21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2014 Grid of the Future Symposium

Circuit Breaker Asset Management Using Intelligent Electronic Device (IED)-Based Health Monitoring

C. SCHNEIDER, M. SKIDMORE, Z. CAMPBELL, J. BYERLY, K. PHILLIPS
American Electric Power (AEP)
United States

SUMMARY

AEP has incorporated asset health analysis and data captured by digital relays into ongoing efforts to streamline and standardize the management of its circuit breaker fleet. Past asset management practices have relied on manually collected data and a deep knowledge of breaker types and history to support maintenance and replacement decisions. The asset management group has developed methodologies to rank the replacement of equipment, and guidelines are proposed to move to condition based maintenance. The Asset Health Center software provides analysis on the traditional manually collected data as well as automated data gathered from historical fault files and a new breaker control package utilizing smart sensors.

KEYWORDS

Asset health, virtual monitoring, asset management, digital relays, automation, circuit breaker, fault file

cmschneider@aep.comote.

I. Introduction

Electrical power transmission and distribution utilities have long been tasked with upgrading, replacing, and maintaining an interconnected fleet of substation equipment. Whether batteries, switches, circuit breakers, regulators, transformers, or any other numerous assets, utilities have had to balance the competing criteria of customer reliability, safety, Operations and Maintenance (O&M) expenses and capital investments when managing their fleet effectively. In the past, during times of rapid electrical grid expansion, much of this fleet was in a younger, healthier state. Currently, many utilities are facing both an aging fleet and downward pressure on O&M expenses. For instance, at American Electric Power, 33% of transformers are 50 years or older and nearly 18% are 60 years or older [1]. The implication is that utilities now must operate a program of asset management in the most effective way possible.

Historically, asset managers were able to operate at a local level. With years of experience and a deep knowledge of the equipment at a relatively small collection of substations, an asset manager was able to effectively administer the maintenance and replacement of his or her assets. As utilities have merged with one another, total assets have increased, operations have become centralized, and the control of the funding for asset management activities has moved further from those who interact with the assets on a daily basis. These factors create the need for a centralized asset management program that includes asset health analysis, condition based maintenance, and dynamic rationalization of capital and O&M spend.

The concept of asset health analysis is not a new one. Utilities have been recording measurements of asset health indicators for years. For circuit breakers in particular, measurements such as contact resistance and time have been used for the purpose of ranking replacements and maintenance. These practices have relied on manual inspection and analysis of the data by a trained engineer. The concept of using a calculated health index is discussed in [2]. New programs such as the Asset Health Center (AHC) aim to reduce human involvement with the initial assessment of incoming data, predict equipment failures and required maintenance, and provide evidence and visibility for the case to renew the grid.

II. Circuit Breaker Asset Management

In AEP's Transmission organization, the station asset management group is responsible for the maintenance, replacement, and failure mitigation of substation equipment. The circuit breaker maintenance work plan has traditionally been driven from both time-based and regulatory-based maintenance guidelines. Each year, a preventative maintenance plan is produced which includes routine inspections, equipment testing, and repairs. In addition, a yearly capital rehab work plan is developed for circuit breakers with the goal of replacing the worst performers and obsolete models based on available funding. Finally, the station asset management group assists field personnel with repair or replacement of failed circuit breakers on an ongoing basis. The asset management group provides decision support to field operations groups based on years of experience and past practices.

The replacement of existing circuit breakers is prioritized based on funding availability, equipment reliability, model obsolescence, and age. Our Transmission station asset management group has developed a ranking methodology specifically for circuit breaker replacement that pulls information from nameplates, inspections, test results, operational history, and trouble reports. The asset manager can use this ranking methodology along with field experience to prioritize a yearly rehab plan.

Circuit breakers are visually inspected on a routine basis. During these periodic checks, the breaker operations and loading are manually logged. The equipment is inspected for abnormal conditions inside the control cabinet and on the main units. The breaker remains in service during the inspection, but it does require a physical visit from trained personnel.

Circuit breaker preventative maintenance intervals are based on breaker model, voltage level, interrupting medium, and breaker application. For each category, our team has developed intervals based on manufacturer's guidance and best practices for both external maintenance and internal maintenance. Additionally, AEP's guidance states that the breaker should operate at least once per year. Both external and internal maintenance require the breaker to be de-energized and isolated. External checks include: measurement of contact resistance, insulation resistance, oil quality, and maintaining the linkage, all where applicable. Internal tests include: timing tests, replacing gaskets, and cleaning of tanks, all where applicable. Circuit breaker corrective maintenance is performed on an as needed basis. Corrective maintenance is event driven based on inspections, operations, and failures.

Another key function of the asset management group is to advocate for funding breaker renewal initiatives. Asset managers need to provide a business case stating the level of maintenance and replacement needed to keep the fleet of assets functioning reliably. To support replacement and maintenance decisions, the asset engineer needs to combine the operational, inspection, testing, and failure data with financial information such as replacement cost, maintenance expense, and book value. Traditionally, both the data collection and analysis have been manual processes. Our AHC team is starting to automate the data collection through the use of health monitoring and Intelligent Electronic Devices (IED) data.

III. The AEP Asset Health Center

The AHC Software Solution is a collaborative effort between AEP and ABB-Ventyx. The tool is a web based interface that allows access from a corporate connected laptop, mobile device, or PC. The software project is a four phase, three year implementation that continually increases functionality and allows for user feedback towards enhanced operation. The software makes use of several available data sources including equipment nameplate information, inspection and test results, SCADA data, fault files, and real time health monitoring equipment. The tool includes algorithms that calculate risk of failure, asset criticality, need for maintenance, and need for replacement [3].

Algorithms are developed by AEP and ABB substation equipment and asset management subject matter experts. *Asset Performance Models* (APM) calculate the health of transformers, circuit breakers, and batteries. In general, these models calculate the probability of an asset failing to perform its intended function. The algorithms can also generate messages to inform users of current abnormal conditions, the possible solution, and a timeline to mitigate the condition. For circuit breakers, the algorithms make use of parameterized models which account for manufacturer design differences. These parameters act as thresholds to assess measurement and inspection data against.

The *Maintain vs. Replace Algorithm* provides decision support to justify the need to replace or continue maintaining an aged asset. O&M tasks (regulated, time based, and condition based) are prioritized based on need and asset criticality. Asset replacement is prioritized based on asset health, remaining useful life, and forecasted maintenance.

The AHC Software Solution provides dashboards in a web browser interface that allow the user to sort through the health assessments and the suggested maintenance and renewal, filtering by asset type, organizational structure, voltage level, or age. An asset monitor dashboard summarizes the risk of failure for the entire population and allows the user to query by several filters and drill into specific assets. Equipment specific dashboards visualize current measurements, history of trend values, and how that data feeds the asset health algorithm. The Maintain vs. Replace dashboard allows the user to see suggested maintenance tasks by area or by asset and visualizes the pending cost of forecasted maintenance.

IV. Breaker Health Monitoring Past Practices

To help facilitate data collection asset management decisions, AEP has previously implemented different technology initiatives. When our company standardized using digital relays for circuit breaker controls, the built in breaker contact wear function was implemented. The function gave the relay the ability to alarm when the breaker had cleared a certain aggregated amount of fault current. There were several issues with this approach. The settings engineer was required to put in detailed information about the circuit breaker and, if it was an existing breaker, information about the breaker's history of fault operations. Additionally, the function would not filter out operations and test currents that were injected during relay testing. Because of these reasons, the built in breaker contact wear function has not been utilized for breaker asset management on a large scale.

Our company has also piloted various models of dedicated breaker health monitoring devices. This type of device has added sensing capabilities, such as SF6 gas pressure and density and motor and heater currents. The device also has onboard analysis that can calculate breaker contact wear, generate alarms, and log data. Our experience with this type of device is that it is too complicated, prone to failure, and duplicates technology that already exists in the control relay. Ultimately, the commercially available devices are more costly than can be justified for the benefit provided.

Moving forward, our company has decided to leverage extensive experience with digital relays for circuit breaker control in order to provide a better solution for breaker health monitoring and analysis. In general the parameters that are important to breaker asset management and can be captured digitally are the following: SF6 gas temperature, moisture and density, operating coil current, motor current, operation counts, load current, voltages, and contact timing. The following sections give an overview of how these parameters are being measured from both existing relay records and a new breaker control package.

V. Parsing Circuit Breaker Control Relay Event Records

AEP has developed a system that automatically obtains event record files from protective relays. Most commonly, these records are: oscillography traces in COMTRADE form, sequence of event data, and event summaries. The system was developed such that disturbance monitoring requirements could be met with minimal personnel involvement [4]. These records tend to illustrate system behavior when there are abnormal conditions present at the location where the relay is installed. This is because these files are only generated in instances where specific system behavior is being looked for. When behavior falls outside of the criteria, which causes an event record trigger to assert, the result is that no event record is generated. When records are generated, they are transferred automatically from the relay to our corporate servers. These servers are easily accessed by numerous personnel. Due to the size and scale of our system footprint, over the time that this system has been in service, the system has accumulated many millions of event record files. Up until recently, most of this data was ignored, which makes very little use of the available data. This is because most operations on the system occur as designed, making a detailed review of each and every operation not necessary. Recently, our P&C engineers have been attempting to make use of this data by mining data out of the plethora of information stored on event record servers.

In order to mine data out of the event records, it is necessary to predefine for what information is being searched. One item, which has been mined from event record data, is associated with circuit breaker health. The metric associated with circuit breaker health being monitored is circuit breaker wear calculated on a per-pole basis. Many relays and other devices have the ability to monitor this metric, but relays have rather limited functionality and can provide false positive event counts while other devices add cost to provide little additional monitoring benefit. The metric is being calculated by parsing COMTRADE files from circuit breaker control relays for instances when the circuit breaker trips due to a fault being present. Also, positive sequence current and voltage must be above a minimum, and maximum RMS current during the event must reach above a minimum value. Meeting these criteria remove the events that are generated when relays are under test conditions from being processed by the parsing algorithm. Circuit breaker wear per pole can be calculated as shown in Equation 1.

Equation 1. $$i^2 t = \int_{ll}^{ul} i^2 \, dt$$

In the equation, *i* is the RMS current per pole, *ll* is the time (in seconds) when the arcing begins, and *ul* is the time (in seconds) when the current is extinguished across the circuit breaker. Because the time of arcing is unknown and varies per breaker type, the algorithm will estimate this time based on the time of trip coil energization.

The parsing algorithm operates by first finding all relays that are used in circuit breaker control applications. This is simple because our company uses a single relay brand and type for this application. It then qualifies each of the event files from those relays based on the relay's analog signal signatures previously mentioned. Then information necessary to calculate the integral of Equation 1 is gathered. The integral is then calculated. Once this occurs, the result is then passed to the AHC PI system for storage and aggregation purposes along with time stamp information and other pertinent details which help to define the operation that caused the integral to be calculated. The AHC PI system uses each of the calculations and performs a sum of all of the individual integral calculations to generate an overall circuit breaker wear metric quantity.

VI. Virtual Monitoring through Standard Breaker Control Relay Package

Transmission circuit breakers range in operational voltages of 34.5 to 765 kilovolts on our transmission system. This transmission system includes thousands of circuit breakers that are responsible for protecting the system during abnormal conditions by interrupting and isolating network branches. Circuit breakers are controlled and monitored using IED like the Schweitzer Engineering Laboratories (SEL) 451 relay. The SEL-451 is responsible for functions such as: breaker control, automatic reclosing, supervisory control and data acquisition, disturbance monitoring, and asset health monitoring.

Asset Health is a real-time monitoring system currently being developed to collect data from monitoring devices, like the SEL-451, for the purpose of equipment health diagnosis. The Asset Health monitoring system will collect data from IED's in real-time to analyzed and archive data that will support the performance trending of the equipment. One objective of the Asset Health monitoring system is to migrate from the present time-base maintenance practices to one of a performance-base with the goal of decreasing Operational and Maintenance (O&M) cost of ownership.

One of the functions of the SEL-451 is to provide monitoring data to the Asset Health breaker monitoring system (see Figure 1). Monitoring data from this SEL-451 shall consist of breaker currents and system voltage measurements for trending data as well as current interruption and timing data during system disturbances from event records. The event records collected by the substation computer are of three types: oscillography, sequence of event, and fault records. The 451 relay that generates the event records is time synchronized using GPS time synchronization using a substation clock. Event records, circuit breaker currents and system voltages are collected and stored on a substation computer that is located on the same LAN. The substation computer will organize breaker asset data and provide these files to that Asset Health system for remote retrieval.

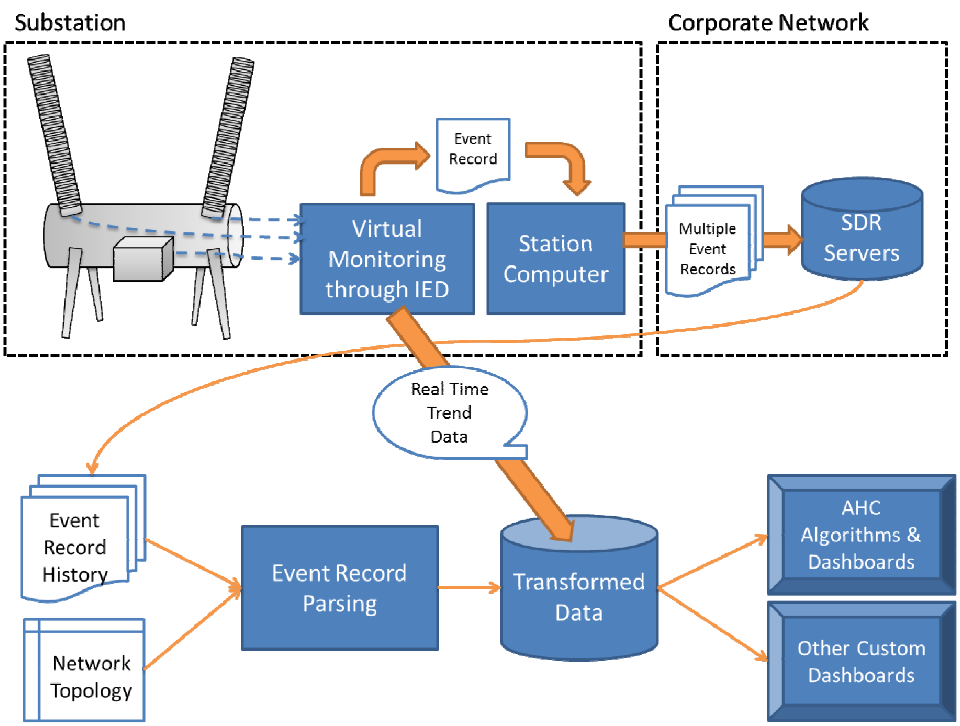

Figure 1 Virtual Monitoring and Data Collection

The circuit breaker health monitoring system also includes remote modules that are located within the circuit breaker equipment. These remote modules take various reading such as SF6 density, motor run time, and trip coil currents and present these data items to a collector device named the circuit breaker monitor (CBM). The CBM is a SEL-2411 relay that is programmable and configurable with many I/O options such as digital inputs, analog transducer inputs, and low energy analog (LEA) inputs.

The 2411-CBM will be time synchronized using GPS time synchronization using a substation clock. This will facilitate proper data alignment of event records between the 451 and the 2411-CBM. The 2411-CBM will collect SF6 gas density, motor currents, and motor starts for trending of these data points. Trend files will be created by the substation computer for Asset Health retrieval.

The 2411-CBM will collect auxiliary ‘a’ and ‘b’ contacts, trip coil currents, and close coil currents during any breaker operation. This data will be stored in an event record on the SEL-2411 which will be collected by the substation computer for local storage. The Asset Health system will retrieve the event records from the substation computer and parse records with SEL-451 records to determine operation type, operation time, and other parameters. The 2411-CBM will also collect circuit breaker auxiliary ‘a’ and ‘b’ contacts and trip/close coil currents during trip or close operations of the breaker. This data will be stored in an event file on the 2411 and will be collected by the substation computer for local storage and remote retrieval by the Asset Health system. These event records will be parsed and combined with the 451 event records to determine advanced monitoring features such as fault clearing times (per pole), operational performance using coil signature analysis, and contact wear using actual i^2t calculations.

When the tools within Asset Health are complete and accurate monitoring of transmission circuit breakers exist, AEP can then justify modifying maintenance intervals. Providing maintenance on an operational and performance base rather than a strict time interval base will provide many benefits to the equipment maintenance organization. Further, correct identification of troubled equipment and focusing maintenance on these assets will have benefits to protection and performance of the system.

BIBLIOGRAPHY

[1] Fleeman, J., “AEP Launches Asset Health Center,” Transmission and Distribution World, Feb 1, 2013, http://tdworld.com/asset-management-service/aep-launches-asset-health-center.

[2] Scheibe, M.; Richert, J., “Data in Hand. Now What?,” Transmission and Distribution World, June 21, 2013, http://tdworld.com/grid-opt-smart-grid/data-hand-now-what?page=1.

[3] Phillips, K.; Schneider, C; Cambraia, P; Munson, M, “Automated Aggregation of Data for Asset Health Analysis,” CIGRE Grid of the Future Symposium, October 20, 2013 http://cigre-usnc.tamu.edu/meetings/grid/documents/2013-presentations/final_pdfs/AssetHealthDataPresentation.pdf.

[4] Jones, C.; Smith, D.; Schnegg, J., "Meeting NERC requirements for oscillography and disturbance monitoring by collecting data from relays," Power Systems Conference, 2009. PSC '09. , vol., no., pp.1,9, 10-13 March 2009