

Field Experiences with HV Circuit Breaker Condition Monitoring

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Abstract—Today, many industry experts agree that the application of time-based maintenance programs is not the most effective use of maintenance resources. Thus, utilities have moved towards condition-based approaches and reliability-centered maintenance. This paper describes the field experience with the Circuit Breaker Sentinel (CBS), which is a monitoring system for SF₆ single-pressure power circuit breakers rated 38 – 800 kV. The CBS monitors interrupter wear, integrity of the SF₆ gas system, the circuit breaker mechanical system as well as electrical control and auxiliaries. Examples demonstrating the value of condition monitoring include: Long reaction time for one of the poles of a 550kV breaker, fault current interruption with subsequent increase in calculated interrupter wear on a 145kV gang (3-pole) operated breaker and slow leak detection on a 145kV independent (single) pole operated breaker. The examples reaffirm that condition monitoring can detect problems and avoid unnecessary maintenance in a way that other maintenance approaches and/or conventional alarms cannot.

Index Terms—Condition Monitoring, High Voltage Circuit Breaker, Circuit Breaker Maintenance, SF₆ emissions, Breaker Timing, Coil Continuity

I INTRODUCTION

Today, many industry experts agree that the application of time-based maintenance programs is not the most effective use of maintenance resources. In an effort to reduce maintenance expenses, many utilities have moved away from the traditional maintenance recommendations, which are principally based on in-service time and number of operations, towards reliability centered maintenance and condition based approaches [3]. A reliability study conducted by CIGRE [1][2] showed that most failures (major or minor) occur in the main insulation to earth followed by compressors and pumps, control elements and the interrupting unit. Focusing on these areas, condition monitoring can increase reliability. On the other hand, the greatest maintenance savings can be expected through on-line monitoring of breaker timing. Third-party monitors often cover only a subset of the components statistically most prone to failure. Comprehensive breaker on-line monitoring systems have so far only been offered by circuit breaker manufacturers.

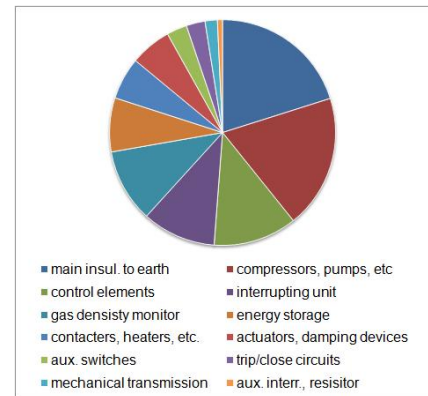


Figure 1 – Circuit Breaker Failures

A follow-up survey focusing on circuit breaker control systems [6] observed a trend for a higher tendency of failures in the first 1-2 years following a maintenance operation, which was interpreted as an indication of the potential for human error when maintenance work is performed on circuit breakers. On-line condition monitoring may help prevent this type of failure.

II CIRCUIT BREAKER SENTINEL

The Circuit Breaker Sentinel (CBS) is a monitoring system for SF₆ single-pressure power circuit breakers rated 38 – 800 kV. The CBS monitors interrupter wear, integrity of the SF₆ gas system, the circuit breaker mechanical system, the electrical control system and auxiliaries. It consists of a modular microprocessor unit and sensors. The CBS unit is installed in the control cabinet, either directly on the panel or on a floor-mount bracket. The sensors are mounted where needed, e.g. the circuit breaker tank, mechanism or inside the control cabinet. They connect to the CBS unit via pluggable connections. Even though the CBS collects data about the circuit breaker, continuous access to, and analysis of, this data is not necessary or intended.



Figure 2 – Circuit Breaker Sentinel

The philosophy behind the CBS is for the user to ignore the data until an alarm occurs. Only then is it necessary to analyze the data in order to decide whether a simple settings change will suffice or whether a more thorough investigation is in order.

A CBS unit consists of one power supply board, an optional Ethernet board and either 1 or 3 main boards. Each board occupies a slot in the enclosure. Therefore different CBS units are referred to as 2-slot, 3-slot, 4-slot and 5-slot units (Figure 3).

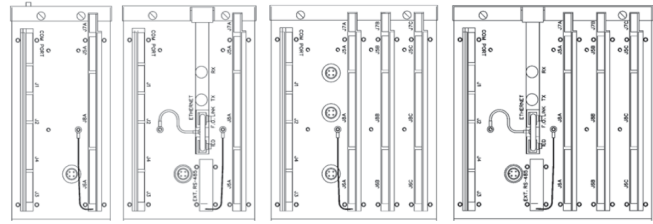


Figure 3 - CBS unit types (2-slot, 3-slot, 4-slot and 5-slot)

A 2-slot unit consisting of a power supply board and one main board is sufficient to monitor a gang (3-pole) operated circuit breaker with a common gas system. The input capability provided by a single main board is listed in Table 1.

The CBS processes signals from various inputs. The coil connections are used for two purposes: a) to detect when the breaker is being operated and b) to monitor coil continuity. Auxiliary switch inputs allow the CBS to distinguish between close, open and close-open operations. The phase current inputs are primarily used for interrupter wear while the travel sensor input enables monitoring of breaker timing. The temperature inputs can be used to measure tank, mechanism or cabinet temperature. The heater inputs allow for monitoring tank, mechanism and anti-condensation heaters. The motor voltage input is used to monitor the runtime and number of starts of the mechanism charging motor. Last but not least the pressure input in conjunction with one temperature input allows monitoring of SF₆ gas density.

Table 1 – Inputs of single CBS main board

3 coil energization / continuity inputs	7 heater current inputs
2 auxiliary switch inputs	2 temperature inputs
3 phase current inputs	1 motor voltage input
1 travel sensor input	1 pressure input

In order to monitor a circuit breaker with independent (single) pole operation, essentially three times the inputs are necessary. If the poles are mounted on a common frame, this requirement is met by the 4-slot unit since it has three main boards. The 3-slot and 5-slot units offer the same monitoring functionality as the 2-slot and 4-slot units, respectively, with the addition of one Ethernet board.

At voltage ratings of 550kV and 800kV, circuit breakers are supplied as three separate poles with significant pole spacing. Using a single CBS unit for this configuration is not efficient because it would require long connections between the CBS unit and its sensors and also increase the field wiring effort. Instead, for these breaker types, each pole is monitored by a separate 2-slot unit. The 2-slot units are connected to sensors installed on the same pole and communicate their data via an RS485 bus. A fourth unit residing in the breaker main cabinet acts as a common data access point. The main unit can also perform light monitoring duties pertaining to the main cabinet. Optionally it can be equipped with an Ethernet board.

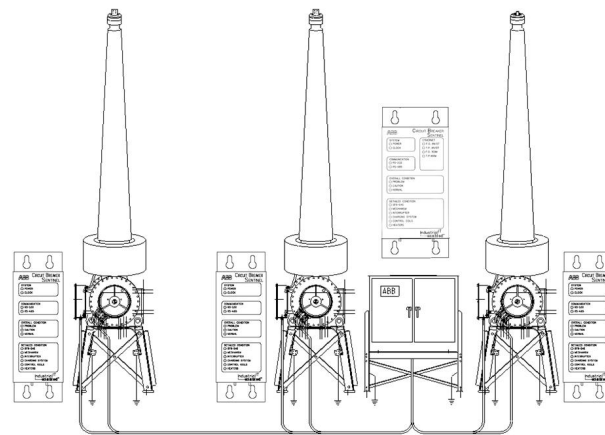


Figure 4 - 550/800kV Configuration

The CBS continuously calculates conditions such as coil continuity, temperature compensated SF₆ gas pressure, leak rates and temperatures (Table 2). With every breaker operation it calculates coil energization times, reaction times, contact speed, mechanism times, total travel and interrupter wear increments. In addition, it keeps track of heater and motor operation. When a condition falls outside defined limits, a two-stage alarm is generated. The first alarm stage is called “Caution” and the second “Problem”.

Each monitored condition has settings that define the expected range as well as distance to alarm levels (caution and problem margins). Conditions can be individually enabled or disabled.

With up to four main boards per installation, over 50 conditions calculated by each main board¹ and at least 5 settings to be defined per condition, a single CBS installation may have over 1000 settings to be defined! Yet, setting up a CBS system for a breaker built to customer’s specification only takes a few minutes. How is that possible? The answer is multi-tier settings support (Figure 5).

Table 2 – Monitored Conditions

Coil Continuity	Breaker Current
Total Travel	Tank / Mech. / Cabinet Temperature
Contact Velocity	Temperature compensated SF ₆ gas pressure
Reaction Time	Leak Rate (5 time spans)
Coil Energization Time	Heater operation
Interrupter Wear	Motor operation
Trip Count	

The set-up begins by selecting the ABB breaker type, followed by the mechanism type. By doing so breaker type specific default settings are recalled. The settings cover SF₆ gas pressure range, interrupter wear limits as well as certain breaker design parameters needed for various calculations. Next a special tool allows the user to quickly select, which inputs are unused for the specific installation resulting in disabling of conditions derived from those inputs. Last the settings for conditions pertaining to breaker timing are defined through test operations while the CBS is in a special learning mode.

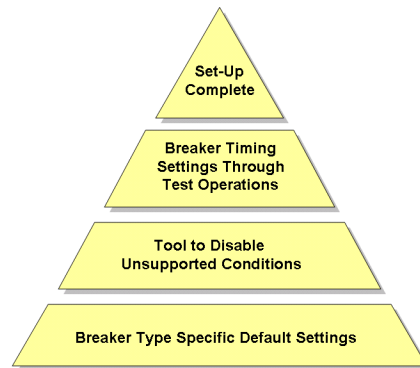


Figure 5 - Settings Support

III MONITORED CONDITIONS

A special group of monitored conditions covers breaker timing. Timing is explained in Figure 6 for a close operation. After a travel curve has been recorded the CBS calculates the reaction time, which is the time from beginning of close coil energization until the contacts start to move, (coil energization is recorded in a separate trace not shown in this figure). It then calculates the mechanism time, which is the time from beginning of coil energization until the travel curve reaches a position where the arcing contacts meet per design. This position is referred to as the “make/break distance” and is measured from the fully closed position.

The total travel refers to the distance traveled from minimum to maximum position, so it includes over travel. The contact speed is calculated between two points on the travel curve as defined by the speed calculation zone. The speed calculation zone is part of the breaker type specific default settings and matches the points used for off-line timing. The timing parameters are calculated and stored separately for close and open operations. For C/O operations the total travel and the contact speed of the opening portion are also calculated and stored separately.

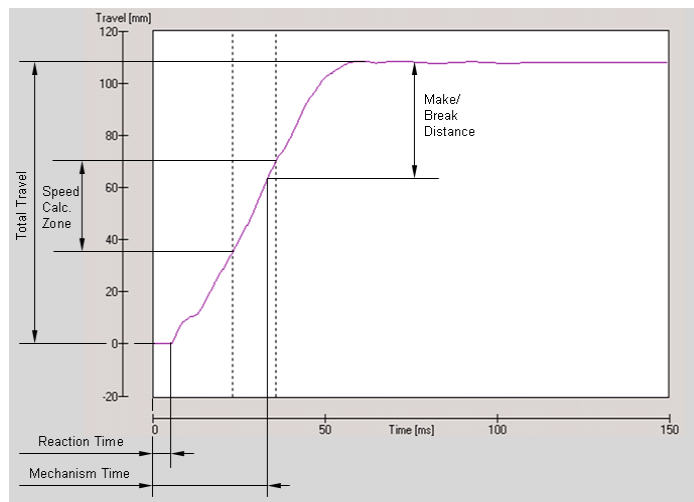


Figure 6 - Breaker Timing Conditions

¹ For each condition listed in Table 2 there are multiple instances, for example close coil continuity, primary trip coil continuity and secondary continuity.

A special circuit monitors coil continuity. The circuit can detect both open and shorted coils. Open/short circuit detection is accomplished by forming a series RLC circuit consisting of the coil resistance (R), the coil inductance (L) and a capacitor (C) internal to the CBS. A small voltage pulse applied to the RLC circuit once per second results in a voltage step across the coil which then decays to zero as the capacitor charges up. The circuit is controlled by a microprocessor which also measures how many microseconds it takes for the voltage across the coil to drop below a certain threshold. The measurement is referred to as the “coil monitor pulse” time and ranges from 50 to 650 microseconds for intact coils (the range covers a variety of coil types). The coil monitor pulses are averaged over one-minute periods. When they fall outside the set limits an alarm is generated.

It is well known that SF₆ liquefies at certain low temperatures and certain high pressure. In the SF₆ state diagram (Figure 7) this phenomenon is described by the liquefaction curve. Above the liquefaction curve and pressure is nearly linear with the gas density serving as a parameter. The ideal gas equation provides a first approximation but more accurate results can be achieved by applying the more complex equations as provided by SF₆ manufactures. Such equations are also implemented in the CBS. The CBS measures tank temperature and gas pressure and immediately calculates the temperature compensated pressure (TCP), i.e. the pressure that would be measured at 20 °C with no change in gas density. With no gas added or lost the TCP remains unchanged (exceptions noted below). Invariability to temperature makes the TCP ideal to track potential leaks: Whether the pressure is measured at temperature T₁ or at temperature T₂ the TCP does not change. In reality, the SF₆ state equations are valid only for a state of equilibrium or for quasi-stationary changes at the most. However, ambient conditions often cause dynamic temperature changes resulting in incomplete temperature compensation: As temperatures climb it appears as if gas density is lost and vice versa.

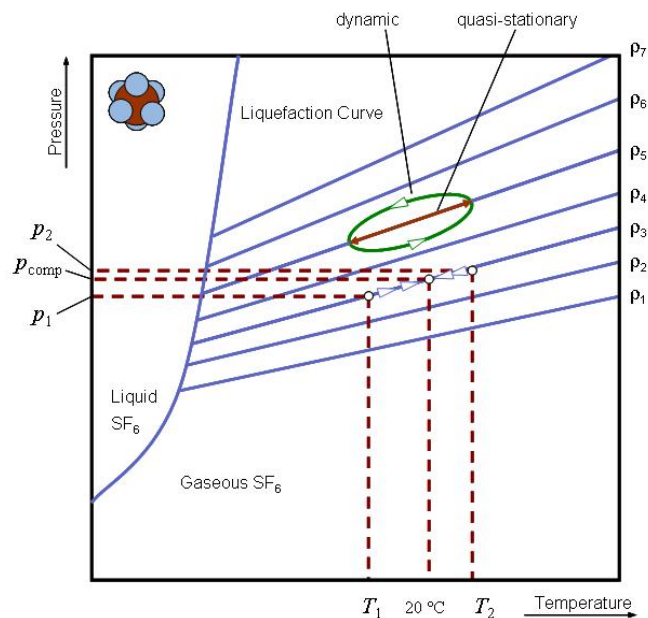


Figure 7 - SF₆ State Diagram

Incomplete temperature compensation is often falsely attributed to the method of separate gas pressure and temperature measurement, whereas sensors that measure gas density directly are assumed to be immune to such effects. The assumption is, however, incorrect. In the absence of gas flow and shock waves, the pressure inside a gas volume is the same at every point. Hence, if a temperature gradient exists, an opposing gas density gradient must also exist. Therefore, the gas density measured near the tank is the same as the gas density calculated from pressure and temperature measured near the tank.

Dynamic temperature changes and consequently incomplete temperature compensation pose a challenge for leak detection and quantification. Especially when analyzing the TCP over the course of a day, a false trend could be inferred from the data, resulting in a nuisance alarm. The CBS prevents false leakage alarms by tracking the history of the TCP in five time spans: seconds, minutes, hours, days and months. It then calculates five separate leak rate values from each time span. Each time span offers unique advantages either in the form of early leak detection or accurate leak quantification. Alarm limits can be defined for each individual time span. Since dynamic temperature changes happen to affect the hourly averages, the corresponding alarm limits are widened thereby preventing nuisance alarms. An example will be given later.

As mentioned above, the CBS also monitors tank and mechanism temperatures, motor starts and runtime as well as heater operation. For these components a slightly different approach is taken, called “functional monitoring”. Functional monitoring considers a default state where the breaker mechanism is fully charged and heaters are functioning as intended. A deviation from the default state is called an “Exception”, even though not necessarily indicative of a malfunction. For example motor starts are treated as “Exceptions” notwithstanding that they are normal part of the in-service condition. The CBS counts exceptions and measures their duration. If either the count or the duration exceeds set limits the CBS alarms, it leads to alarms being generated when a motor has excessive runtime or too many motor starts per day without operation. Also, an alarm is generated if a permanent heater is off for longer than a set time period. Defining a grace period for heater malfunctions allows for brief substation-wide AC outages without causing alarms or for slight deviations in the performance of thermostat versus their specified performance.

The typical third-party breaker monitor calculates interrupter wear by forming the integral of the square of the current from the time the An auxiliary switch opens until current extinction. The method is commonly referred to as I^2t . I^2t is only a rough approximation of actual interrupter wear, especially if the start of the integration is more or less arbitrary and ignores the design of the interrupter. The CBS offers the advantage of factoring the interrupter design into its interrupter wear calculations. Interrupter design parameters are part of the breaker type specific default settings.

The stages of current interruption are illustrated in Figure 8 (a-f): Initially the breaker is closed, with both main contacts and arcing contacts engaged. When the breaker opens, the main contacts separate first causing the current to commute to the arcing contacts. As soon as the arcing contacts separate an arc is drawn between them (b). Because the CBS measures contact travel, the time of arcing contact separation is known, at which point the CBS starts feeding every current sample into a special equation that calculates contact erosion. From this point until arc extinction, the arcing contacts are subject to erosion which is exactly what the CBS calculates.

As the arcing contacts separate further, the auxiliary nozzle becomes exposed to arcing (c). Again the CBS detects when this happens and starts feeding every current sample into a special equation designed to calculate nozzle ablation.

When the arcing contacts separate further the main nozzle becomes subject to ablation (d) which is taken into account by the CBS through a separate calculation. As the arcing contacts continue to separate, the aforementioned parts of the interrupter, i.e. arcing contacts, auxiliary nozzle and main nozzle continue to experience wear (e) until the arc is finally extinct (f).

The distinction between contact erosion and nozzle ablation is an important one. At load current magnitudes contact erosion can add up substantially as the number of operations approach the manufacturer-specified limit while nozzle ablation is virtually non-existent. It is not until fault current levels are reached that nozzle ablation accounts for a significant portion of interrupter wear.

Interrupter wear models were originally derived by the scientists at ABB's corporate research center in Daettwil, Switzerland. After being adopted and implemented in a condition monitoring unit, their validity was proven at ABB's power lab in Baden, Switzerland.

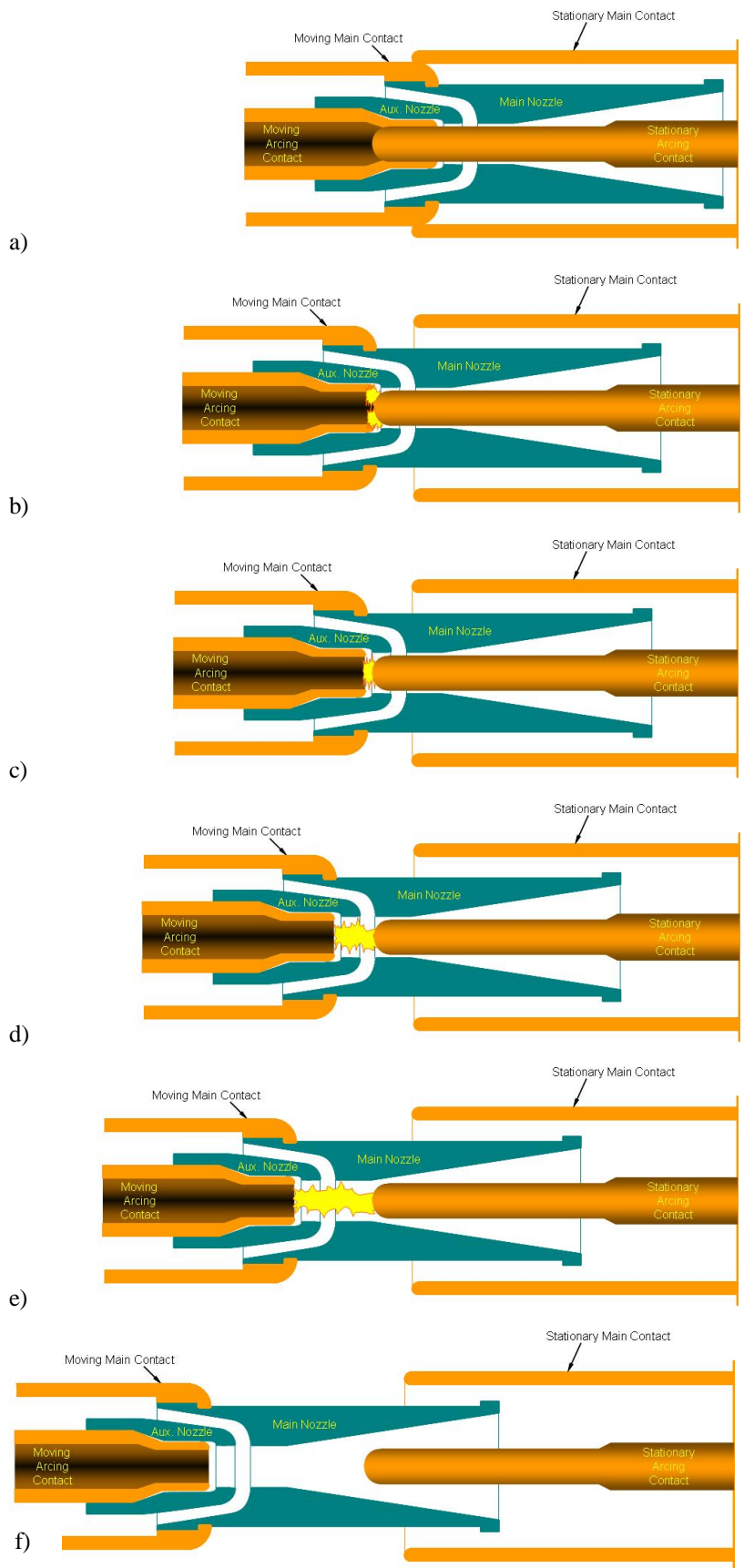


Figure 8(a-f) - Stages of current interruption

IV FIELD EXPERIENCES

The CBS was released for sales in early 2004. The first units went in service later that year. Between 2004 and March 2011, roughly 340 breakers shipped with a CBS installed. Figure 9 shows a breakdown over voltage rating.

The CBS is typically installed at the factory, where it is also configured and tested on the breaker with which it is shipped. ABB personnel load the most recent firmware and the breaker-specific default settings; they disable unused conditions, test all sensor inputs and perform 13 test operations, including one close-open operation.

More recently, CBS systems have also been retrofitted to ABB breakers in the field. Approximately 100 units have been delivered and/or installed as retrofits.

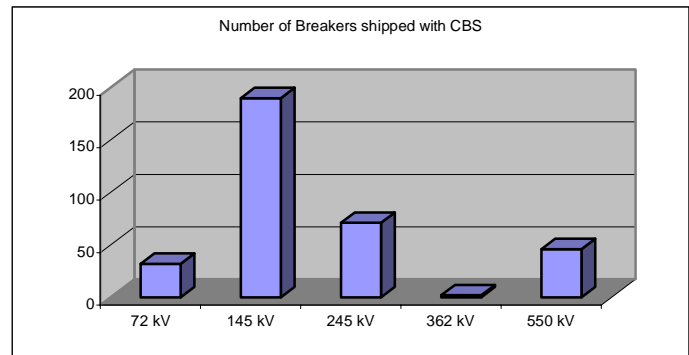


Figure 9 - Breakdown of CBS shipments over voltage rating

Figure 10 shows the contact travel curves and binary signals recorded by a CBS installed on a 550 kV breaker. The travel curves of pole 1 and 2 are almost identical whereas the travel curve of pole 3 (red) shows a longer reaction time. Auxiliary switch timing (A and B) as well as close coil energization (CC) also show a delay for pole 3. Graphs were created using CB Insight™, the user-interface software that comes with the CBS. Although not shown, CB Insight™ can be used to overlay travel curves from different operations of the same pole, revealing varying reaction times for pole 3 in this case.

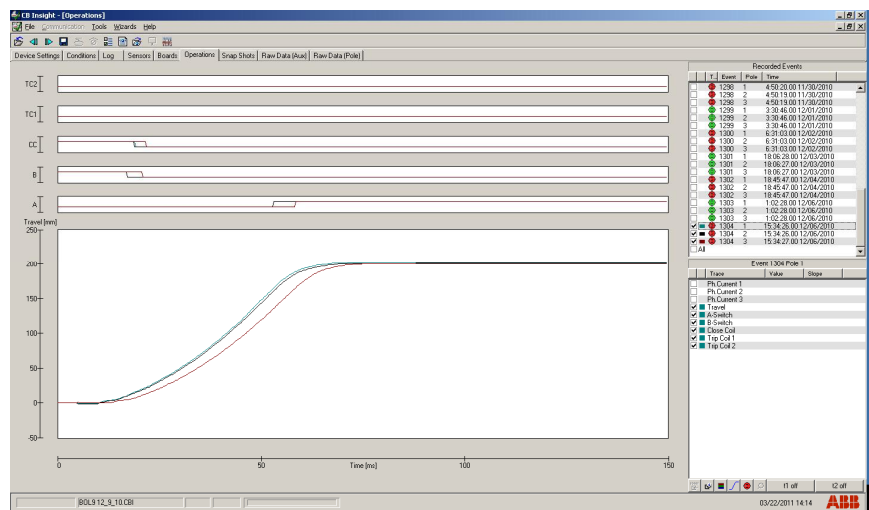


Figure 10 - Travel Characteristic: Pole 3 has long reaction time

Figure 11 shows the “Conditions” tab for the same data download. As can be seen, the CBS has calculated the timing parameters from the travel curves and is alarming on reaction time (14.1 ms), mechanism time (56.1 ms), and close coil time (21.9 ms). CB Insight™ marks all values that are outside the alarm limits using a caution sign, so they can be identified at first glance.

Condition	Unit	Pole 1 / Common	Pole 2	Pole 3	Main Cab
Travel (Close)	mm	202.64	202.12	200.58	
Travel (Open)	mm	203.15	200.07	198.02	
Travel (C/O)	mm	196.99	194.43	192.38	
Closing Speed	m/s	5.59	5.38	5.25	
Opening Speed	m/s	9.41	9.1	8.82	
Open Speed(C/O)	m/s	9.35	8.98	8.5	
React.Time(C)	ms	11.1	5.1	14.1	
React.Time(O)	ms	7.8	5.7	5.4	
Mech.Time(C)	ms	51	51.6	56.1	
Mech.Time(O)	ms	17.7	18.9	18.9	
Close Coil Time	ms	19.2	18.9	21.9	
Pr. T.C. Time	ms	9.9	10.8	10.8	
Sec. T.C. Time	ms	12.3	12.9	13.2	
Contact Wear		27 %	22 %	25 %	
Aux Noz Wear		0 %	0 %	0 %	
Nozzle Wear		0 %	0 %	0 %	
Trip Count		644	645	645	
RMS Current	kA	0.29	0.87	0.29	
Tank/Oil Temp.	C	10.09	9.73	9.66	
Mech./Cab. Temp.	C	10.07	9.75	9.43	
Comp. SF6 Pres.	psig	87.5	85.81	89.1	
Leak Rate A	ps/s	0	0	0	
Leak Rate B	ps/min	0	0.01	0.01	
Leak Rate C	ps/hour	0.01	0.01	0	
Leak Rate D	ps/day	0	0	0	
Leak Rate E	ps/month	0.1	0.11	0.11	
Tank Heat.1 (T) Off At Low Temp.		---	---	---	
Tank Heat.1 (T) On At High Temp.		---	---	---	
Mechanism Heat. Off		2 sec. (2.x)	2 sec. (2.x)	2 sec. (2.x)	
Mech Heater (T) Off At Low Temp.		2 sec. (2.x)	2 sec. (2.x)	2 sec. (2.x)	

Figure 11 - Conditions: Pole 3 has timing alarms

Furthermore, time-based maintenance can only provide a snap shot of the breaker condition for the given day but not reveal variations over time and while in service. Even though the alarm limits can be set by the user to match the breaker timing specification (as available) this is not recommended. The true value of condition-based maintenance lies in detecting a change of circuit breaker behavior so that actions can be planned long before the behavior becomes a problem. As mentioned above, setting the alarm limits for timing parameters automatically around values measured during commissioning is supported by the CBS (Figure 5).

Another example is given in Figure 12, where the CBS recorded a fault tripping of a 145kV gang (3-pole)-operated breaker. The interrupted current is slightly asymmetrical with an amplitude of about 17.5 kA. The fault occurred on the phase connected to pole 3. Because the CBS has knowledge of the interrupter geometry it knows that the contacts separate after 43 mm of travel. At the time of contact separation it starts to feed every current sample into an equation for contact wear. Similarly, it calculates auxiliary nozzle and main nozzle wear. The details of interrupter wear calculation were explained above (Figure 8).

After selecting the “Conditions” tab on the same data download (Figure 13) it can be seen that the contact wear for pole 3 has increased to 1%. Wear for main and auxiliary nozzles were still less than 1% and therefore rounded off. To bring up the exact value the user right-clicks on the value, selects “Configure” and then divides the calculated value by the scaling factor, resulting in 0.62 %.

The example illustrates how interrupter wear calculation works on real-life installations. Obviously, for a breaker with 63 kA fault current rating it takes many 17.5 kA interruptions to reach 100% interrupter wear, at which point the interrupter should be inspected. The CBS interrupter wear limits are calibrated to IEEE test duty 5, i.e. three asymmetrical opening operations at rated fault current [5]. Many breakers may not even experience such fault duties over a 30 year period.

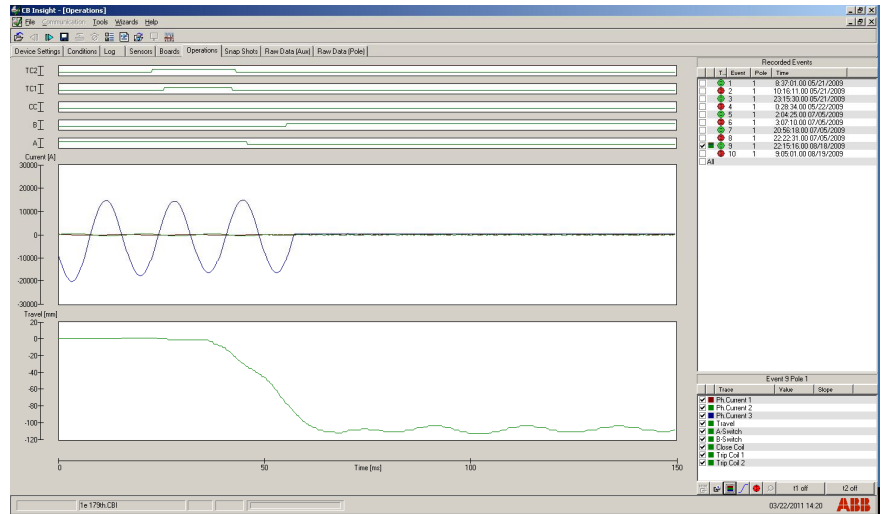


Figure 12 – Recording of a fault tripping

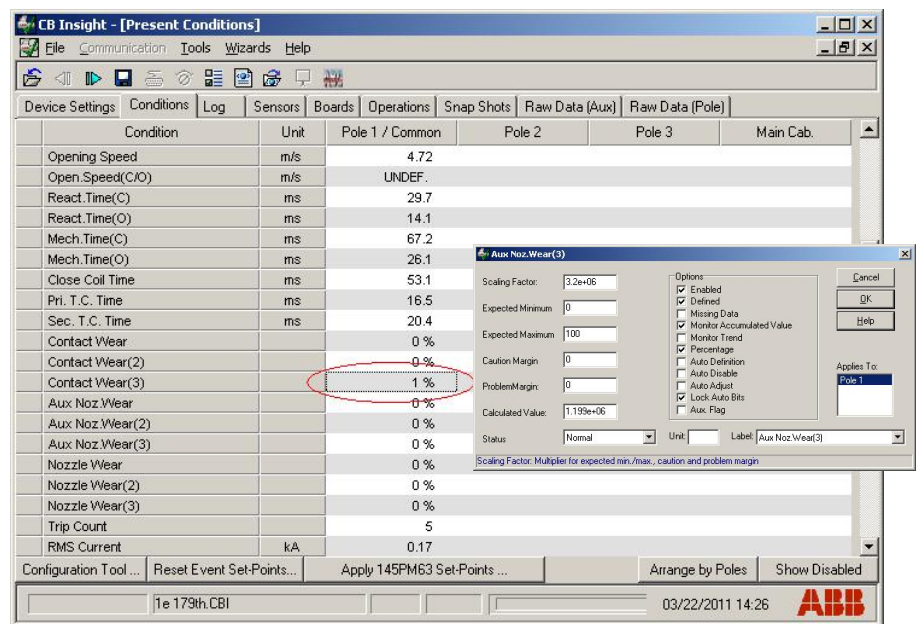


Figure 13 – Contact wear increased after fault tripping

Herein lies the advantage of condition-based maintenance, namely avoiding unnecessary interrupter maintenance. Without interrupter wear monitoring the industry practice is to perform interrupter maintenance about every 10 years. Maintenance involves removing the breaker from service, opening the tank and disassembling the interrupter. Many times the interrupter is found to be in perfect condition; however, reassembly can introduce metal particles and other defects resulting in breaker failure shortly after. Use of the CBS avoids this problem because interrupter maintenance can be delayed until the CBS indicates it is necessary and even then only for the pole on which it is needed.

Release of the greenhouse gas SF₆ into the atmosphere has become an increasing concern, making the example presented in Figure 14 rather appropriate. It shows the history of the temperature corrected pressure (TCP) inside the tank of a 145 kV independent (single) pole operated breaker. The TCP values are shown for the last 60 minutes, the last 60 hours (2 ½ days) the last 60 days and – in this case – the past 7 months. The monthly averages clearly show that a leak started to develop one or two months ago. The daily averages allow calculation of the leak rate in psi/day. The CBS simultaneously calculates leak rates using data from all five time spans (values of the past 60 seconds are not shown in this example) and refers to them as leak rates A - E.

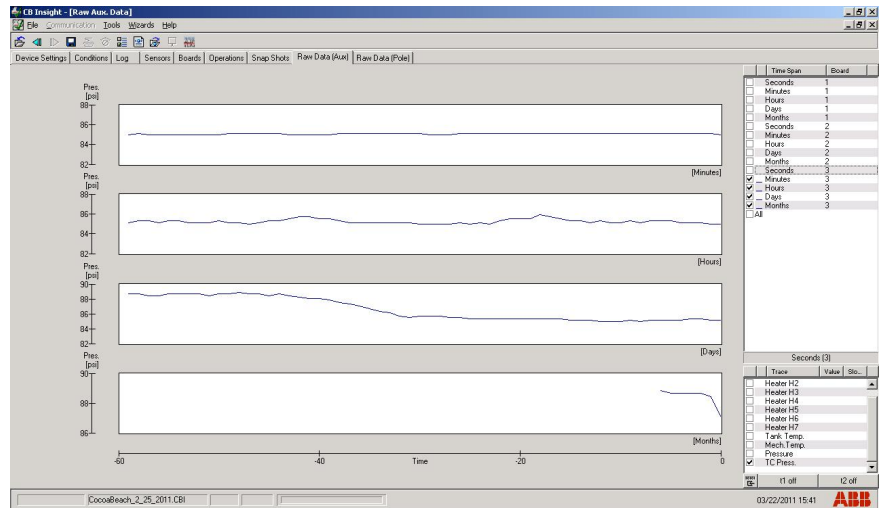


Figure 14 – Pressure history showing downward trend in daily and monthly averages

The leak rates from these time spans are shown on the conditions tab (Figure 15). However, a certain number of values is required before a leak rate is displayed, which is why leak rate E (psi/month) is still listed as undefined. Leak rate D (psi/day) on the other hand is 0.1 psi/day (representing an average calculated from all 60 TCP values). Leak rate D also has a caution sign indicating that the condition is presently causing an alarm. A major difference between the alarms generated for the purpose of condition-based maintenance versus conventional alarms is that CBS alarms usually do not require immediate action. Instead they alert qualified personnel to situations that – if left unattended – can result in a problem later on. In this particular example, with the present TCP being 85.32 psi and the leak rate being 0.1 psi/day, the TCP would prospectively reach the first alarm limit of 76 psi within 93 days.

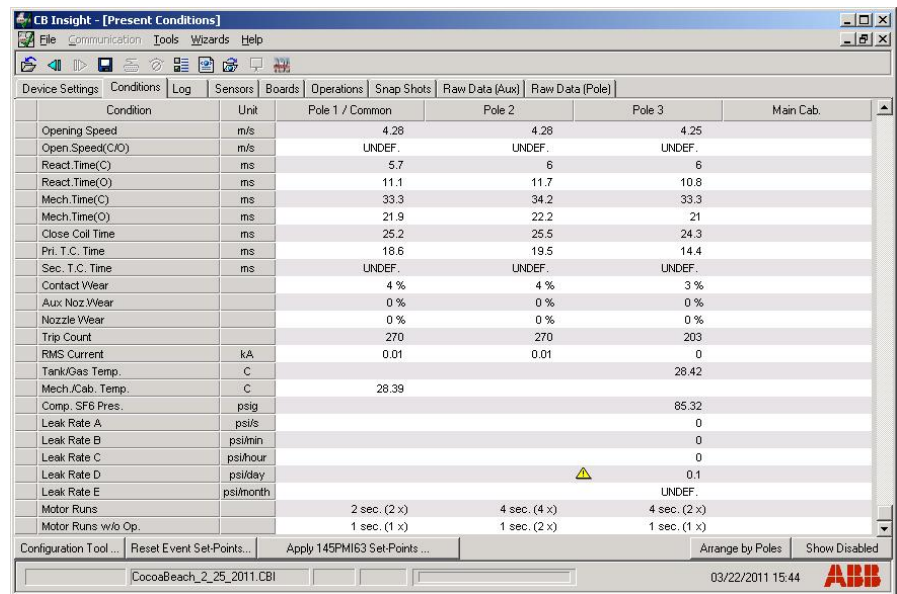


Figure 15 – Alarm due to leak rate calculated from daily averages

The first response to a CBS alarm should always be a review of the CBS data by a maintenance engineer. To that end the CBS instruction book provides guidance and special emphasis was put on CB Insight™ to be a user-friendly and intuitive, yet powerful tool. All CBS alarms are user-manageable. They can be resolved through either a simple settings change requiring only a few mouse-clicks or by correcting the breaker condition causing the alarm. Again, this example shows how condition monitoring can detect problems that standard maintenance techniques and/or conventional alarms cannot. Notice that the drop in pressure is minute and barely noticeable by someone checking the pressure gauge from time to time. Furthermore through condition monitoring a leak was detected about 3 months before it would have caused a conventional gas alarm.

Compressors and pumps belong to one of the categories mentioned in the introduction, which can potentially fail. Compressors are used for pneumatic whereas pumps are employed for hydraulic mechanism. In both cases the element is driven by a motor, which is why monitoring the motor run time and number of starts allows for an assessment of the compressor/pump as well. For example consider a worn compressor/pump. Because of its reduced efficiency it takes a longer motor runtime to recharge the mechanism energy storage. Also worn motor brushes can be detected due to increased motor runtime. Monitoring motor runtime is therefore also applicable to spring drives where the motor winds up the close or trip spring. Pneumatic and hydraulic

systems can be prone to internal leakages resulting in increased number of motor starts. Thus, a variety of problems within the mechanism charging system can be detected early through monitoring of motor starts and runtime.

Figure 16 shows the conditions page for a CBS installed on a gas-insulated switchgear circuit breaker rated 550 kV. The caution sign marks a value in the row labeled “Motor Runs” and the column labeled “Pole 1 / Common”. The value of 1 minute denotes the longest motor run time recorded for the present day as well as the day before. The value “25 x” refers to the total number of motor starts recorded either for the present day or – if greater – for the day before. The motor run time caused the alarm. In this case the alarm was not caused by a mechanism problem but was the result of

Condition	Unit	Pole 1 / Common	Pole 2	Pole 3	Main Cab.
Aux Noz/Wear(2)		DISABLED	DISABLED	DISABLED	DISABLED
Aux Noz/Wear(3)		DISABLED	DISABLED	DISABLED	DISABLED
Nozzle Wear		0 %	0 %	0 %	0 %
Nozzle Wear(2)		DISABLED	DISABLED	DISABLED	DISABLED
Nozzle Wear(3)		DISABLED	DISABLED	DISABLED	DISABLED
Trip Count		21	21	21	21
RMS Current	kA	0	0.04	0.02	
RMS Current(2)	kA	DISABLED	DISABLED	DISABLED	DISABLED
RMS Current(3)	kA	DISABLED	DISABLED	DISABLED	DISABLED
Tank/Gas Temp.	C	13.37	13.78	13.59	
Mech./Cab. Temp.	C	DISABLED	DISABLED	DISABLED	DISABLED
Comp. SF6 Pres.	psig	88.07	87.91	88.11	
Leak Rate A	psifs	0	0	0	
Leak Rate B	psiminh	0	0	0	
Leak Rate C	psifhour	0	0	0	
Leak Rate D	psifday	UNDEF	UNDEF	UNDEF	
Leak Rate E	psifmonth	UNDEF	UNDEF	UNDEF	
Tank Heat 1 (T) Off At Low Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Tank Heat 1 (T) On At High Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Tank Heat 2 (T) Off At Low Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Tank Heat 2 (T) On At High Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Tank Heat 3 (T) Off At Low Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Tank Heat 3 (T) On At High Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Mechanism Heat Off		DISABLED	DISABLED	DISABLED	DISABLED
Mech Heater (T) Off At Low Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Mech Heater (T) On At High Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Cabinet Heater Off		DISABLED	DISABLED	DISABLED	DISABLED
Cab. Heater (T) Off At Low Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Cab. Heater (T) On At High Temp.		DISABLED	DISABLED	DISABLED	DISABLED
Motor Runs		1.0 min (25 x)	57 sec (23 x)	57 sec (25 x)	
Motor Runs w/o Op.		22 sec (5 x)	5 sec (2 x)	9 sec (5 x)	

Figure 16 – Alarm caused by excessive motor run time

commissioning tests that required the mechanism to be discharged for safety reasons. After completion of the tests the mechanism was recharged, leading to a motor run time longer than under normal service conditions. To clear the alarm the user right-clicked on the offending value and selected “acknowledge”. Notice that the alarm settings could have been changed to tolerate motor run times following a complete mechanism discharge. Such a settings change, however, could potentially mask real problems during normal service conditions.

V SUMMARY AND CONCLUSIONS

At the time of this writing roughly 340 Circuit Breaker Sentinel units have been shipped and/or taken in service on new breakers and about 100 units have been delivered and/or installed for retrofit purposes. Installations cover a mix of ABB circuit breakers ranging from 72 kV through 550 kV. The CBS monitors the four major systems of a circuit breaker, namely parts on high voltage, insulation to ground, mechanism as well as auxiliaries and controls. The user-interface software CB Insight™ provides settings support in the form of breaker-type specific settings, a tool to disable unused conditions, as well as controlling a special CBS learning mode that automatically finds settings for breaker timing based on test operations. For breaker timing the CBS records a travel curve as well as binary signals. It then automatically calculates parameters that are checked against alarm limits. The CBS uses a special interrupter wear algorithm that combines the research from ABB’s scientists with real-time current and travel measurement. For SF₆ gas monitoring the CBS takes into account the imperfections in the data derived from either measuring or calculating gas density near the tank as opposed to the average gas density (total gas mass divided by total gas volume). Examples where the value of condition monitoring has been demonstrated include: Excessive motor run time for a 550 kV GIS circuit breaker, long reaction time for one of the poles of a 550 kV dead-tank breaker, fault current interruption with subsequent increase in calculated interrupter wear on a 145 kV gang (3-pole) operated breaker and slow leak detection on a 145 kV independent (single) pole operated breaker. The latter three examples reaffirm that condition monitoring can detect problems and avoid unnecessary maintenance in a way that other maintenance approaches and/or conventional alarms cannot. In the hands of a maintenance engineer condition-based maintenance is a powerful tool with the potential to outperform other maintenance approaches.

VI REFERENCES

- [1] CIGRE WG 13.06 studies on the reliability of single pressure SF6-gas high-voltage circuit-breakers, Janssen, A.L.J. Brunke, J.H. Heising, C.R. Lanz, IEEE Transactions on Power Delivery, Jan 1996, Volume 11, Issue 1, p. 274
- [2] Worldwide reliability survey of high-voltage circuit breakers, Heising, C.R. ,IEEE Industry Applications Magazine, May/Jun 1996, Volume 2 , Issue 3, p. 65
- [3] If It Ain't Broke..., Desai, B. Walther, M. Haufler, J. ,IEEE Power and Energy Magazine, Nov.-Dec. 2010, Volume 8, Issue 6, p. 48
- [4] 33602A-CBS-009, Instructions for the Circuit Breaker Sentinel™,(CBS)™, ABB, 2010
- [5] IEEE Std C37.09-1999: IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, Switchgear Committee of the IEEE Power Engineering Society, June 1999
- [6] WG A3 12: 'Failure survey on circuit breakers control systems', Technical brochure 259 Report, October. 2004