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Study Committee A3

Transmission and Distribution Equipment

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Health Indexing and Reliability Assessment of EHV SF6 Circuit Breaker

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Motivation :

Reliability assessment and life cycle enhancement of EHV SF6 circuit breaker fleet through a single health model is challenging as the condition assessment rules, limiting guideline for different parameter varies with different OEM.

There was a need of solution, that doesn't require any investment on additional sensorization. Solution should utilize all available maintenance, testing data and help in Run , Repair, Replacement decision.

Method / Approach:

A unified rule-based health indexing 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 can be used by utility irrespective of circuit breaker manufacturer. Step wise procedure illustrated here.

Parameters For CB Health Model:

Selection of parameters depends upon circuit breaker technology, mechanism type and application. It should provide significant information about the overall equipment health. Health indexing model input parameters shown below.

- **General information inputs:** 1) asset ageing, 2) last maintenance history, 3) last overhauling history 4) user experience with different OEM.
- **CB operational life inputs:** 5) Normal operational count, 6) Fault operation count 7) Cumulative short circuit count into model.
- **CB dielectric health inputs:** 8) Capacitance and tan delta of grading capacitor (if available), 9) SF6 dew point, 10) SF6 moisture content, 11) SF6 pressure and 12) SF6 purity.
- **CB Operating mechanism and contact wear and tear issues inputs:** 13) mechanism Closing time, 14) Opening time, 15) Closing time discrepancy within phases, 16) Opening time discrepancy within phases, 17) Close velocity, 18) Open Velocity, 19) Closing coil resistance 20) Opening coil resistance.
- **Power contact as subsystem inputs:** 21) Static contact resistance (main contact), 22) Contact and conductor temperature (thermo-vision scanning) and 23) Auxiliary Contact erosion.

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".

Table-1 Conditional grading rule

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.

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Conditional grading approach of all input parameters are illustrated in table-2 to 11.

Table-2 Scoring System for CB 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. cumulative short circuit value is to be calculated and checked against the limit of 20,000* to decide on maintenance action.

Table-3 Sample overhauling & electrical life expectancy criterion

	Overhaul (Criteria)		Electrical Life $\Sigma nxI2$			
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 (R).

Table-4 Scoring System for GC, SF6 moisture condition

SF6 Moisture Content (PPM)		% Tan delta of Grading capacitor		% Deviation in Capacitance of grading capacitor (%)*		Condition Score
Min	Max	Min	Max	Min	Max	
0	120	0	0.2	-2.50	5	4
120	210	0.2	0.4	-5	-2.50	3
210	300	0.4	0.5	5	10	2
300	330	0.5	0.7	<-5		1
330	∞	0.7	∞	>+10%		0

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

Table-5 Scoring System for dielectric (SF6) condition

SF6 Pressure (Bar)		SF6 Purity (%)		SF6 Dew point (°C)		Condition Score
Min	Max	Min	Max	Min	Max	
7	∞	99	100	- ∞	-40	4
6.5	7.0	98	99	-40	-35	3
6	6.5	97	98	-35	-30	2
		94	97	-30	-26	1
0	6	0	94	-26	∞	0

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Table-6 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	+1.5	-1.5	+1.5	4
-3.0	-1.5	-3.0	-1.5	3
+1.5	+3.0	+1.5	+3.0	
-5	-3	-	-	2
+3	+5			
<-5		<-3		1
>+5		>+3		

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

Table-7 Scoring System for Closing & Opening time discrepancy within phases

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

Table-8 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-9 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).*

Table-10 Scoring System for main contact resistance, Aux contact resistance and contact temperature deviation

Main contact resistance deviation in per unit (p.u.)*		Auxiliary contact resistance DCRM test in micro ohm (μΩ)		Temperature difference (Δt) based on comparisons between similar components of CB under similar loading in °C		Condition Score
Min	Max	Min	Max	Min	Max	
0	1	0	150	0	3	4
1	1.2	150	200	4	10	3
1.2	1.3	200	500	11	15	2
1.3	1.4	500	1000	15	∞	1
1.4	∞	1000	∞			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.*

Assignment of weightage (typical):

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 score evaluation:

A quantified scoring system is used to represent the circuit breaker health. The total HI of CB is as proposed in figure below.

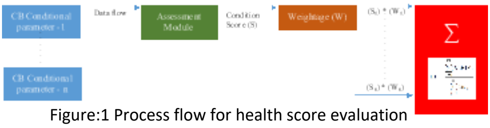

Figure:1 Process flow for health score evaluation

A calculation of the overall Health Index is performed, where 100% represents excellent health and less than 30% represents "poor" health. Total scores are used for trend analysis. For each component, the health index calculation involves dividing its total condition score by its maximum condition score, then multiplying by 100.

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Considering all the discussed parameters and factors, the total HI score of CB is calculated. Interpretation to be done as per table below

Table-12 Health score interpretation

Health Index score	Required Action Plan	Reliability status
85 - 100	Normal Maintenance	Good
70 - 85	Increased monitoring and normal Maintenance	Fair
50 - 70	Increase diagnostic testing, possible remedial work or replacement needed depending on criticality	Alarm
30 - 50	Start planning process to replace or rebuild considering risk and consequences of failure	Critical
0 - 30	Immediately assess risk; replace or rebuild based on assessment	Replace

Deterioration in important condition monitoring function:

The circuit breaker condition assessment function, consists of some key health indicators which could impact the asset management strategy.

Table-13 Interpretation of Condition Monitoring Function

		Health Status				
	Score	4	3	2	1	0
Sr. No.	Parameter Name					
1	Number of CB operation (Normal)	Good	Fair	Alarm	Critical	Replace
2	Number of CB operation (Fault)	Good	Fair	Alarm	Critical	Replace
3	Time Since Last Maintenance	Good	Fair	Alarm	Alarm	Alarm
4	Capacitance of GC	Good	Fair	Alarm	Replace	Replace
5	Tan delta of GC	Good	Fair	Alarm	Critical	Critical
6	SF6 Pressure	Good	Fair	Alarm	Critical	Replace
7	SF6 dew point	Good	Fair	Alarm	Critical	Critical
8	Close time	Good	Fair	Alarm	Critical	Critical
9	Closing time discrepancy	Good	Fair	Alarm	Critical	Critical
10	Open time	Good	Fair	Alarm	Critical	Critical
11	Opening time discrepancy	Good	Fair	Alarm	Critical	Critical
12	Close Velocity	Good	Fair	Alarm	Alarm	Alarm
13	Open Velocity	Good	Fair	Alarm	Alarm	Alarm
14	Closing coil resistance	Good	Fair	Alarm	Replace	Replace
15	Tripping coil resistance	Good	Fair	Alarm	Replace	Replace
16	Contact Resistance	Good	Fair	Alarm	Critical	Replace
17	Contact temperature	Good	Fair	Alarm	Critical	Replace
18	Contact erosion	Good	Fair	Alarm	Critical	Replace

CB final health status evaluation:

Step-1: Health score falling in different health zone as per Figure-1 equation 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.

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Case study-1:

Degradation of Power Contact (Main & Arcing) in 400kV Circuit Breaker: In 400KV switching station Y Pole of CB was identified with low health score 62, health status '**REPLACE**' category. During further investigation it was observed that the CB has experienced higher number of fault and AR operation, due to which the Auxiliary contact resistance found on higher side in DCRM. The erosion even started impacting main contact resistance.

Complete overhauling of interrupter pole and drive mechanism, replacement of worn-out contact 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 pole of CB Health score & Health status

		Before Overhauling		
		Health score	62	REPLACE
Diagnostic Techniques	UOM	Values	Score	Health status
Age	years	10	3	
Experience with CB type		0	4	
Number of CB operation (Normal)	No.	1006	4	GOOD
Number of CB operation (Fault)	No.	12	0	REPLACE
Capacitance of GC	pF	1700	4	GOOD
Contact Resistance (Present value)	μΩ	67.2	0	REPLACE
Contact & Conductor temperature (Δ rise)	°C	2	4	GOOD
Tan delta of GC	%	0.1	4	GOOD
Contact erosion (Auxiliary contact)	μΩ	1245	0	REPLACE
Time Since Last Maintenance	years	0.01	4	GOOD
Time Since Last Overhaul	years	10	0	
Close time		60	3	FAIR
Close time discripancy		1.2	4	GOOD
Open time		22	4	GOOD
Open time discripancy		0.4	4	GOOD
Close Velocity	M/sec	2.58	0	ALARM
Open Velocity	M/sec	4.51	0	ALARM
SF6 Moisture Content	μL/L	100	4	
SF6 Pressure	bar	7.19	4	GOOD
SF6 Purity	%	99.9	4	
SF6 dew point	°C	-30.8	2	ALARM
Closing coil resistance	Ohm	215.3	4	GOOD
Tripping coil resistance	Ohm	230.3	3	FAIR

Conclusion: 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.

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