DYNAMIC RATINGS

WHITE PAPER

IMPROVING RELIABILITY THROUGH DIRECTED MAINTENANCE

Author: Chris Rutledge

ABSTRACT

Circuit Breakers are highly critical to the power-protection system given their assignment of physically interrupting power flow for the protection of critical assets. However, misoperation of breakers remains one of the most common root cause failures present within the substation. These failures can often be attributed to the circuit breaker's mechanical systems remaining in a static state for extended periods of time, while still being required to operate at optimum levels to clear high magnitude faults within a few cycles of their inception. These long periods of inactivity in conjunction with exposure to thermal variations and the ingress of contaminants can lead to degradation of the mechanism's lubrication and control systems. While cyclic testing and maintenance of a circuit breaker's operating systems by maintenance personnel is the most common means of keeping breakers in optimal operating condition, this approach can at times lead to misdiagnosis of potential failure modes. Some factors which contribute to this misdiagnosis are limitations of the testing and maintenance procedures being implemented, excessive operations occurring between maintenance cycles, and in some instances, intrusive internal inspections resulting in a subsequent misoperation.

This paper illustrates the effectiveness of online breaker monitoring, utilizing the analysis of high-speed waveform capture, as a means of ascertaining a breaker's operational condition. Through waveform analysis of the main contacts and trip coil, the asset owner can evaluate many of the breaker's vital operational parameters, such as degradation of the breaker's lubrication, integrity of the trip coil, problems within the breaker's operating mechanism and slow operating times. The implementation of online monitoring allows parameters to be recorded in real-time under actual operating conditions. This offers many advantages over off-line testing, which can often cause many abnormalities to go misdiagnosed, as any operation of the breaker before testing and simulated test voltages can lead to the early development of problems going undetected. Online monitoring raises the asset owner's awareness of the breaker's real-world performance, allowing resources to be directed more proactively, thereby reducing the chance of a problematic condition being misdiagnosed or possibly created as the result of traditional cyclic testing and intrusive internal inspections.

CIRCUIT BREAKER MAINTENANCE

Circuit breaker maintenance is a highly critical component of the reliability and safety of any power system. Breakers are relied upon to protect from abnormal electrical conditions in applications ranging from residential homes to high voltage transmission systems, whether it be the common household breaker, responsible for the protection of the home's electrical system from excessive current flow, to high voltage substation breakers which provide not only protection against fault current, but are also used for transferring loads and controlling cap banks and other var compensating equipment, ensuring steady power factor and system reliability. While the common household breaker requires little to no maintenance, as it is simply a switch reliant upon an electromagnet or bimetal strip to initiate operation, modern high voltage circuit breakers are quite complex. To gain a better understanding of how this equipment operates and the potential failure modes, it is beneficial to think of a high voltage circuit breaker as a series of subsystems. This would consist of the mechanical system, the electrical system, and the insulating system.

Mechanical System

The mechanical system or mechanism of a circuit breaker consists of multiple moving parts working in unison with a stored energy system to actuate the physical opening and closing of the main contacts. Though designs vary greatly between models, the mechanism generally consists of a stored energy system, a plunger actuated by either a trip or close coil, latch, a main cam, bearings, and linkage connecting the main operator via a series of gears and levers to the main contacts. The majority of breaker failures, both major and minor, can be attributed to a malfunction of one or more components within this mechanical system. Long periods of inactivity can lead to degradation of the mechanical systems lubrication, causing a separation of the grease's oil from its thickener compound, reducing the grease's thixotropic properties, which can lead to slower operating times, seizure of bearings and excessive frictional wear. Though this type of misoperation is highly preventable, it can be difficult to detect through the sole use of offline testing and maintenance as any operation of the breaker before testing can mask the underlying issue, and often these conditions can develop between time-based maintenance intervals. Another major contributor to mis-operation related to the breaker's mechanical system is the failure of the stored energy system. Stored energy systems consist of a charging motor and utilize hydraulic, pneumatic, or spring energy to provide the energy required for opening and closing the breaker's within the required timing parameters. While many breakers have relaying designed to lockout due to low stored energy, conditions such as leaks and excessive motor currents or starts may go undetected until a misoperation occurs as a result of the problem developing between maintenance intervals. By combining the most effective off-line and online testing methods into a highly customizable online monitoring package, capable of performing the advanced analytics, many of these operating deficiencies can be detected well in advance of breaker failure.

Electrical System

Electrical control systems in circuit breakers require a combination of relays, control wiring, switches, fuses, and CTs to ensure proper operation during their function of controlling switching operations for overcurrent protection and system control. While the failure of the electrical system is not as common as that of the mechanical components, their incipient markers are more difficult to detect during routine maintenance, making them likely to occur suddenly between service intervals, resulting in a failure to open or close on command. A good example of this is failure of the cabinet heaters. Inspections performed during the warmer times of the year would likely cause an inoperable cabinet heater to be overlooked. Though the loss of the heater wouldn't have an immediate effect on breaker operation, it would allow condensation to form in the control cabinet, which in turn could lead to corrosion of the control wiring, possible short circuits and premature aging of electrical components. Contacts are another critical component of the electrical system. These usually consist of the arcing contacts which are responsible for carrying the make/break current portion of the switching operation, the main contacts which carry the main load current flowing through the breaker and the auxiliary contacts which make and break the control circuit during switching operations. Assessing the contact condition in the field requires an internal inspection of the breaker to be performed. This is a time-consuming process, requiring up to thirty-six working hours to complete. If these inspections are set on a time-based interval, it can often lead to unnecessary internal inspections, as contact wear and nozzle ablation are determined by the accumulated fault current incurred, which has no correlation to time in service. This is problematic in that not only are these unnecessary inspections a waste of resources, but the intrusiveness of this type of inspection introduces the possibility of creating a problem where one did not previously exist.

Insulating System

The insulating system of the breaker consists of the bushings and the insulating medium of the main tank. Various insulating mediums such as SF6, mineral oil, vacuum, or air are used to extinguish arcing during switching operations and to provide insulation between live parts of the breaker and ground. The integrity of these systems is critical as the development of leaks can result in a loss of pressure and dielectric strength, diminishing the ability of the breaker to extinguish arcing, resulting in catastrophic failure. Regardless of the insulating medium used, routine testing must be performed to detect adverse changes in dielectric properties, moisture content, and integrity. Monitoring of SF6 insulating systems is of the highest priority of all insulating mediums due to the adverse effect a loss of gas density can have on the ability of a breaker to effectively extinguish arcing and potentially causing the breaker to fall into an inoperable state if pressure levels fall below the manufacturer's established operating limits. Also, SF6's classification as a hazardous greenhouse gas has led the EPA to place strict reporting regulations on utilities concerning the volume of gas on site and levels released to the atmosphere through leaking equipment and improper handling.

BREAKER MONITORING

Through the application of breaker monitoring, many of the conditions which can lead to breaker failure can be identified in their incipient stages, allowing for prognostic evaluation of breaker conditions to trigger corrective maintenance before the occurrence of a system event. To achieve optimal breaker reliability, this monitoring should assess conditions concerning each of the breaker's subsystems.

MECHANICAL MONITORING

While there are multiple parameters to be considered when assessing the condition of a breaker's mechanical systems, the introduction of high-speed waveform capture of the operating coils and main contacts offers a high level of insight concerning a breaker's real-time operating condition and the development of operational defects. Figure 1. illustrates an example of a breaker in good operating condition.

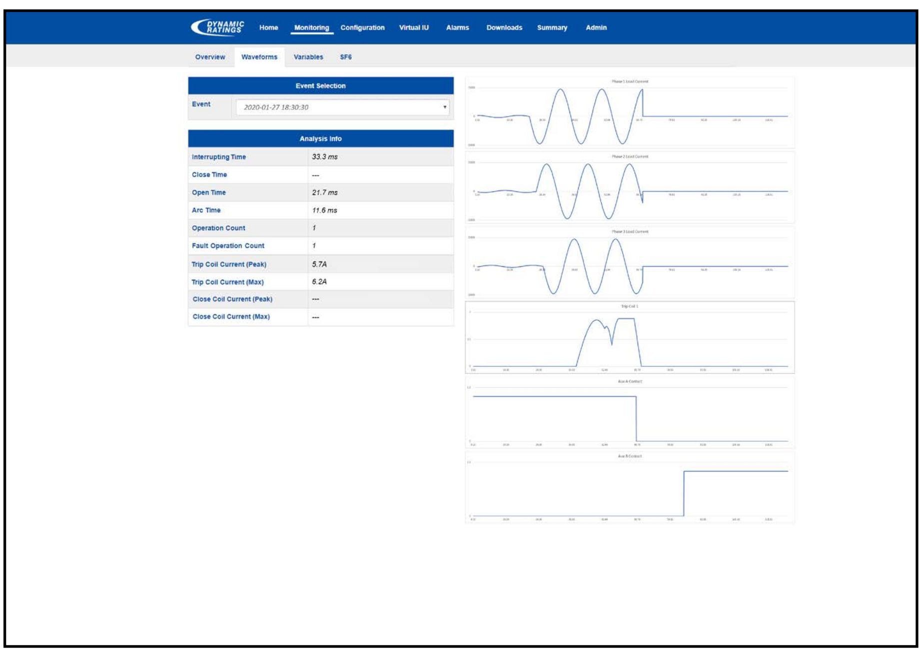

Figure 1

By overlaying the trip coil waveform capture of two separate operations for a given breaker the following assessments can be made:

- Condition of lubrication (signatures and times are nearly identical for each operation)
- The latch is in good condition (unlatching time and time to buffer line up for each capture)
- Main bearings and linkage are in good condition (main contacts open times match and are within specification)
- Auxiliary contact is in good condition (de-energization of trip coil matches for each operation and no static in waveform signature)
- Trip coil condition (energizing current within specification and signatures match for each operation)
- DC supply and control wiring condition (DC supply voltage within specification with no sag present during breaker operation and no AC ripple)
- Delta times for main contacts within specification

So, it is apparent that a lot of data concerning the operation of the breaker can be ascertained through monitoring of the trip coil's waveform, DC voltage supply, and main contact current. Figure 2 illustrates a breaker that is beginning to demonstrate slow opening times. While this is a minor failure, as the breaker would still be able to perform its primary job of clearing the fault, without interventive maintenance, breaker functionality will likely degrade to the point of causing a system event.

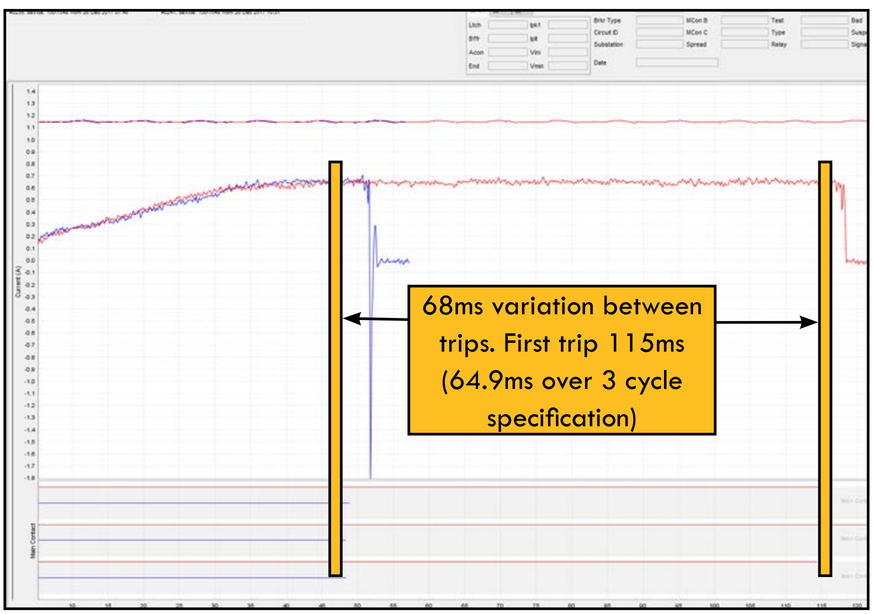

Figure 2

- First trip exceeds specified limits for this breaker
- Latch times for both trips relatively the same
- Second trip 68ms faster than first trip (an indicator of lubrication degradation of the main bearing)
- Static at auxiliary contact operation indicates potential problem developing with contacts

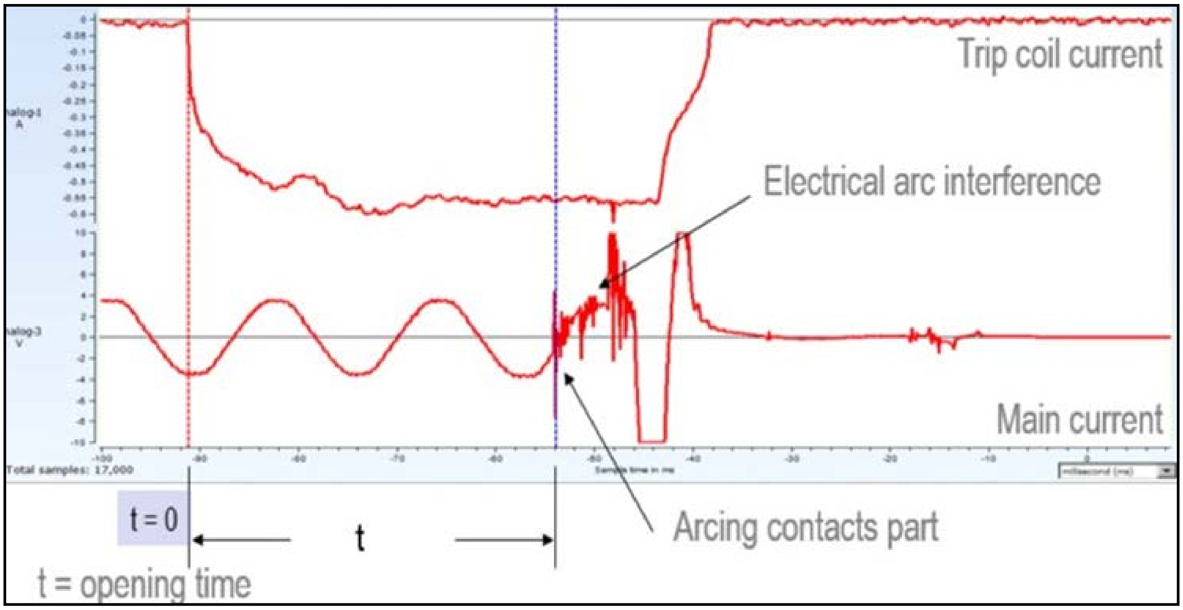

Figure 3

High-speed waveform capture of the main contacts also allows for a more accurate estimation of contact wear. Although the main current path in modern breakers accounts for fewer than 15% of all breaker failures, internal maintenance is often scheduled prematurely, resulting in unnecessary use of resources. This is frequently caused by time-based maintenance programs or internal maintenance based solely on operations counts with no consideration of the accumulated fault current. Online monitoring using waveform capture allows the actual arc time to be calculated beginning at the point of deformation in the waveform when arcing begins as the main contacts separate till current flow reaches zero, indicating the completion of fault interruption. This waveform also allows for the amplitude of the fault current to be measured, increasing the accuracy of the cumulative I2T calculation, allowing maintenances to be scheduled more efficiently.

LIMITED THROUGH FAULT EXPOSURE

Online breaker monitoring has proven to be highly effective at detecting operational abnormalities that may often go unobserved through traditional maintenance testing. One of the most critical components of breaker operation more easily observed through the use of online monitoring is the detection breakers for which the interrupting time has exceeded acceptable rating for that equipment. This is often missed with routine maintenance as any operation of the breaker prior to recorded testing can lead to misleading timing results, as the initial operation tends to break loose components of the lubrication and bearings thereby making the breaker look as though it is functioning within operational parameters. This misinterpretation of the breaker's performance is critical as slow interrupting times greatly increase the duration to which transformers are exposed to excessive fault current, effectively aging the transformer prematurely as cumulative fault values are a product of both current amplitude and duration. Increases in either of these values place excessive thermal and mechanical wear on the transformer. Also, this failure to detect the slowing of breaker rated interrupting times during time-based inspections and testing could eventually lead to lubrication and wear of mechanism components become degraded to the point that the breaker is rendered inoperable. The pictures in figure 4 illustrate complete failure of a transformer and the resulting fire in the control room due to a high side transmission breaker failing to operate.

During this event, the fault is thought to have occurred somewhere on the low side bus between the bank breaker and the transformer. The relay for the high side breaker issued a trip signal to the breaker which failed to open. Due to the distance between stations, fault levels were too low to cause a trip of the transmission breaker at upstream station, leaving the fault present on the transformer for over 6 minutes and ultimately resulting in transformer failure and a fire in the control house. The mis operation of the breaker was determined to be caused by seized up main bearing of the operating mechanism, despite this breaker having passed inspection four years before this event occurred.

Figure 4

TRIP CIRCUIT MONITORING

Trip circuit or red-light monitoring is another critical function of online monitoring. Trip circuit monitoring verifies the integrity of the control wiring, fuses, 52 A switch, trip coil, and all components in the trip circuit through the detection of low current flowing through the circuit when the breaker is in the closed position.
As the integrity of the trip circuit can be compromised by conditions such as faulty fuses, worn fuse holders, shoted or open operating coils and faulty wiring, many of these conditions can often occur between inspection intervals, resulting in a failure of the breaker to operate under fault conditions.

SF6 MONITORING

Most modern high voltage circuit breakers and switchgear primarily utilize SF6 as an insulating medium due to its high density and dielectric strength. These properties allow for a reduction in breaker size at higher voltage applications, and the reformation of by-products produced when extinguishing an arc back into SF6 makes it highly efficient and relatively low maintenance for use in circuit breaker applications. However, the ability of SF6 breakers to effectively extinguish arcing is directly related to the pressure and temperature of the SF6 gas. Online monitoring allows gas pressure, temperature, and dewpoint to be constantly observed. This allows the asset owner to observe leakage rates and determine the amount of time until the pressure falls below operational levels, resulting in actuation of the 63-pressure relay, which serves to activate a tripping or blocking scheme. With this knowledge, the asset owner is provided a window of time in which to schedule planned maintenance and to avoid emergency outages.

CONCLUSION

Due to aging equipment and decreased operating budgets, effective breaker management using off-line testing and time-based maintenance has proven to be increasingly ineffective, resulting in a greater number of unplanned outages and the premature failure of substation equipment due to higher levels of cumulated through-fault exposure. Through the utilization of online monitoring, many of the conditions common to breaker failure could be detected before an event occurred, allowing maintenance resources to be directed towards preventing the occurrence of substation events as opposed to responding to unplanned emergency outages, allowing for extended equipment service life and a reduction in budgeting required for operational maintenance.

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For information about our circuit breaker monitoring options, contact sales@dynamicratings.com.

Asia / Oceania
+61 3 9574-7722
sales.asia@dynamicratings.com

Americas
+1 262 746-1230
sales.us@dynamicratings.com

Europe/ Africa
+44 1617 681111
sales.eu@dynamicratings.com

www.dynamicratings.com