Modern on-line monitoring for high voltage circuit breakers

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1 Summary

Continuous monitoring of circuit breakers started in the 90s inspired by an airplane «Blackbox».
The basic idea at that time was to keep track of the breaker parameters to understand the reason in case of failure. The main circuit breaker parameters were recorded and stored locally in a flash memory. Periodically or after a failure, the data could be collected and analysed by an operator.
It was the beginning of condition monitoring and preventive maintenance. The effort needed was consistent. The data had to be collected, downloaded and interpreted manually. Different data format and software available made the job exhausting and too expensive to be regularly implemented.
Thanks to the presently available computation and communication technology, a new generation of breaker condition monitoring systems can be defined.
Starting from a solid set of measured parameters, a modern monitoring system must be able to process the data, comparing them with the allowed limits and raising an alarm if needed.
Parameter trends must be evaluated to detect drifting that could become critical. In this way, a maintenance action can be planned in time.
Limits and critical trends are circuit breaker specific. The possibility to also remotely upload a new configuration in case of an update can make the difference between introducing or not an improvement.
The Web based software provides the possibility to check the circuit breaker status without being dependent on a vendor specific software installed on the remote computer.
This is only possible if a robust communication is in place based on standardized protocols. Big data downloading for an enterprise monitoring server can profit using a standardized Comtrade format to ensure full compatibility. Looking at the future, IEC 61850 compliant would make the system ready to interconnect it with modern substation assets based on this communication protocol.
Although the circuit breaker is a quite reliable device, a flexible, easy to use and configurable monitoring system would allow the BCM to assess its condition efficiently with limited effort.
The automatic data pre-processing will efficiently focus the expertise resources on the critical equipment only. The trend observation compared to the average parameter behaviour of the same breaker typology allows predicting critical situations and planning for maintenance only where and when needed.

2 Keywords

Circuit Breaker
Online performance monitoring
Condition assessment
Travel curve
Electrical wear
Communication protocol
Coil current
SF6 & Compressor Analysis

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3 Introduction

Moving from time based maintenance to condition based maintenance is a recognized step to take for an efficient asset management to reduce costs and improve reliability. Only a reliable assessment of the asset condition can support sound maintenance strategy making the difference between a nice theory and actual economic benefit. In the transformer world, the healthy status of the machine is more and more assessed by means of the continuous observation of different parameters and their trends along the time, installing on-line monitoring systems.
For circuit breakers, this is not the case yet. Although online monitoring and periodic diagnostic testing of switching equipment are considered to be the most valuable tools for maintenance management [1], in the circuit breaker world this practice is less common and the time-based maintenance is still predominant.[2].
Continuous measuring solutions being mainly compared to a “Blackbox” in an airplane were quite in fashion for switchgears in the 1990s when the monitoring concept started being pursued. The main circuit breaker parameters were recorded and stored locally in a flash memory. Periodically or after a failure, the data could be collected and analysed by an operator. After a first enthusiasm, this practice was very often discontinued. The required effort for collecting and evaluating the apparatus data, having a pretty high reliability, was consistent.
The need to go on site using different download interfaces and dedicated software installed on a laptop computer for reading and interpreting the data, were some of the difficulties. Data were continuously recorded by the system, but the evaluation of trends could only be carried out periodically. In an unlucky situation, the indication of a potential critical trend of a parameter, could only be detected after the failure had already occurred.
The technology progress in computation and communication of electronic boards available at affordable cost, is the base of new generation of the monitoring systems for circuit breakers.
Although the measured parameters are pretty much the same, they are now evaluated by an automatic data processing system, that raises an immediate alarm when they are out of tolerances or showing an abnormal trend. The stored parameter history can be remotely analysed before deciding how to proceed. The asset managers can focus their investigations more thoroughly for the alarmed cases only, instead of wasting their time evaluating the plethora of data from healthy switchgears.
The collected experience helps to better define parameter tolerance and trend limits that can be accepted for the specific circuit breaker.
A modern Breaker Condition Monitoring device collects only useful data and processes them per understandable criteria easy to set. It is simple to connect, alerts the user in case of anomalies and allows an immediate access to a deeper information level when required. It runs locally on web-based software making data reachable by means of a standard browser. This paper gives an example of how such a system should look like.

4 Basic concept

In Figure 1 a functional structure of the monitoring system is shown.

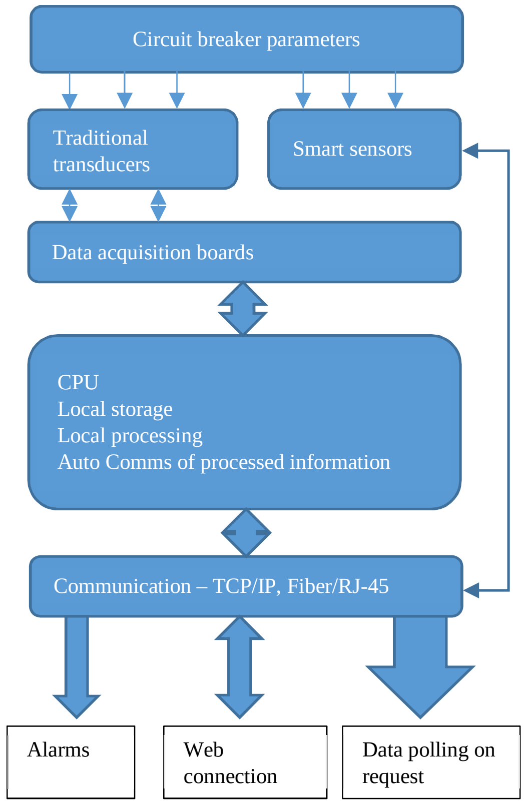

Figure 1
Principle structure of a monitoring system

The parameters needed to monitor the circuit breaker are measured by acquisition boards reading different transducers or in case of smart sensor they can directly talk via communication port (for example Multi-Drop Modbus).
The data are processed locally, compared with configurable parameter limits.
The web based system can be accessed with any computer with a secure TCP/IP connection.
The software runs locally and it is visualized via a Web browser of the remote computer.

No dedicated software must be installed on the PC. A local visualizer allows an event analysis of recorded operation and parameters recorded.
For data collections in an enterprise database and for statistical analysis with other circuit breakers a data pooling can be requested by the database server.

5 Environmental requirements

The monitoring system must function reliably in a high voltage substation exposed to high electromagnetic disturbances. A high electromagnetic immunity for both radiated and conducted energy is a primary requirement.
Not to be underestimated is the working temperature range since very often the monitoring system is installed inside the control cabinet of the circuit breaker. For high temperature climatic zones, temperatures up to 60°C can be foreseen. In desert areas, where cabinet ventilation is not recommended due to sand ingress and relevant contamination, inside cabinet temperature can reach 80°C. Maximum working temperature of 85°C should be specified.

6 What to measure

The parameters to acquire and monitor are meant to provide a sound assessment of different circuit breaker components and functions.

Table I
Summary of measured parameters and monitored functions / components.
The big X and the small x shows how relevant the measured parameter is for the specific monitored item.

	measured parameter									
monitored function / component	Contact travel	Coil Voltage	Coil Current	Motor voltage	Motor current	Aux contacts	Main current	SF6 density	SF6 humidity	cabinet temperature
Operating Mechanism										
operating time		x	X			X				
velocity	X		x			X				
over travel	X									
charging time				x	X					
charging current					X					
number of charges				x	X					
energy stored				x	X					
Main circuit										
operating time	x	x	X			X				
operating speed	X		x			x				
SF6								X	x	
cumulted interruptions	x		x			X	X			
insulation	x					X		X	X	
Auxiliary circuits										
"battery" voltage		X		X						
coils integrity		x								
temperature										X
Tightness										
leakage								X	X	

The same measured parameters can provide useful information of different aspects as summarized in **Error! Reference source not found.**.
In the following, some comments are provided to what is measured and why.

6.1 Insulating / quenching medium

Specifically, for high voltage circuit breakers this is the SF6 density or pressure parameter.
Primary target is to assess its quantity by measuring the density or the pressure rescaled to 20°C.
Two are the main reasons:

- prevent or limit leakage for environmental reason
- ensure the breaker functionality for insulation and switching for clearing electrical faults.

SF6 relays are already installed in a circuit breaker having typically an alarm level and a lock out level below which the breaker cannot be operated any longer.
The continuous gas density monitor, in addition to already installed density relays, allows automatic trend analysis along the time achieving an early leakage detection (see Figure 2). The monitoring system can send an alarm or only a warning for SF6 leakage. Additionally, based on density logged data, an estimation of when the critical level will be reached can be estimated. The whole analysis is fully atomized.

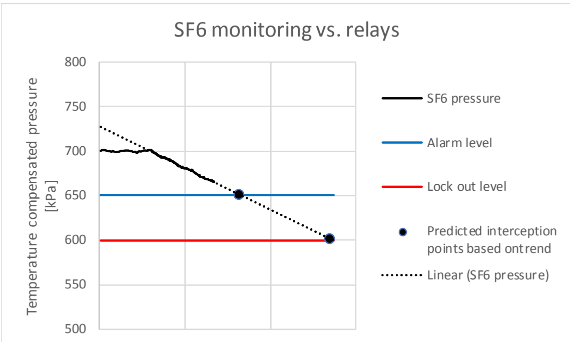

Figure 2
SF6 monitoring vs relay pressure detection.
Trend analysis allows an earlier leakage detection estimating when the alarm and lock out pressure will be reached.

The asset manager can watch the density log remotely before planning a maintenance or an inspection.
In addition to quantity, the available "Smart" sensors also allow assessing the quality of the SF6 by measuring the moisture content.
These sensors are coupled via a Modbus RS-485 communication port.
Also in this case the advantage in comparison to a periodic SF6 analysis is the possibility to early

detect a critical trend and planning for maintenance instead of reacting under urgency.

6.2 Operation and Timing

Every time the circuit breaker operates, an event is recorded. The operating time for every Closing and Opening operation are measured and compared with the reference values recorded as “finger print” at breaker installation or after maintenance.
The same is valid for CO and O-CO sequences.
The parameters to measure are:

- Voltage command
- Current in the opening and closing coil for detecting the command
- Commutation of auxiliary contacts (also known as 52 a/b) to put in relation to separation or touch of the main contacts. The time difference between auxiliary and main contact separation is available in the routine test report and can be entered as offset to evaluate the correct operating time (see Figure 3).

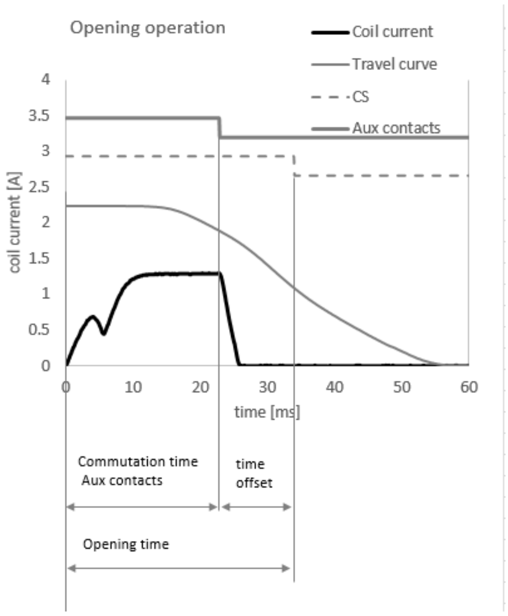

Figure 3
Example of Opening operation with typical coil current shape.
Opening time: from beginning of coil current to separation of main contacts (not available online).
The commutation of recordable Aux contacts can be used instead.
Time offset to be entered for correction

Although the operating command could be detected measuring the relevant voltage applied to the control circuit, it is good practice to measure the coil current instead.
This ensures that the opening or closing coil received the operating command since the current could flow through all the interlocking relays of the control circuit. Additionally, the coil current shape can reveal a lot of information regarding the healthy condition of the operating mechanism and the coil itself.
Measuring both the voltage initiate command and coil current could enhance the diagnostic capability in case of miswiring or coil malfunction.
Also in this case a reference current impulse is recorded as reference “fingerprint”.
To not interfere with Closing and Opening operating circuits, it is common practice to measure the coil current by means of a non-invasive current sensor. A split core current transformer is used in case of AC coils. In the much more frequent case of DC coils, a Hall effect sensor is preferred to a shunt that should be inserted in series within the DC control circuit, and could become a potential failure source.

6.3 Auxiliary voltage

It is the voltage used for applying commands to the operating coils. It is very often called “Battery voltage”, since these circuits are typically DC energised using Vented / Flooded Lead Acid - batteries. Monitoring can be as support for diagnostic in case of non-operation. For proper operation, this voltage should not fall below 70% for the trip circuit and 85% for the closing circuit.

6.4 Travel curve

A travel curve measurement is usually carried out during the routine testing, after which the travel transducer is disassembled.
Getting a permanently installed travel transducer allows recording the position of the contact vs. time for every circuit breaker operation.
Again, according to the “fingerprint” concept, a travel curve is recorded as reference and an alarm is raised if the curve exceeds given tolerances.

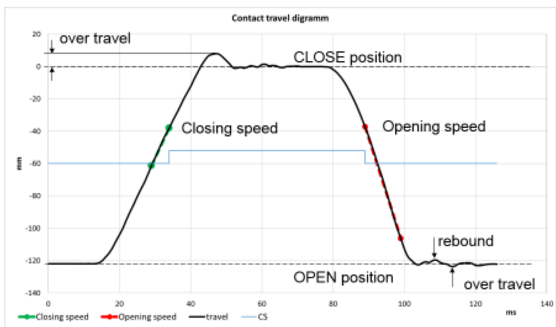

Figure 4
Typical travel curve for a CO operation.
Main calculated parameters are shown:
- Opening speed
- Closing speed
- Overtravel by closing operation
- Overtravel and Rebound by opening operation

Additionally, the following parameters are evaluated (see Figure 4):

- Opening speed
- Closing speed
- Overtravel by closing operation
- Overtravel and rebound by opening operation.

6.4.1 Opening speed

The opening contact speed of the circuit breaker is a crucial parameter to guarantee its switching capability and mechanical endurance. The manufacturer specifies minimum and maximum tolerances. A too low value can impair the capacitive switching capability as well as the short circuit current interruption (see Figure 5).

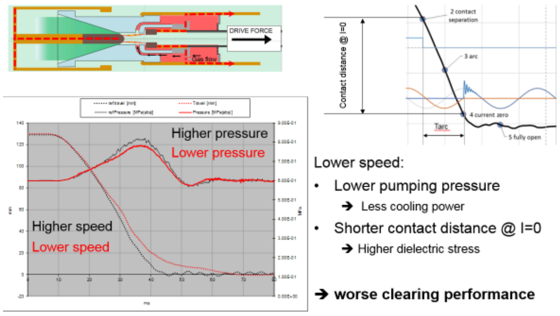

Figure 5
Impact of lower speed on switching performance

A too high opening speed can cause mechanical overstress and result in higher overvoltage in case of inductive current switching

The speed is evaluated between two points covering the region that is important for the interruption process: typically, 10 ms after contact separation. Anyhow different manufacturers define these points in different ways:

- both points as percentage of the stroke (i.e. 40% and 80% of the stroke)
- first as percentage of the stroke and the second after a fix interval (i.e. 40% of the stroke and 10ms thereafter)
- first one at contact separation and the second one after a fix interval.

A flexible configuration interface for the travel measurement is needed for covering every case. Using the same measurement point definition as given by the circuit breaker manufacturer, allows a better comparison with the reference values stated in the routine test report.

6.4.2 Closing speed

It impacts on making capability of the circuit breaker. An insufficient speed by closing operation increases the duration of pre-arc resulting in a heavier thermal stress of the arcing contacts.

The time interval between contact touch and current commutation to main contacts increases as well exposing the tulip to higher current values and consequent electrodynamic forces (see Figure 6). The resulting higher friction between tulip and plug could prevent the breaker from completing the closing operation with a failure of latching, or in the worst-case, damage of arcing contact system and catastrophic fault

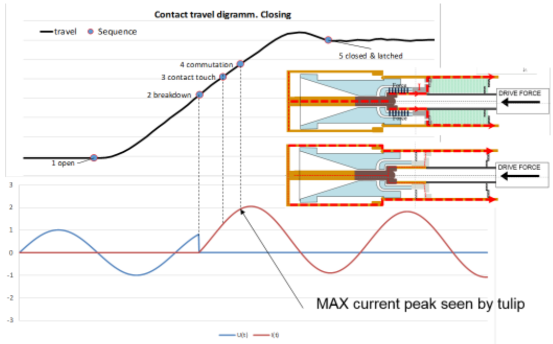

Figure 6
Current making by closing operation.
A lower closing speed will increase the time between breakdown and contact touch as well as from contact touch to commutation. This increases the thermal and mechanical stress of tulip and plug.

When the closing speed exceeds the maximum value, depending of the specific design the consequence can go from higher mechanical stress to irreparable damages of nozzle, plug and tulip with fatal consequences on the next opening operation.

Also, here the speed is evaluated between two points covering the region important for current making: typically, 5 ms before contact touch. As in the opening operation these two points can be defined in different ways:

- both points as percentage of the stroke (i.e. 60% and 80% of the stroke)
- second one as percentage of the stroke and the first one a fix interval prior it (i.e. 80% of the stroke and 5ms before)
- second one at contact touch and the first one a fix interval prior it.

Having a flexible configuration interface allows using the same point definition used by breaker manufacturer.

6.4.3 Overtravel by closing

In many circuit breakers equipped with spring operating mechanism, a minimum overtravel is required to ensure latching by closing. The manufacturer provides tolerances on these parameters no to be exceeded: A too little overtravel would result in a Close Open operation

(see Figure 7) and a too high value would cause mechanical overstress of the latching system.
Due to friction increase and spring relaxation, the overtravel has the tendency to reduce the life of the circuit breaker.

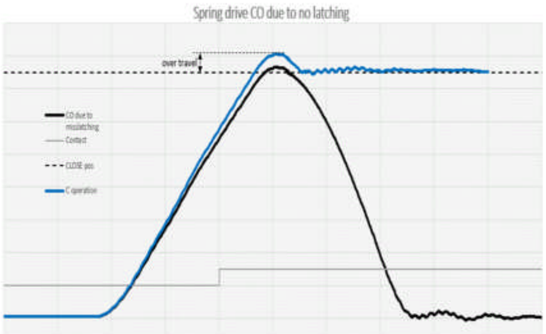

Figure 7
Travel curve of a circuit breaker with spring operating mechanism.
- If the overtravel is below the minimum, the latching is not successful and the contacts open again. A Close operation results in a Close-Open

For spring operating mechanism, monitoring the overtravel at every close operation provides an in indication of the energy margin still available for secure latching. Based on its trend a breaker maintenance or simply a pre-load adjustment of the closing spring can be planned.

6.4.4 Overtravel and rebound by opening
Sometimes these two parameters are also specified by the manufacturer. A rebound by opening means the contacts come together after having reach their fully open position representing a risk of re-strike by clearing. An excessive overtravel while opening could come from a too high opening speed or a possible problem with the damper of the operating mechanism. The consequence is a general higher mechanical stress up to a damage of the interrupter due to internal collisions.

6.4.5 Travel transducer and transfer function
All the travel curve parameters are referred to the actual position of the contacts, which is not accessible for measurement. The travel transducer takes the movement from the most convenient accessible point along the linkage between operating mechanism and interrupter.
What is measured is not the actual contact displacement and the relationship between the two values is not linear. A typical case is the use of a rotary travel transducer applied to the shaft of the interrupter bell crank (see Figure 8). The transducer measures an angle that is relation with the actual contact displacement with a function defined by the linkage geometry. A linear re-scaling of the input signal to the actual contact stroke introduces a linearity error that is higher towards the extreme position of the linkage and for a wider angular movement.

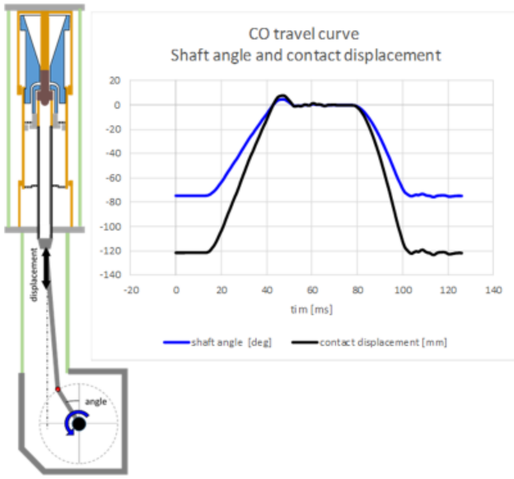

Figure 8
Example of travel measurement at the bell crank shaft. The relationship between the angle and the displacement is not linear.

A monitoring offering a configurable translation function instead of using a linear re-scaling coefficient can represent a significant improvement in case of non-linear linkages avoiding evaluation errors. A principle diagram is given in Figure 9.

Figure 9
Principle data processing for getting the actual contact displacement.

Last words regarding the transducer typology. If for routine tests resistive rotary or linear transducers are commonly used, for permanent installation a contactless digital quadrature encoder technology is preferred due to its higher reliability and accuracy.

6.5 Charging motor of the operating mechanism
Every circuit breaker is equipped with an operating mechanism that supplies the needed energy for the operation.
The energy, stored as elastic energy in springs or pressure in hydraulic operating mechanisms, must be restored every time it is used.
This function is absolved by an electric motor acting on the spring charger or on the pump in case of hydraulic operating mechanisms.

Monitoring the charging time and charging current, provides information about the heathy condition of the operating mechanism.
If measuring the voltage applied to the motor is the simplest way to record the charging duration, measuring the adsorbed current, provides the confirmation the motor is running. A change of absorbed current could additionally warn for possible problems:

- A higher value indicates increased friction in the charging mechanism or an over range of the closing spring, which could come from a miss adjustment of the end switch stopping the motor at the charged spring position.
- A lower value could again be indication of miss adjustment of the end switch as well as a relaxation of the closing spring. This should be confirmed by a smaller over travel recorder by closing.

For hydraulic drives, a more frequent recharging of the pump without breaker operation as well as a tendentially longer pumping time after operation reveals a possible oil leakage from high to low pressure compartment.

6.6 Main current & electrical wear

Measuring the interrupted current for every operation allows an estimation of the electrical wear of the circuit breaker.
The arcing contact erosion and nozzle ablation take place when the arc is burning between the circuit breaker contacts during the interruption process.
The commonly called "Integral square t" is actually a more general formula as shown in (1).

$$wear \approx K(i) \int_{CS}^{i=0} |i|^n dt \qquad (1)$$

$K(i)$: *wear coefficient function of current level*
n: *exponent values, interrupter design specific*

The exponent *n* , typically varying between 1 and 2 is design dependent parameter and should be provided by circuit breaker manufacturer.
Examples are 1.8 as suggested by [4] or 1.45 as stated in [5].
The wear coefficient takes in account the different "effectiveness" in the wearing process of the same integral value by different current level. It is also design specific.
The integration must be carried out from contact separation to current zero only, because only during this time interval an arc is burning between contacts (see Figure 10).
The contact separation time can be calculated from commutation of auxiliary contacts (52 a, b) adding an Offset Trip factor in milliseconds (taken from routine test report of the circuit breaker) as done for the online evaluation of the opening time.
Summing all the integral contributions of every open operation gives the accumulated wear effect that is compared with the reference one provided by the breaker manufacturer.

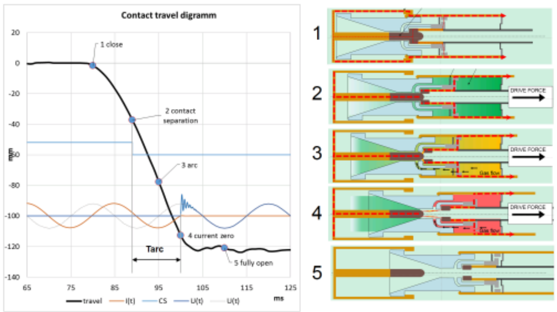

Figure 10
Opening operation with clearing sequence.
Wear must be calculated for the arcing time only: from contact separation to current zero.

For the current measurement, an auxiliary current transformer is connected on the secondary winding of the (main) current transformer installed in the substation.
Care must be taken to select the protection core to be able to measure the current up to the short circuit level without any saturation effect. Metering cores, although more accurate, are not suitable for this task since are designed to saturate as soon as the current exceeds the nominal value to avoid overload of metering instruments.
Since the secondary wiring of the protection core current transformer is part of the protection circuit of the substation, it is common practice to the use non-invasive measurement transducer: A coaxial split core auxiliary current transformer to be clamped around the wire, simplifies the installation avoiding any interference with the protection circuit.

7 Temperature and heathers

The ambient as well as cubicle temperature are monitored and logged all the time. An extreme temperature could provide an information to correlate in case of SF_6 alarm or simply used as check for consistency check of working time of heaters, which are also monitored measuring the adsorbed current.

8 Limits, trends configuration

For all the measured parameters, acceptable ranges can be defined. If the measured value is outside the given limits, warnings and alarms are generated.
The computational power presently available

makes it possible to implement locally more complex evaluations and additional tasks.
Besides absolute limits to compare with, trend analysis is also available to better assess the circuit breaker conditions. An example is given in 6.1 for SF6 monitoring where the trend analysis can provide a prediction of the user configurable reached alarm level. Additionally, based on the data available in local log, forecast for emissions for current calendar year can be generated as well as reports by calendar years.
Cross comparisons among different parameters can support better identification of possible reasons for an abnormal trending. By travel analysis, for example, if an increase of the overtravel by a closing operation is detected, a further analysis can be carried out:
If a reduction of opening speed is also observed, an opening spring relaxation could be the reason.
If the charging time of the motor increased, the end switch could have a problem causing overcharging of the closing spring and premature motor damage.
Examples of how looking at the consistency of different information can enhance the diagnostic is given in the Examples provided in paragraph 10.
Cross correlation rules could be configurable by the users as well as the limits and trend set up.
Starting from a basic configuration interface, the user should be able to customize it for every specific circuit breaker. The possibility to save, recall and import a configuration prevents mistakes and reduces the commissioning costs in case of multiple installation of the same breaker type.

9 Communication & Web based software

A modern monitoring system must require the lowest possible effort to be used.
This starts with a robust communication configuration ensuring remote access control for every functionality.
Being independent from any specific communication software is also a key element.
A Web based system being accessed via a secure IP connection using a standard internet browser is the preferred and simplest solution.
It will offer a web page configuration and basic review of data, and will provide complete circuit breaker analysis with automatically processed user-friendly information for a quicker understanding of how the breaker performed under all operating conditions. The automated breaker analysis information, configuration updates, and operating code/firmware updates will be accessible with remote communications capability. Automatic data/info retrieval will be accomplished using the Auto-Polling and Auto-Comms functions.
Auto-Sending / Auto-Comm functionality to a third-party software for critical alarms / events / summaries should be also provided.
Data download must be also available for big data files for a more complex analysis and statistical collection by an enterprise monitoring server. To ensure the best compatibility with every asset management server the data format used for file transfer should be per IEEE COMTRADE C37.111-2013, also known as Optional Analog Data Format.
IEC61850 standard is defining the communication protocol of the future substations and should also covered. This requires the system to support Parallel Redundancy Protocol (PRP) to interface to redundant networks on IEC61850 station bus
From a hardware perspective, the following communication ports will be available:
3 Ethernet ports:

- 1 RJ-45 for local connection.
- 2 FO Ethernet 100Base-FX, 820nm, multimode, ST connectors for remote access communications and interface to a dual redundant IEC 61850 station bus using PRP.
- 01 x USB-2.0 for local data collection, firmware upgrades and optional external devices
- 02 x RS-485 (BCM is master) multi-drop ports for multifunction sensor data retrieval. Typically used for SF6 density sensors to collect data related to gas density, pressure, temperature and dew points (depending on the sensor output). These ports can be ordered with Fibre optic interface connections.

10 Example of problems detected by online monitoring

Examples of problems detected thanks to installed circuit breaker monitoring systems. Cases 2 and 3 show how correlating different information can provide advance diagnostic capability.

10.1 Case 1

Burned Out Trip Coil caused by shorted windings is easily confirmed after reviewing the readily recognizable noise on the waveform signature and the steep rise time in the upper portion of the initial waveform rise time. (see **Error! Reference source not found.**)
This Case Study confirms that a graphics record analysis is necessary to verify the condition of the Trip Coils.
These conditions will cause circuit breaker out of tolerance operation alarms for pulse width, under the curve area analysis and breaker operation timing.

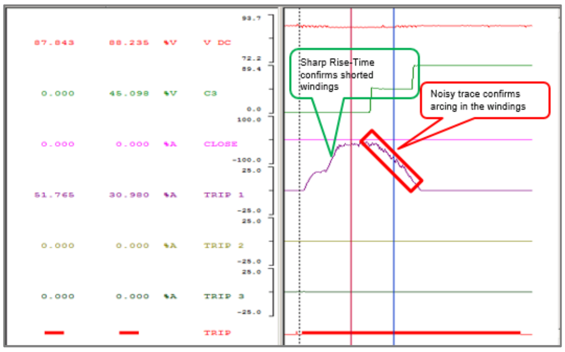

Figure 11
Burned Out Trip Coil detected analyzing the coil shape after an alarm raised due to finger print discrepancy.

10.2 Case 2

Trip coil abnormal shape raised an alarm that could be an indication of a coil problem (see Figure 12). A review of the missing Trip Initiate #2 signal as shown on the command channel was caused by a mis-wire. A more detailed visual inspection of the circuit breaker cabinet was performed to analyse the cause of the abnormally long Trip Initiate #1 signal and distorted Trip coil signature.

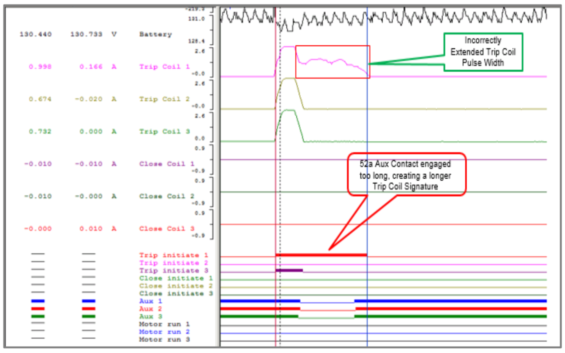

Figure 12
Abnormal coil shape and extended Trip Initiate #1 impulse duration. A deformed 52a auxiliary contact housing was the reason for preventing the proper spring-contact open-close snapping operation.

10.3 Case 3

Again, another case of miswiring detected by means of condition monitoring diagram analysis. (See Figure 13). A wiring error in the control cabinet was determined to be the cause of the error by looking at the inconsistency of all three Close Coil currents and all three Close Initiate command signals being shown as not in synchronism with each other. The Trip Initiate #2 signal is coincident with the Close Coil signatures, which is not correct. The appearance of a Trip Initiate signal in conjunction with a bonafide Close operation is not possible, hence the determination that there is a cabinet miswire.

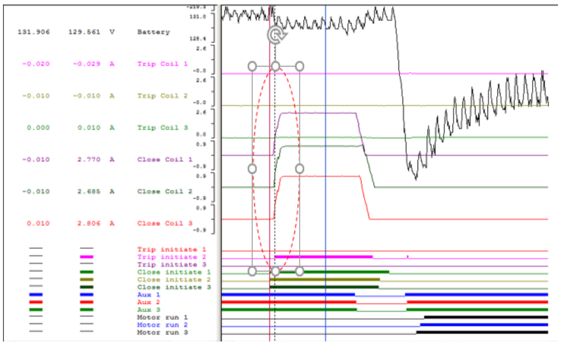

Figure 13
Closing operation.
Discrepancy is detectable between command signal and beginning of coil current. A trip command signal is also visible, which cannot be.

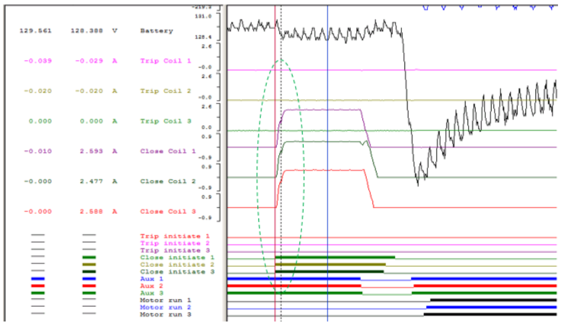

Figure 14
Closing operation after proper rewiring within the cabinet. Now the Close Initiate commands and current in the Closing Coils start simultaneously. All three spring recharging motors have been engaged to rewind the spring mechanisms.

10.4 Case 4

With the aid of a condition monitoring system's graphics record acquisition capability, the correct Trip Initiate command operation with proper Trip Coil current signatures can be confirmed.

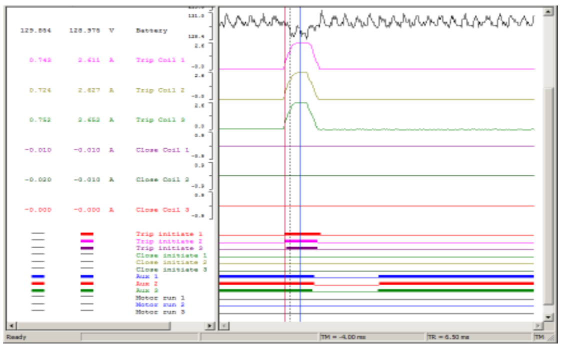

Figure 15
Tripping operation after the miswire correction within the cabinet and switching the wires from the defective 52a Aux contact housing to an undamaged spare contact. Now the Trip commands and current in the Tripping coils start simultaneously and all three Trip Coil signatures are operating correctly.

10.5 Case 5

Confirming proper spring recharging or compressor motor operation. Initial Motor current surge and operating current as well as motor maximum current level can be confirmed.

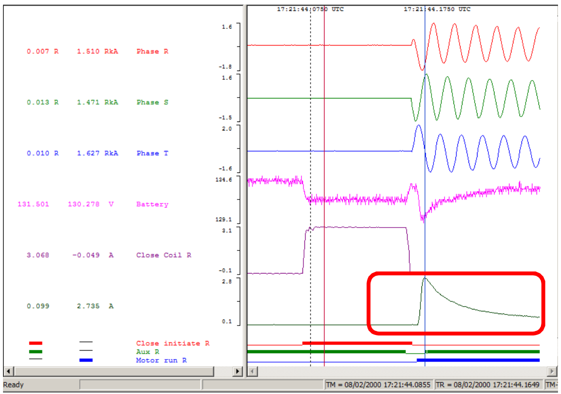

Figure 16

Closing operation shows phase currents switching on as the mains close, battery voltage operational levels, Close coil current signature, initial motor surge current and decay to running current level, Close Initiate command, 52a/52b aux contact operation and spring recharging motor initiation. Record will stop, but BCM will measure the total Motor run time, report its value and initiate an alarm if the timer values are exceeded.

10.6 Case 6

Large industrial customer was experiencing single-phase fuse blowing on a radial feeder. Local power company and customer had no effective means of recording the event that caused the fuse blowing. Installation of a Digital Fault Recorder was too expensive, but installing an online circuit breaker condition monitor was a much more cost-effective solution. The blown fuses occurred randomly during normal system load flow and on rainy and dry days.

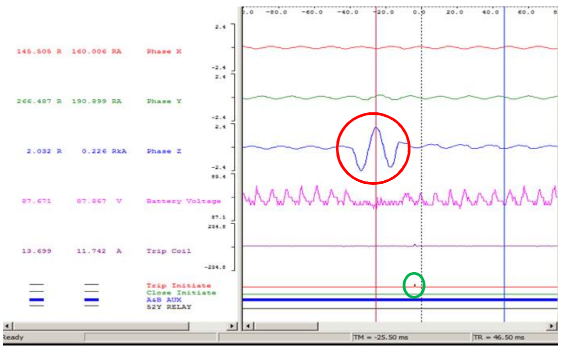

Figure 17

Electromechanical relay was set to Trip the breaker if the overcurrent condition lasted for 2 or more cycles. The graphics record Phase X/Y/Z traces and the A&B Auxiliary contact trace showed conclusively that the circuit breaker was not tripped during the 1.5cycle 2,000-amp fault.

This particular record proved the electromechanical relay performed correctly during a 2,000-amp fault shown within the graphics record's red circle that lasted for only 1.5 cycles instead of the pre-programmed 2-cycle Trip setting.

The BCM caught all overcurrent occurrences on Phase Z caused by an imbalance of phase loading inside the customer's factory.

The portion of the Trip Initiate signal contained within the green circle confirms a 1msec time duration that the Tripping contacts of the electromechanical relay remained closed, which was not enough time to fully energize the circuit breaker's Trip Coil. The online breaker condition monitor captured dozens of similar faults over a period of a month. An investigation of the blown fuse material indicated gradual degradation of the fusing material with every fault that eventually caused the fuse to randomly open thereby interrupting power on Phase Z on the radial feeder supplying power to the industrial customer.

An engineering study of 3-phase loading within the customer's factory provided information on how to redistribute the electrical power, which mitigated all previous single-phase overloading that led to intermittent fuse degradation and opening.

11 Conclusions

Although the needed measured parameters remained substantially the same, the more powerful computational possibility achievable with modern monitoring systems allows a more precise and much faster condition assessment of circuit breakers. A user configurable automatic evaluation process makes the monitoring more effective reducing the required effort and relevant costs. The enhanced communication possibilities make the information available remotely real time allowing a fast reaction when a warning is received. The compatibility with standardized communication protocol and a web based software ensure independency from specific software promoting statistical data collection that can be the base of a more precise limit definition. Integration of IEC61850 standardized communication protocol should guarantee long term hardware upgrade compatibility. An extended working temperature range will guarantee high reliability inside control cabinet of circuit breakers installed in hot desert areas All these features together should make the online monitoring for circuit breakers less expensive to manage and more attractive to use, allowing them to profit of the benefits of the condition based maintenance.

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