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A3
PS-2 Lifetime Management of Transmission and Distribution Equipment

# Health Indexing and Reliability Assessment of EHV SF6 Circuit Breaker

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## SUMMARY

Transmission is one of the important aspects of Power System. Renewable integration is increasing day by day. Grid operation is changing as the switching is increased to ensure economic dispatch and also to control sudden changes in power flows and mitigate critical contingencies caused by the generation variability. With increased switching in circuit breaker under normal as well as fault condition ensuring reliability is one of important aspect of utility. Reliability assessment and life cycle enhancement of EHV SF6 circuit breaker is challenging as the condition assessment rules, limiting guideline for different parameter varies with different OEM. This document describes a practical asset health indexing calculation method that combines the impact of all available data and also utilizes criteria based on the industry's common practices, OEM guidelines

This paper represents a practical approach to evaluate the operational health and reliability of EHV circuit breakers in substations by health indexing formulation. A unified rule-based engine is developed which can accommodate circuit breaker operational, fault data and all critical condition monitoring parameters to evaluate the health score. The model is applicable for 400KV and above voltage level spring operated SF6 circuit breakers. The same model can be used by utility irrespective of circuit breaker manufacturer. The proposed health index also provides a valuable input for substation maintenance personnel. The applicability of the proposed methodology is explored and validated using the actual circuit breaker operational and condition data collected in the field for different manufacturer. It will help in timely identification of CB health issues and early planning of maintenance action.

## KEYWORDS

CB, DCRM (Dynamic Contact Resistance Measurement), CBM, SF6, Asset Health score, Life expectance

## BACKGROUND:

Adani Transmission Ltd is India's biggest private transmission utility. We maintain large population of EHV circuit breakers. The breakers are installed at different voltage level starting from 11kV to 765kV across the country, operating at different fault levels of grid, catering to multiple application type like ICT, reactor charging, Long & short Transmission Line energization, Fixed series compensation circuit ON-OFF, Auto reclose operation (for 400KV and above voltage level), fault isolation etc. It is important to assess and monitor health of asset from enterprise level. Keeping eye on reliability of CB fleet to ensure timely monitoring, analysis, maintenance and replacement activities. Being critical asset, a simplified & effective health model of circuit breaker is designed based on operational and condition monitoring parameters. The solution doesn't require any investment on additional sensorization and is formulated using all available maintenance, offline testing data.

## MONITORING PARAMETERS FOR HEALTH MODEL:

There are advance sensors available in the market for circuit breaker monitoring. However, due to heavy cost investments it is used only for some critical application. For rest of the asset base, condition monitoring is carried out through time based and condition based maintenance involving important operational parameters available through SCADA and regular maintenance.

Selection of parameters depends upon circuit breaker technology, mechanism type and application. It should provide significant information about the overall equipment health. It was a challenging task, multiple deliberations with OEM, CIGRE reliability survey report reference, OEM manuals helped to identify vital health parameters. As a part of model input information related to Circuit breaker General, Operational health, Breaker Contact condition (main and auxiliary), insulation /dielectric system and operating mechanism considered.

**General information** covers 1) asset ageing, 2) last maintenance, 3) last overhauling history 4) user experience with different OEM. **CB operational life** covers 5) Normal operational count, 6) Fault operation count 7) Cumulative short circuit count into model. **CB dielectric health** covers 8) Capacitance and tan delta of grading capacitor (if available), 9) SF6 dew point, 10) SF6 moisture content, 11) SF6 density and 12) SF6 purity. In recent CIGRE reliability survey report **CB Operating mechanism and contact wear and tear issues** considered as major failure reason of CB failure. Importance given to those aspect by selecting 13) mechanism Closing time, 14) Opening time, 15) Closing time discrepancy within phases, 16) Opening time discrepancy, 17) Close velocity, 18) Open Velocity, 19) Closing coil resistance 20) Opening coil resistance. Further parameters related to 21) Static contact resistance (main contact), 22) Contact and conductor temperature (thermo-vision scanning) and 23) Auxiliary Contact erosion considered to assess condition of the **Power contact** as subsystem.

## CONDITIONAL GRADING OF PARAMETERS:

Conditional grading applied to 23 number of health parameters, categorized as Good, Fair, Alarm, Critical and Replace. The scoring system allotted to convert condition into score ranged from "0" to "4".

| | |
|---|---|
| **4- GOOD** | Asset is healthy from operational and CBM aspect. Normal maintenance. |
| **3 -FAIR** | Deterioration observed in health parameter, not violating limit. Normal maintenance |
| **2-ALARM** | CBM test results violating limit. Increase maintenance frequency. |
| **1- CRITICAL** | Deteriorated health. Start planning process to replace or rebuild. |
| **0-REPLACE** | End of life. Immediately replace or rebuild. |

**a) GENERAL INFORMATION:** The circuit breaker ages over the period of time 5 parameters were monitored under general monitring category mentioned in Table 1 taking support of OEM manual and opearational record.

Table 1: Scoring System for general information factor

| Ageing in (Years) | | Number of CB operation* (Normal) | | Number of CB operation (Fault) | | Time Since last maintenance (Years) | | Time Since Last Overhaul (years) | | Condition Score |
|---|---|---|---|---|---|---|---|---|---|---|
| **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | |
| 0 | 5 | 0 | 2500 | 0 | 3 | 0 | 0.8 | 0 | 4 | 4 |
| 5 | 10 | 2500 | 5000 | 3 | 5 | 0.8 | 1 | 4 | 4.5 | 3 |
| 11 | 20 | 5000 | 7500 | 5 | 8 | 1 | 1.5 | 4.5 | 5 | 2 |
| 21 | 30 | 7500 | 10000 | 8 | 10 | 1.5 | 2 | 5 | 7 | 1 |
| 31 | ∞ | 10000 | ∞ | 10 | ∞ | 2 | ∞ | 7 | ∞ | 0 |

Note: *M2 duty cycle i.e. 10,000 no load operation considered. For M1 duty cycle i.e. 8,000 no load operation, conditional grading to be prepared accordingly.

In addition to fault operation count, fault current plays major role to decide on health of circuit breaker contact life. In case of violation in the fault operation number (refer table-1), detail investigation and record of fault current during every fault operation is to be maintained. Further, cumulative short circuit value is to be calculated and checked against the limit of 20,000* to decide on maintenance action.

Table 2: Sample overhauling & electrical life expectancy criterion

| Overhaul (Criteria) | | | Electrical Life ΣnxI2 | | | |
|---|---|---|---|---|---|---|
| **Technology** | **Time Based (Years) #** | **Mechanical operation (N)** | **Electrical operation (n)** | **Rated Fault current (KA)** | **At Rated fault current (n)** | **At 50% of rated fault current(n)** |
| SF6/Spring type-1 72.5kV | 10 | 10,000 | 2,000 | 31.5 | 8 | 32 |
| SF6/Spring type-2 132kV | 10 | 10,000 | 2,000 | 40 | 13 | 50 |
| SF6/Spring type-3 245kV | 10 | 10,000 | 2,000 | 50 | 8 | 32 |
| SF6/Spring type-4 420kV | 10 | 10,000 | 2,000 | 50 | 8 | 32 |

Note: *for type1,2,3 72,5-245kV:Σ n x I^2 = 20,000, for type-4 420-550kV :Σ n x I^1.9 = 20,000; where n = number of short-circuits, I = short-circuit current, kA (RMS)

**b) DIELECTRIC CONDITION:** Circuit breaker dielectric system is an important criterion for the healthy working of circuit breaker with increased age and number of fault operation.

Table 3: Scoring System for dielectric condition based on 6 parameters

| %Tan delta of grading capacitor (%) | | % Deviation in Capacitance of grading capacitor (%)* | | SF6 Moisture Content (PPM) | | SF6 Pressure (Bar) | | SF6 Purity (%) | | SF6 Dew point at atmospheric pressure (°C) | | Condition Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | |
| 0 | 0.2 | -2.50% | 5% | 0 | 120 | 7 | ∞ | 99 | 100 | - ∞ | -40 | 4 |
| 0.2 | 0.4 | -5% | -2.50% | 120 | 210 | 6.5 | 7.0 | 98 | 99 | -40 | -35 | 3 |
| 0.4 | 0.5 | 5% | 10% | 210 | 300 | 6 | 6.5 | 97 | 98 | -35 | -30 | 2 |
| 0.5 | 0.7 | <-5% | | 300 | 330 | | | 94 | 97 | -30 | -26 | 1 |
| 0.7 | ∞ | >+10% | | 330 | ∞ | 0 | 6 | 0 | 94 | -26 | ∞ | 0 |

Note: a) ***** % Deviation from benchmark result (commissioning result) for grading capacitor capacitance. b) Loss factor measurement (tanδ) value as per CIGRE TB 368 [1]

**c) OPERATING MECHANISM CONDITION:** Circuit breaker operating mechanism is an critical aspect to be monitored. Major CB failures are attributed to issue of operating mechanism failure. Conditional grading to be done as per OEM guideline.

Table 4: Scoring System for Closing & Opening time deviation

| Closing time deviation from benchmark results (ms)* | | Opening time deviation from benchmark results (ms)** | | Condition Score |
|---|---|---|---|---|
| **Min** | **Max** | **Min** | **Max** | |
| -1.5 ms | +1.5 ms | -1.5 ms | +1.5 ms | 4 |
| -3.0 ms | -1.5 ms | -3.0 ms | -1.5 ms | 3 |
| +1.5 ms | +3.0 ms | +1.5 ms | +3.0 ms | |
| -5 ms | -3 ms | - | - | 2 |
| +3 ms | +5 ms | | | |
| <-5 ms | | <-3 ms | | 1 |
| >+5 ms | | >+3 ms | | |

**Note:** a) *****Closing time, **Opening time deviation from benchmark result is the deviation from Commissioning or last overhauling test report.

Table 5: Scoring System for Closing & Opening time discrepancy within phases

| Closing time discrepancy within phases (ms) | | Opening time discrepancy within phases (ms) | | Condition Score |
|---|---|---|---|---|
| **Min** | **Max** | **Min** | **Max** | |
| 0 ms | 3 ms | 0 ms | 3 ms | 4 |
| 3 ms | 5 ms | 3 ms | 3.33 ms | 2 |
| > 5 ms | | > 3.33 ms | | 1 |

Table 6: Scoring System for Close velocity & Open velocity deviation

| Close velocity deviation from benchmark results (m/s)*** | | Opening velocity deviation from benchmark results (m/s)**** | | Condition Score |
|---|---|---|---|---|
| **Min** | **Max** | **Min** | **Max** | |
| -0.15 | +0.15 | -0.15 | +0.15 | 4 |
| -0.30 | -0.15 | -0.30 | -0.15 | 3 |
| +0.15 | +0.30 | +0.15 | +0.30 | 3 |
| < -0.30 | | < -0.30 | | 1 |
| > +0.30 | | > +0.30 | | |

**Note:** a) *****Close velocity (m/s) deviation from benchmark result (Commissioning or last overhauling test report). b) ******Opening velocity (m/s) deviation from benchmark result (Commissioning or last overhauling test report).

Table 7: Scoring System for Closing & Opening coil resistance deviation

| **Closing coil resistance deviation in % from benchmark results (%)*** | | **Opening coil resistance deviation in % from benchmark results (%)**** | | **Condition Score** |
|---|---|---|---|---|
| **Min** | **Max** | **Min** | **Max** | |
| -5% | +5% | -5% | +5% | 4 |
| -10% | -5% | -10% | -5% | 2 |
| +5% | +10% | +5% | +10% | 2 |
| <-10% | | <-10% | | 0 |
| >+10% | | >+10% | | |

**Note:** a) ***Closing coil resistance deviation from benchmark result (Commissioning or last overhauling report). b) ****Opening coil resistance deviation from benchmark result (Commissioning or last overhauling report).

**d) POWER CONTACT CONDITION:** Healthiness of main (male, female) and auxiliary (arcing) contacts are proportional to remaining life of circuit breaker. High fault current, number of fault operation deteriorates power contact condition, hence impacts reliability and failure probability increases. Conditional grading to be done as per OEM guideline.

Table 8: Scoring System for main contact resistance deviation

| **Main contact resistance deviation from benchmark results in per unit (p.u.)*** | | **Condition Score** |
|---|---|---|
| **Min** | **Min** | |
| 0 | 1 | 4 |
| 1 | 1.2 | 3 |
| 1.2 | 1.3 | 2 |
| 1.3 | 1.4 | 1 |
| 1.4 | ∞ | 0 |

**Note:** a) ***Main contact resistance deviation from benchmark results in per unit (p.u.) is equal to = (Present CRM value / Commissioning or last overhauling CRM value). b) Main contact resistance higher than 75 μΩ require OEM's intervention for overhauling of interrupter.

Table 9: Scoring system for contact & conductor temperature (Infra-red thermography)

| **Temperature difference (ΔT) based on comparisons between CB components temperature and ambient air temperatures in °C** | | **Temperature difference (Δt) based on comparisons between similar components of same CB under similar loading in °C** | | **Condition Score** |
|---|---|---|---|---|
| **Min** | **Max** | **Min** | **Max** | |
| 0 | 5 | 0 | 3 | 4 |
| 6 | 10 | 4 | 10 | 3 |
| 11 | 20 | 11 | 15 | 2 |
| 21 | 40 | 15 | ∞ | 1 |
| 40 | ∞ | | | 0 |

Table 10: Scoring System for Auxiliary (arcing) Contact erosion based on DCRM test

| **Auxiliary contact resistance DCRM (Close-open) test in micro ohm (μΩ)** | | **Condition Score** |
|---|---|---|
| **Min** | **Max** | |
| 0 | 150 | 4 |
| 150 | 200 | 3 |
| 200 | 500 | 2 |
| 500 | 1000 | 1 |
| 1000 | ∞ | 0 |

**ASSIGNMENT OF WEIGHTAGE:**

It is critical task in the process of Health indexing formulation. Sensitivity of health model depends on right weightage selection based on actual failure mode history. Importance weighting is assigned to each factor in a range from "modest importance" to "very high importance, in consultation with subject matter experts. This will be further tuned as per utilities own experience and failure history. Different circuit breaker group may have different weightage rule assigned, if required . Weightage system shall be periodically reviewed based on feedback and asset experience (if needed).

Table 11: Typical Weightage system for EHV SF6 CB

| **Sr. No.** | **Monitoring parameters** | **Weight K= (Wi)** |
|---|---|---|
| 1 | Ageing | 2 |
| 2 | User experience with CB type | 1 |
| 3 | Number of CB operation (Normal) | 4 |
| 4 | Number of CB operation (Fault) | 5 |
| 5 | Time Since Last Maintenance | 2 |
| 6 | Time Since Last Overhaul | 1 |
| 7 | Capacitance of grading capacitor | 4 |
| 8 | Tan delta of grading capacitor | 6 |
| 9 | SF6 Moisture Content | 1 |
| 10 | SF6 Pressure | 3 |
| 11 | SF6 Purity | 1 |
| 12 | SF6 dew point at atmospheric pressure | 4 |
| 13 | Close time | 8 |
| 14 | Closing time discrepancy within phases | 5 |
| 15 | Open time | 8 |
| 16 | Opening time discrepancy within phases | 5 |
| 17 | Close Velocity | 4 |
| 18 | Open Velocity | 4 |
| 19 | Closing coil resistance | 5 |
| 20 | Tripping coil resistance | 5 |
| 21 | Contact Resistance | 8 |
| 22 | Contact & Conductor temperature | 4 |
| 23 | Auxiliary Contact erosion | 10 |

## HEALTH INDEX EVALUATION:

A quantified scoring system is used to represent the circuit breaker health. This involves the following steps:

1. “Deterioration” assessments or scores are converted to health scores in a defined range from “perfect health” to “very poor condition.”
2. Importance weighting is assigned to each factor in a range from “modest importance” to “very high importance.”
3. General deterioration index is formulated by calculating the maximum possible score by summing the multiples of steps 1 and 2 for each factor.
4. The general deterioration index is normalized to a maximum score of 100 based on having a defined acceptable/ minimum number of condition criteria available.
5. The dominant factors are normalized to a maximum score of 100.
6. The total HI of CB is as proposed in figure below

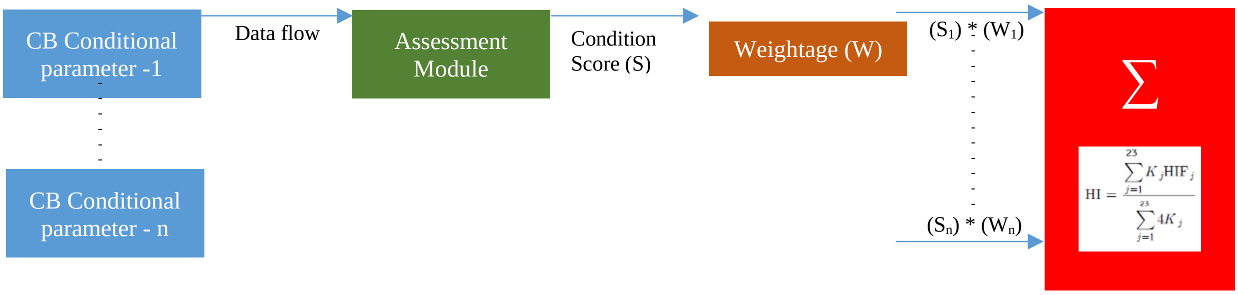


Figure:1 Process flow for health score evaluation

A calculation of the overall Health Index is performed, where 100% represents excellent health and less than 30% represents “poor” health. Preparation of summary of the scoring system and the main condition parameters that are used in this study for condition assessment. Total scores are used in trend analysis. For each component, the health index calculation involves dividing its total condition score by its maximum condition score, then multiplying by 100. This step normalizes scores by producing a number from 0 (completely degraded circuit breaker) to 100 (perfect condition). Considering all the discussed parameters and factors, the total HI score of CB is calculated and interpreted as per table 12.

Table: 12 Health score interpretation

| Health Index score | Description | Required Action Plan | Reliability status |
|---|---|---|---|
| 85 - 100 | Some aging or minor deterioration of a limited number of components | Normal Maintenance | **Good** |
| 70 - 85 | Significant deterioration of some components | Increased monitoring and normal Maintenance | **Fair** |
| 50 - 70 | Widespread significant deterioration or serious deterioration of specific components | Increase diagnostic testing, possible remedial work or replacement needed depending on criticality | **Alarm** |
| 30 - 50 | Widespread serious deterioration | Start planning process to replace or rebuild considering risk and consequences of failure | **Critical** |

| Health Index score | Description | Required Action Plan | Reliability status |
|---|---|---|---|
| 0 - 30 | Extensive serious deterioration | Immediately assess risk; replace or rebuild based on assessment | **Replace** |

**DETERIORATION IN CONDITION MONITORING FUNCTION :** The circuit breaker condition assessment function, consists of some key health indicators (refer Table 13) which could impact the asset management strategy.

Table 13: Interpretation of Condition Monitoring Function

| Sr. No. | Parameter Name | Condition Score HIF (Si) | Health Status | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Number of CB operation (Normal) | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Replace |
| 2 | Number of CB operation (Fault) | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Replace |
| 3 | Time Since Last Maintenance | 4,3,2,1,0 | Good | Fair | Alarm | Alarm | Alarm |
| 4 | Capacitance of grading capacitor | 4,3,2,1,0 | Good | Fair | Alarm | Replace | Replace |
| 5 | Tan delta of grading capacitor | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Critical |
| 6 | SF6 Pressure | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Replace |
| 7 | SF6 dew point at atmospheric pressure | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Critical |
| 8 | Close time | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Critical |
| 9 | Closing time discrepancy within phases | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Critical |
| 10 | Open time | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Critical |
| 11 | Opening time discrepancy within phases | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Critical |
| 12 | Close Velocity | 4,3,2,1,0 | Good | Fair | Alarm | Alarm | Alarm |
| 13 | Open Velocity | 4,3,2,1,0 | Good | Fair | Alarm | Alarm | Alarm |
| 14 | Closing coil resistance | 4,3,2,1,0 | Good | Fair | Alarm | Replace | Replace |
| 15 | Tripping coil resistance | 4,3,2,1,0 | Good | Fair | Alarm | Replace | Replace |
| 16 | Contact Resistance | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Replace |
| 17 | Contact & Conductor temperature | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Replace |
| 18 | Contact erosion (Auxiliary contact resistance) | 4,3,2,1,0 | Good | Fair | Alarm | Critical | Replace |

**CB FINAL HEALTH STATUS INTERPRETATION**

- **Step-1:** Health score falling in different health zone as per Equation-1 and Table 12 to be considered as overall health status of asset.
- **Step-2:** In addition to step-1, health status based on different condition monitoring parameter as per Table 13 to be evaluated
- **Step-3:** Asset health status as per Step-1, 2 to be reviewed and most severe status to be considered as final asset health status

**CASE STUDY-1** Degradation of Power Contact (Main & Arcing) in 400kV Circuit Breaker:

In one of our 400KV switching station Y Phase CB was identified with lower health score 62 and health status indicated as 'Replace' category. Other two phases (R&B) score were 72 and 78. During further investigation it was observed that the circuit breaker has experienced higher number of fault and auto reclose operation, due to which the Auxiliary contact resistance was found on higher side in DCRM result. The erosion even started impacting main contact resistance.

Complete overhauling of interrupter pole and drive mechanism followed by replacement of worn-out contact was ensured. After overhauling Health score improved to 97.5 from 62. Health category improved from 'REPLACE' to 'FAIR'. Timely action could avoid potential failure, power interruption, enhance asset security, safety and avoid costly repairs.

Table: 14 Y Phase CB Health score & Health status

| | | | **Before Overhauling** | | | **After Overhauling** | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Old Health score** | 62 | REPLACE | **New Health score** | 97 | FAIR |
| **Sr. No** | **Diagnostic Techniques** | **UOM** | **Values** | **Score** | **Health status** | **Values** | **Score** | **Health status** |
| 1 | Age | years | 10 | 3 | | 12 | 2 | |
| 2 | Experience with CB type | | 0 | 4 | | 0 | 4 | |
| 3 | Number of CB operation (Normal) | number | 1006 | 4 | GOOD | 1352 | 4 | GOOD |
| 4 | Number of CB operation (Fault) | number | 12 | 0 | REPLACE | 0 | 4 | GOOD |
| 5 | Capacitance of grading capacitor | pF | 1700 | 4 | GOOD | 1700 | 4 | GOOD |
| 7 | Contact Resistance (Present value) | µΩ | 67.2 | 0 | REPLACE | 46.2 | 4 | GOOD |
| 9 | Contact & Conductor temperature (Δ rise) | °C | 2 | 4 | GOOD | 2 | 4 | GOOD |
| 10 | Tan delta of grading capacitor | % | 0.1 | 4 | GOOD | 0.1 | 4 | GOOD |
| 11 | Contact erosion (Auxiliary contact resistance) | µΩ | 1245 | 0 | REPLACE | 63 | 4 | GOOD |
| 12 | Time Since Last Maintenance | years | 0.01 | 4 | GOOD | 0.01 | 4 | GOOD |
| 13 | Time Since Last Overhaul | years | 10 | 0 | | 0 | 4 | |
| 14 | Close time | mS | 60 | 3 | FAIR | 58.4 | 4 | GOOD |
| 16 | Closing time discripancy within phases | mS | 1.2 | 4 | GOOD | 1.2 | 4 | GOOD |
| 17 | Open time | mS | 22 | 4 | GOOD | 22 | 4 | GOOD |
| 19 | Opening time discripancy within phases | mS | 0.4 | 4 | GOOD | 0.4 | 4 | GOOD |
| 20 | Close Velocity | M/sec | 2.58 | 0 | ALARM | 3.01 | 4 | GOOD |
| 22 | Open Velocity | M/sec | 4.51 | 0 | ALARM | 4.85 | 4 | GOOD |
| 24 | SF6 Moisture Content | µL/L | 100 | 4 | | | 4 | |
| 25 | SF6 Pressure | bar | 7.19 | 4 | GOOD | 6.8 | 3 | FAIR |
| 26 | SF6 Purity | % | 99.9 | 4 | | 99.9 | 4 | |
| 27 | SF6 dew point at atmospheric pressure | °C | -30.8 | 2 | ALARM | -39 | 3 | FAIR |
| 28 | Closing coil resistance | Ohm | 215.3 | 4 | GOOD | 206.9 | 4 | GOOD |
| 29 | Tripping coil resistance | Ohm | 230.3 | 3 | FAIR | 211.7 | 4 | GOOD |

CB interrupter main & arcing contact (deteriorated) condition during inspection:

Figure-2:
Arcing contact tip

Figure-3
Puncture in nozzle of Arcing contact

Figure-4
Main contact deteriorated

Figure-5
Main (male) contact

## **CASE STUDY-2** Degradation of Grading Capacitor % tan delta in 765kV Circuit Breaker:

R Phase CB of 765KV switching station, during annual outage one of the grading capacitor identified with higher %tan delta issue. %Tan delta value obtained was 2.5 %. CB health status fall under “REPLACE” category. While checking on historical information, it was observed that the last measured value (2 years back) of grading capacitor was 0.2%. Slight deviation (6.7%) observed in the grading capacitance value. Hence it was evident that the capacitor experienced a premature accelerated ageing. The GC was replaced with a spare capacitor and. The CB health status improved to ”FAIR”, system reliability ensured.

This is a typical case where before and after rectification overall health score was good. However based on deterioration in one of the critical condition monitoring function (i.e. GC ) circuit breaker health status felt under REPLACE category. Hence maintenance team ensured timely replacement action.

Table: 15 706 bay R Phase CB Health score & Health status

| | | | **Before GC replacement** | | | **After GC Replacement** | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Old Health score** | 87 | REPLACE | **New Health score** | 94 | FAIR |
| **Sr. No** | **Diagnostic Techniques** | **UOM** | **Values** | **Score** | **Health status** | **Values** | **Score** | **Health status** |
| 1 | Age | years | 6 | 3 | | 6 | 3 | |
| 2 | Experience with CB type | | 0 | 4 | | 0 | 4 | |
| 3 | Number of CB operation (Normal) | number | 940 | 4 | GOOD | 940 | 4 | GOOD |
| 4 | Number of CB operation (Fault) | number | 0 | 4 | GOOD | 0 | 4 | GOOD |
| 5 | Capacitance of grading capacitor | pF | 1790 | 3 | FAIR | 1690 | 4 | GOOD |
| 6 | Contact Resistance (Present value) | μΩ | 41.86 | 3 | FAIR | 41.86 | 3 | FAIR |
| 7 | Contact & Conductor temperature (Δ rise) | °C | 1.5 | 4 | GOOD | 1.5 | 4 | GOOD |
| 8 | Tan delta of grading capacitor | % | 2.45 | 0 | REPLACE | 0.09 | 4 | GOOD |
| 9 | Contact erosion (Auxiliary contact resistance) | μΩ | 0.531 | 4 | GOOD | 0.531 | 4 | GOOD |
| 10 | Time Since Last Maintenance | years | 0.1 | 4 | GOOD | 0.1 | 4 | GOOD |

| | | | Before GC replacement | | | After GC Replacement | | |
|---|---|---|---|---|---|---|---|---|
| | | | Old Health score | 87 | REPLACE | New Health score | 94 | FAIR |
| **Sr. No** | **Diagnostic Techniques** | **UOM** | **Values** | **Score** | **Health status** | **Values** | **Score** | **Health status** |
| 11 | Time Since Last Overhaul | years | 0.1 | 4 | | 0.1 | 4 | |
| 12 | Close time | mS | 43.3 | 4 | GOOD | 43.3 | 4 | GOOD |
| 13 | Closing time discripancy within phases | mS | 0.4 | 4 | GOOD | 0.4 | 4 | GOOD |
| 14 | Open time | mS | 18.55 | 4 | GOOD | 18.55 | 4 | GOOD |
| 15 | Opening time discripancy within phases | mS | 0.4 | 4 | GOOD | 0.4 | 4 | GOOD |
| 16 | Close Velocity | M/sec | 2.9 | 4 | GOOD | 2.9 | 4 | GOOD |
| 17 | Open Velocity | M/sec | 4.2 | 3 | FAIR | 4.2 | 3 | FAIR |
| 18 | SF6 Moisture Content | μL/L | | 4 | | | 4 | |
| 19 | SF6 Pressure | bar | 7 | 3 | FAIR | 7 | 3 | FAIR |
| 20 | SF6 Purity | % | 91.82 | 0 | | 91.82 | 0 | |
| 21 | SF6 dew point at atmospheric pressure | °C | -47.3 | 4 | GOOD | -47.3 | 4 | GOOD |
| 22 | Closing coil resistance | Ohm | 212 | 4 | GOOD | 212 | 4 | GOOD |
| 23 | Tripping coil resistance | Ohm | 209 | 4 | GOOD | 209 | 4 | GOOD |

Faulty grading capacitor internal condition during inspection :

Figure-6 GC opened

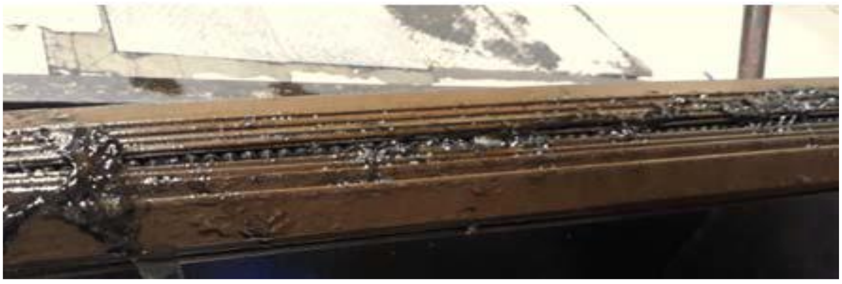

Figure-7 Inside GC black sludge formation observed across capacitor stack

## CONCLUSION

This paper explains a unified rule-based CB health indexing engine, which can accommodate CB operational, fault data and all critical condition monitoring parameters to evaluate the health score and health status. It helps asset owners to understand practically how to evaluate health indexing and benchmark circuit breaker health. Convert condition into score for maintenance planning and decision making. Health indexing is a useful tool to condense a large amount of technical data and test result analysis into a score. It conveys the information about overall asset condition by analysis of available test data. Further trend analysis of health score will help in prioritizing selection of assets for further investigation or investment. Circuit breaker health indices are not only for alarm management. In addition, diagnostic information indicates a serious or severe problem, an immediate response is required.

The health indexing formulation and reliability assessment will help asset owners to categorize circuit breaker fleet and map reliability status like, Good, Fair, Alarm, Critical and Replace.

This will further help in assessing asset longevity and planning of OPEX and CAPEX. It is a powerful tool that quantifies the equipment condition based on various conditional parameters that are related to short- or long-term degradation.

## BIBLIOGRAPHY


[1] Working Group A3.18 CIGRE Technical Brochure 368. “OPERATING ENVIRONMENT OF VOLTAGE GRADING CAPACITORS APPLIED TO HIGH VOLTAGE CIRCUIT-BREAKERS”, Year 2009

[2] IEC 62271 High-voltage switchgear and controlgear – Part 100: Alternating-current circuit-breakers

[3] Adani Transmission Ltd Condition monitoring limiting guideline for EHV and UHV assets

[4] Adani Transmission Ltd. Maintenance manual for circuit breakers

[5] OEM Operation and maintenance Guideline.