronism-check element and alarm if a difference is detected when the breaker is closed.

D. Bus Arrangement Considerations

Bus arrangement is another consideration for breaker failure. Fig. 5 shows a straight bus unit connection where a single breaker is used to tie the generator to the system. In this arrangement, the scheme is straightforward. A synchronism-check element connected to voltages on either side of the unit breaker detects slip as an indication that the breaker is open. If no slip is detected within the time delay set for the breaker failure operation following an initiating event, then the generator is cleared from the bus by tripping additional circuit breakers.
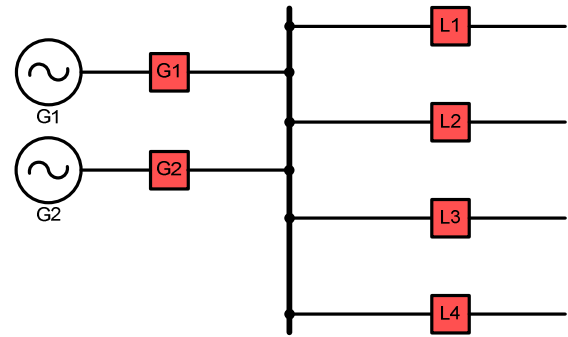

Fig. 5.   Straight Bus (Single-Breaker) Configuration

In multibreaker bus arrangements, such as a ring-bus, breaker-and-a-half, or double-bus design, the synchronism-check breaker failure detection has a selectivity limitation. Fig. 6 illustrates a multibreaker scheme to consider. If a trip signal is given to the two breakers and one of the two fails to open, the synchronism-check detection indicates this failure but cannot determine from voltage alone which bus to clear to properly isolate the generator and prevent motoring. This, in itself, is a serious limiting factor of the scheme because clearing of multiple buses at the station can potentially result in the loss of additional generation units or an undesired and adverse interruption of normal system power flows. There are possible solutions to overcome this limitation, however.
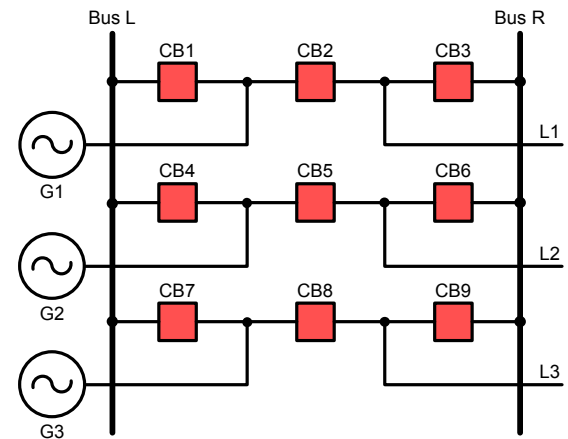

Fig. 6.   Breaker-and-a-Half Bus (Dual-Breaker) Configuration

As with most protection schemes, there are tradeoffs to consider between security and dependability. We must consider the mode and consequences of damage that the protection is designed to prevent, as well as the consequences of the actions taken to prevent the damage. One solution to the multibreaker selectivity problem is to modify operational processes. Once load has been ramped down on the unit and the low/reverse power relay has operated to remove the unit from the system, current to reliably detect a complete open-pole condition may not be present. If the shutdown sequence can be modified to open one of the two breakers earlier in the shutdown sequence while sufficient load remains on the unit, current-based breaker indication can be used for breaker failure for the first open breaker. A failure to open in this condition can trigger an alarm in order to signal operator intervention to manually take the required steps to clear the generator gracefully. If the first breaker opens properly, the shutdown process can continue normally, with the synchronism-check scheme detecting a failure to open and automatically opening the required breakers to clear the generator for the failure of the second breaker to open.

In dual-breaker arrangements, it is important to arrange the breaker failure initiates such that only generator shutdown trips are routed through the synchronism-check breaker failure scheme. In the previous discussion on modifying the shutdown sequence, the manual trip of the first breaker should not initiate the new scheme because the unit remains in synchronism for this first trip. Similarly, if one of the line relays initiates tripping of the shared breaker for a line fault, the unit remains in synchronism through the bus-side breaker. So initiating the new scheme for a line fault trip may cause a misoperation.

If the operational changes to allow opening the breakers individually are not possible, the synchronism-check detection scheme may still offer benefit by reliably detecting an extended motoring condition. If 52a contacts are available from the two respective breakers, these contacts may be used to direct clearing efforts from the breaker failure scheme by selecting the proper bus to be cleared. Although this seems to offer no advantage over the original 52a-based failure to open detection, implementation of the hybrid scheme described in Section VI, Subsection B enhances both security and dependability of the scheme over using 52a status only. If, for instance, the trip has been issued and both 52a contacts indicate open but the synchronism-check element indicates the generator remains connected to the system, steps must be taken to remove the unit from the system before damage occurs. The steps to take for this condition depend on the time to damage for the particular machine and the consequences of clearing more than one bus.

If time allows, sequential tripping of the buses allows for tripping of the second bus to be avoided if tripping the first bus isolates the unit properly. Depending on the operator action availability and the allowed motoring time to damage, the condition could be made to alarm the operator to allow manual intervention. Ultimately, the decision must be made regarding the potential for damage that exists related to a breaker failure and the adverse effects to the grid of clearing multiple buses.

VI. Setting Methodology

A. Single-Breaker Bus Example

When the generator is tied to the system, there should be no calculated slip. The relay considered for this application has a dedicated status bit to indicate zero slip. This indication can be used to build supplemental breaker failure logic to improve the operation for a failure of the breaker to open. Additional consideration can be given to adding other identifying conditions seen in the values available in the synchronism-check relay to qualify the breaker failure and inherently add security. Fig. 7 shows the protection one-line diagram for the first settings example.
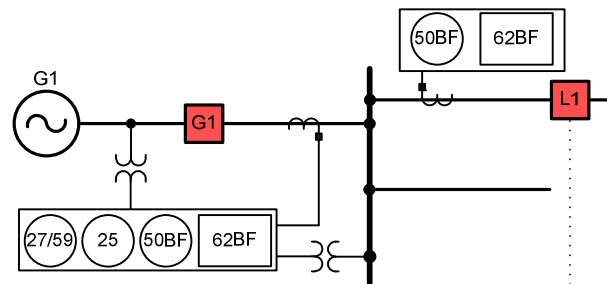

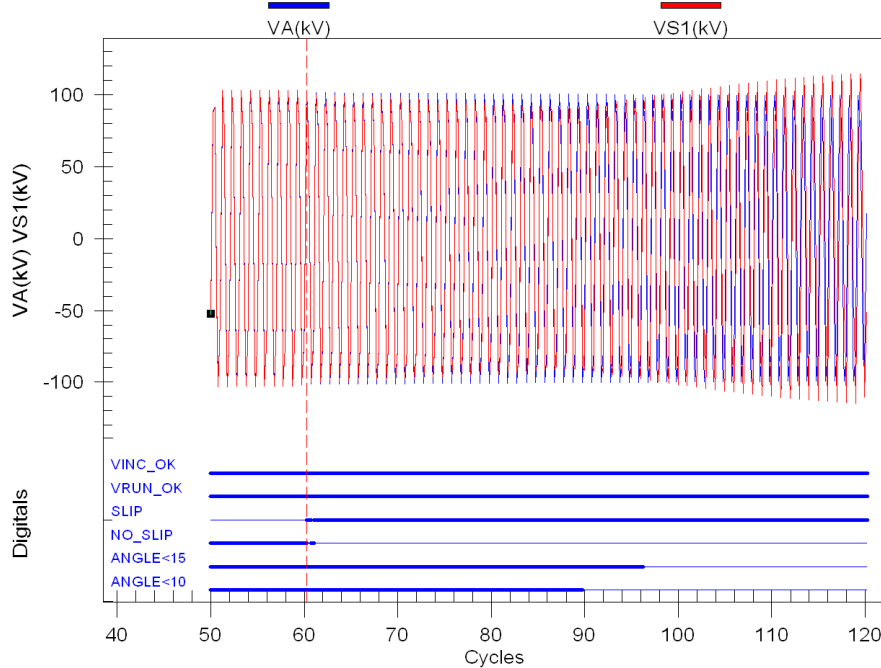Fig. 7.   Single-Breaker Application Example

Fig. 8.   Correct Separation

Fig. 8 shows the oscillography of a steam turbine generator separation from the system. From a review of this oscillography, specific settings can be determined for this unit, incorporating the slip detection and the elements added to increase security. Noticeable for this particular disconnection event is the pickup of the slip frequency indication bit (SLIP) and the deassertion of the zero slip frequency bit (NO_SLIP). In the relay to be applied, the slip frequency bit asserts when measured slip between the two sides of the breaker is greater than 0.005 hertz.

The assertion of the slip bit alone would properly stop the breaker failure timer. For the additional elements included to increase security, there is a change in the voltage levels for the signals from both sides of the breaker, but voltage within the healthy window (VINC_OK and VRUN_OK) is maintained beyond the 60 cycles recorded after the opening of the generator breaker. Also noticeable is the angle separation beyond 10 degrees (ANGLE<10) and then 15 degrees (ANGLE<15). ANGLE<10 occurs approximately 23 cycles after the breaker opens, separating the generator from the system. Another 5 degrees of separation occurs in just 6 additional cycles, showing that the slip of the two systems is increasing over time.

Reviewing this information and applying a conservative margin factor of two, we can apply a time delay of 45 cycles. The new logic declares that the breaker has failed to open if there is a generator separation trip and, after a 45-cycle delay, the slip frequency is zero along with an angle difference of less than 10 degrees and voltages are within the healthy window. All three conditions are required to be present to initiate a breaker failure backup trip.

Protection engineers must consider several factors related to a specific application and satisfy their own requirements related to security, reliability, speed, and operational processes. As in many cases in protection, one size does not fit all. In this particular application, a 45-cycle delay allows the clearing actions to be taken well in advance of time for damage to the generator to occur.

B. Multibreaker Bus Example

Similar to the straight bus example, there should be no calculated slip when the generator is tied to the system. The same relay considered for that example can be applied in the multibreaker application with similar methodology. The significant difference in the multibreaker scheme is due to modifications to overcome the inherent selectivity limitation, discussed in Section V, Subsection C. Fig. 9 shows a protection one-line diagram of the multibreaker design to be considered for this example. This scheme is implemented using a dual-breaker relay that has breaker failure and synchronism-check functions for two breakers.
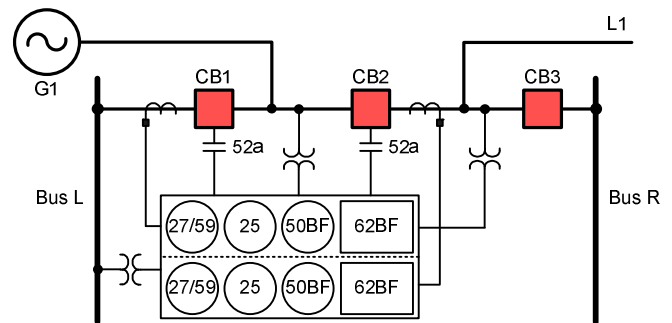

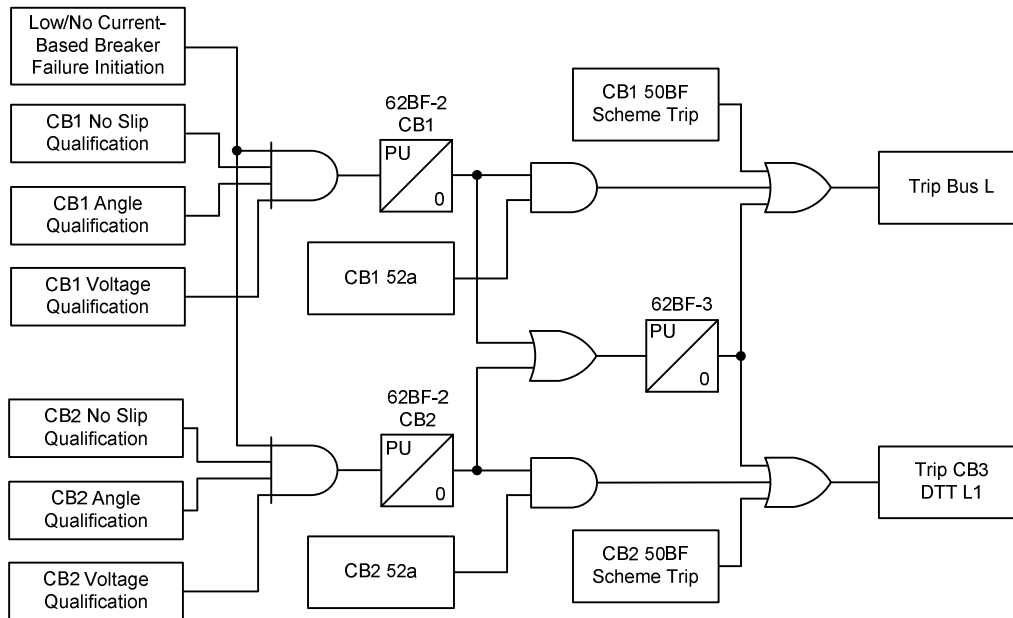Fig. 9.   Multibreaker Application Example

Fig. 10.   New Breaker Failure Scheme With Sequential Tripping Logic

In this application, a change to sequential tripping to allow one of the two breakers to open under sufficient load to allow current-based open detection would help overcome the selectivity issue. If the first breaker fails to open properly, steps can be taken at that time to open additional breakers to isolate the generator from that side. Opening of the second breaker can then be done to disconnect the generator from the system with the synchronism-check-based open detection driving the breaker failure for the second breaker. As discussed previously, the initiation conditions must be properly considered to avoid a breaker failure operation for all but a shutdown sequence trip. Routine trips of one breaker should not initiate breaker failure via the synchronism-check logic because the generator is not intended to separate from the system.

If the operational process cannot be modified to allow for tripping the first breaker under load, the scheme can still offer improvement by directing clearing efforts by way of the 52a contacts if a change has been detected in either of the breakers but a synchronism check indicates that the generator remains tied to the system. Fig. 10 shows the logic changes required to direct tripping based on the 52a contact. For simplicity, details of the current-based (50BF) open detection have been omitted.

This dual-breaker modification only uses the 52a indication to provide a backup trip after the synchronism-check-based scheme has determined that the generator has not been separated from the system. This offers improvement over the mechanical-only breaker failure tripping logic for security failures of the 52a contact. The 62BF-3 then starts to allow the initial breaker failure trip time to separate the generator from the system. If the synchronism-check-based scheme still

indicates that the generator is connected to the system, both zones are cleared to prevent motoring damage to the turbine generator. This logic offers improvement over the mechanical-only breaker failure tripping logic for dependability failures of the 52a contact.

This example illustrates one of the benefits of a breaker-and-a-half bus arrangement. Referring to the Fig. 6 expansion of the Fig. 9 example, incorrectly isolating both Bus L and Line 1 only removes one network element (generator or line) from the transmission grid, which is no worse than what would happen if CB2 experienced a breaker failure and everything worked correctly. So the new proposed breaker failure scheme significantly improves protection of the turbine generator from damage for a breaker failure incident without major adverse effects to the grid.

VII. Conclusions

Turbine generator protection involves many protection elements that detect abnormal operating conditions that, if not detected, can result in costly damage. Some of these abnormal operating conditions are accompanied by very low current flow through the generator breaker. Reverse power protection is one such protection element that is often used for normal shutdown of a steam turbine generator via a process known as sequential tripping. This scheme operates many times over the life of the system. Motoring a steam turbine generator while drawing only a few hundred milliamperes of secondary current in the relay circuit can cause significant damage to the turbine. The time to damage can be less than the time for an operator to detect and respond to a failure of the breaker to open.

Traditionally, current detection has been supplemented with mechanical detection of breaker status using a 52a contact to detect a generator breaker failure to open condition. Mechanical protection can suffer from both dependability and security failure modes. This paper has presented a new breaker failure logic scheme that uses an electrical measurement to detect failure of a generator to separate from the system. It uses three measurements from a microprocessor-based synchronism-check element to detect when the generator has remained in synchronism with the system after being tripped.

The main points of the paper are summarized in the following list:

- Traditional current-based breaker failure remains a critical component to protection schemes.
- A deficiency exists for breaker failure schemes applied for tripping with little or no current.
- The addition of the 52a mechanical indication may help in many instances but is not infallible.
- The use of a synchronism-check-based failure to open detection overcomes the deficiencies of the mechanical (52a) detection.
- A selectivity limitation does exist with the synchronism-check detection scheme when applied to dual-breaker bus arrangements and must be considered.

VIII. REFERENCES

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[2] IEEE Guide for AC Generator Protection, IEEE C37.102-2006.

[3] M. J. Thompson, "Fundamentals and Advancements in Generator Synchronizing Systems," proceedings of POWER-GEN International, Orlando, FL, December 2010.

IX. BIOGRAPHIES

Greg Hataway received his BS in Electrical Engineering from the University of Alabama in 1991. He has broad experience in the field of power system operations and protection. Upon graduating, he served nearly 12 years at Alabama Electric Cooperative, where he worked in distribution, transmission, and substation protection before assuming the role of superintendent of technical services. He joined Schweitzer Engineering Laboratories, Inc. (SEL) in 2002 as a field application engineer in the southeast region of the United States. After 8 years at SEL, he rejoined PowerSouth Energy Cooperative in 2010 as a division engineer in power delivery. Greg has authored numerous technical papers and guides and is a member of the IEEE Power and Energy Society.

Jonathan Ellison received his BS in Electrical Engineering from Auburn University in 2003. He has broad experience in the field of power system operations and protection. Upon graduating, he has served 7 years at PowerSouth Energy Cooperative, where he is presently a principal engineer in system protection engineering.

Michael J. Thompson received his BS, magna cum laude, from Bradley University in 1981 and an MBA from Eastern Illinois University in 1991. He has broad experience in the field of power system operations and protection. Upon graduating, he served nearly 15 years at Central Illinois Public Service (now AMEREN), where he worked in distribution and substation field engineering before taking over responsibility for system protection engineering. Prior to joining Schweitzer Engineering Laboratories, Inc. (SEL) in 2001, he was involved in the development of several numerical protective relays while working at Basler Electric. He is presently a principal engineer in the engineering services division at SEL, a senior member of the IEEE, a main committee member of the IEEE PES Power System Relaying Committee, and a registered professional engineer. Michael was a contributor to the reference book *Modern Solutions for the Protection, Control, and Monitoring of Electric Power Systems*, has published numerous technical papers, and has a number of patents associated with power system protection and control.