Advantages of comprehensive monitoring for critical circuit breakers

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***Abstract*— Critical circuit breakers are the objects of careful preventive maintenance programs where utilities require reliable operation. The ability of the asset to operate when needed is a critical component of equipment protection from further damage. These maintenance programs can be very expensive with more frequent and comprehensive tests and inspections and failure of the breaker to operate when needed can cause significant collateral damage. In many cases this becomes a burden on the operation and maintenance budgets as well as time consuming for the engineer to successfully manage.**

High voltage circuit breakers are valuable assets and monitoring of these assets enables utilities to proactively maintain equipment. This paper will review the different aspects of circuit breaker monitoring such as mechanical integrity, SF6 gas levels, contact wear, control electronics and stored energy system.

Keywords—circuit breaker, monitoring, SF6, GIS, condition based maintenance

I. Introduction

Circuit breakers are considered the second most important asset in a substation, after power transformers. Their reliable operation is key to operate, protect and isolate electrical circuits in the substation. While there are different types of circuit breakers, based on different technologies to actuate and to extinguish arcs, they are all composed of various mechanical components subject to wear and tear and insulating materials subject to leaks and possible loss of their insulating properties.

Being critical components of a power system, circuit breakers are subject of careful preventive, or time-based, maintenance as well as corrective maintenance when necessary. As there are many old circuit breakers using older technology, the maintenance required to keep them operational is expensive: test operation, contact replacement, overhaul, gas refill, etc.

II. Drivers for comprehensive online monitoring

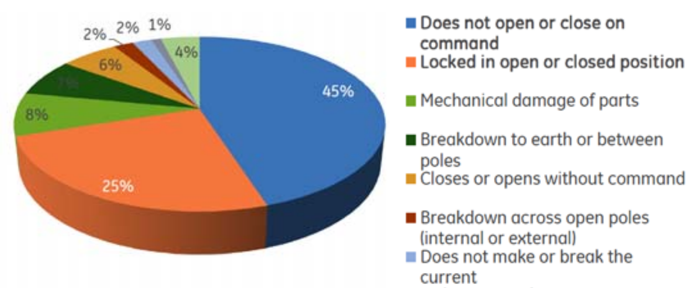
Electrical operators cover extensive area including many unmanned installations; grids are increasing their complexity; maintenance organizations are constantly challenged with budgets not increasing in proportion of the growth of the grids and with loss of expert resources due to retirement. On the operations side there are stringent requirements from the regulators for reliability, availability and environmental targets with non-negligible penalties in case of non-compliance. It is imperative to optimize equipment life, reliability, budget expenditure and resource allocation.

Those drivers initially influenced installation of online monitoring to power transformers starting with expensive step-up, continuing to transmission, distribution and industrial assets. Online monitoring of power transformers is widespread now with demonstrated success by a proven track record of numerous documented saves and positive influence in operation and maintenance budgets.

Circuit breakers also benefit from online monitoring as demonstrated in the following sections.

III. Circuit breaker failure modes

Cigré working group A3.06 compiled failure modes data from many circuit breakers of 83 utilities, classifying into Major and Minor faults. Major faults are defined as one that will result in backup protection required to remove the fault or mandatory removal of breaker from service within 30 minutes for non-scheduled maintenance.



Source: Cigré Working Group A3.06 – Final report of 2004-2007 International Enquiry on Reliability of HV Equipment, Part 2: HV CB Failure - 2012

Exploring possible causes of the most frequent failure modes:

1. Does not open/close on command:
   a. Open or shorted trip coil or close coil
   b. Problems with trip latch or mechanism
   c. Loss of stored interrupting energy
   d. Control circuit failure
   e. Mechanical linkage failure between operating mechanism and interrupters
   f. Critical drop in mechanism cabinet temperature
   g. External circuit failure

2. Locked in open or closed position:

a. Circuit breaker operation blocked

The above failure modes can be detected by monitoring techniques.

1.a. Monitor trip/close coil continuity
1.a. Monitor open/close circuit for possible increase in current or monitor trip/closing time
1.b. Monitor time for circuit breaker to operate
1.b Monitor trip coil energy consumed or current and voltage drop during time for breaker to operate
1.c. Monitor stored energy pressure or position of stored energy spring
1.d. Monitor control circuit continuity and dc voltage at circuit breaker and controls
1.d. Monitor auxiliary contact timing (on non-current carrying contacts)
1.e. Monitor primary current interruption during change of state of operating mechanism
1.e. Monitor timing sequence between operating mechanism and interruption
1.f. Monitor mechanism temperature or mechanism heater current and ambient temperature
1.g. Monitor station battery voltage at circuit breaker and continuity of trip circuit
2.a. Early warning of any gas leaks
2.a. Trending of monitored parameters to catch abnormalities

IV. Independent Sensors vs. Comprehensive Monitoring

GIS breakers normally have some sort of sensor to get SF6 density as it is now mandatory in many places to monitor at least SF6 leaks. Some will have additional sensors. Monitoring other types of breakers is less frequent except by what is done by protection relays in terms of checking open or short in control circuit. Some earlier breaker monitors may cover a small number of failure modes, still leaving several possible sources of problems unmonitored. Those still bring benefits to the user.

A comprehensive breaker monitoring system monitors nearly all the parameters that indicate any failure in the breaker as shown in previous section. By having all the information in the same Intelligent Electronic Device (IED) on the same database, the comprehensive breaker monitoring can show the breaker behavior from different angles and allow a cross correlation of the various indications, greatly increasing the probabilities of detecting any potential failure developing and reducing the number of false alarms.

V. Detection of Root Causes of Breaker Failures

IEEE developed a standard that advises how to detect and monitor the root causes of breaker failures:

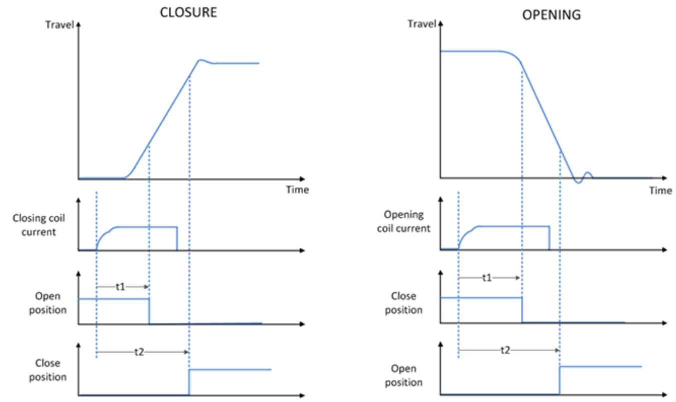
IEEE Standard 37.10.1 – 2000, Guide for the selection of Monitoring for Circuit Breakers

A. *Control circuit integrity*

- Open or short in control circuit
- Shorted trip or close coil
- Lack or low DC voltage supply

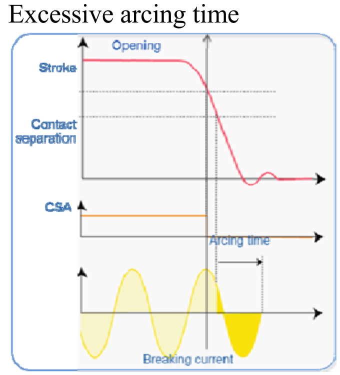
B. *Mechanical integrity*

- Breaker responds to command and open/closes
- Time to operate



C. *Arc extinction*

- Excessive arcing time



- Arcing contact wear

$$\text{Cumulated electrical wear} = \sum_{\text{operations}} \int_{t_0}^{t_1} I_{cc}^2 \cdot dt$$

D. *Dielectric integrity*

- SF6 gas leaks
- When gas replenishment is next due

E. *Stored interruption energy*

- Spring rewinding time
- Rewinding/pump motor current

F. *Environment*

- Extreme cold conditions
- Cabinet heater integrity

VI. Benefits from Transitioning to Condition Based Maintenance

Moving from reactive or preventive maintenance to condition based maintenance brings a lot of benefits. Instead of maintenance based on fixed time interval or number of operations, move to condition based maintenance based in the monitoring of key parameters and accumulated knowledge of breaker operations.

Comprehensive breaker monitoring systems enable this transition to condition based maintenance as they continuously monitor the critical parameters of the circuit breaker and detect the most important failure conditions before they occur. They combine the information received from various sensors about the condition of breaker, trends data in a short-term and long-term time series, stores data for years of operation and transmits the information via modern communication protocols to SCADA, monitoring centers, data historians and corporate asset performance monitoring systems.

Unnecessary maintenance reduces asset availability, uses resources, increases lifetime cost, risks damage to gas seals and frequently is a cause of problems. Maintenance based on time intervals or number of operations does not necessarily detect all the potential causes of failures and may prove to be innocuous.

VII. SF6 GAS, AN EXTRA CONCERN

Most high voltage circuit breakers today use SF6 gas to extinguish the arc. SF6 gas is a green house gas and is not good for the environment (32,000x the warming potential of CO2)

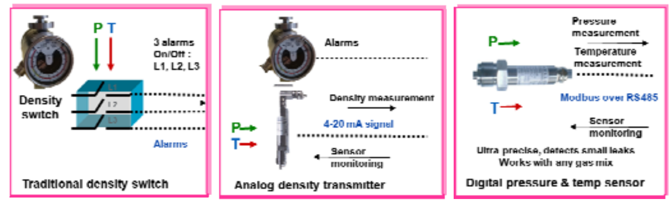
SF6 gas is expensive to buy and there are now penalties in many countries for releasing SF6 into the atmosphere, so leaks are doubly costly

Reporting gas usage to EPA or environmental agencies becoming mandatory in many countries

Older SF6 density switches do not detect SF6 leaks early or problems in the cables. Analog SF6 density transmitters are subject to spurious alarms due to EMC and are not precise enough.

Comprehensive breaker monitoring systems must use very precise digital SF6 temperature and pressure sensors capable of detecting very small leaks of SF6. Those sensors transmit independently the values of pressure, temperature and humidity via digital communications protocol in one unique link to the IED allowing the monitoring system to monitor pure gases, gas mixtures and the new generation of green gas such as g[3].

The monitoring system will indicate the need to do maintenance before a serious leak and will accurately report when it is the time to replenish and prevent the breaker to reach critical levels of SF6 that could block the breaker operation.



VIII. CONCLUSION

Circuit breakers are one of the most important assets on the power system and require maintenance to keep them available to interrupt system faults when needed. The ustilization of transformer monitoring to use condition based maintenance rather than time based maintenance has allowed the industry to understand how to minimize maintenance costs while still maintain equipment. The same types of monitoring and diagnostics that are employed to transformers to optimized maintenance can also be employed on high voltage circuit breakers.

Several Cigre and IEEE studies have explored the cause of circuit breaker failures. These studies can be used to identify the likely failures, which can then be monitored to allow condition based maintenance of those systems rather than time based maintenance.

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