

Substation Maintenance Instruction

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SMI 161 Condition assessment of assets using health index

SECTION 8 – DISTRIBUTION SUBSTATIONS

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8.1 Asset description

Distribution substations in the distribution network are static devices that assist in the distribution of electrical energy to end users. They consist of a transformer with insulated copper windings installed on laminated iron cores and immersed in oil that insulates and cools the internal components. Other components of a distribution substation assembly include the HV switchgear, LV distribution board, bushings, enclosure/building, and base/foundation.

8.2 Condition assessment

Distribution substations generally represent an essential element of distribution systems. Substations operate under dynamic load conditions; hence both loading and the environment are the main contributors to their aging and breakdown. These conditions degrade the transformers insulation, terminations and switchgear. Eventually they can lead to equipment failure, which can have significant consequences to customer supply.

The components mentioned in Section 8.1 are assessed based on set criteria and given a condition based rating. The assessed condition of these components is the foundation on which the health index is calculated.

8.3 Condition rating

The condition rating process includes field inspections and detailed review of maintenance records and test reports. Each criterion represents a factor that is critical in determining the component's condition relative to potential failure.

The following tables contain specific definitions used for each condition rating for each component or test evaluated:

8.3.1 HV switchgear partial discharge level

Condition Rating	Description
A	TEV level is $\leq 9\text{dB}$ or Ultrasonic level $\leq 5\text{dB}$
B	TEV level between $10\text{dB} - 20\text{dB}$ or Ultrasonic level between $6\text{dB} - 12\text{dB}$
C	TEV level $> 20\text{dB}$ or Ultrasonic level $> 12\text{dB}$
D	- TEV level $> 20\text{dB}$ or Ultrasonic level $> 12\text{dB}$ AND indicators of discharge are found: - o Presence of white residue - o Verdigris - o Smell of ozone - o Pulse count of measured TEV > 50
E	- TEV level $> 20\text{dB}$ or Ultrasonic level $> 12\text{dB}$ AND at least one critical factor is found: - o Discharge audible by ear - o Discharge emanating between cable terminations - Any significant carbon tracking.

8.3.2 HV cable termination partial discharge level

Condition Rating	Description
A	TEV level is $\leq 9\text{dB}$ or Ultrasonic level $\leq 5\text{dB}$
B	TEV level between $10\text{dB} - 20\text{dB}$ or Ultrasonic level between $6\text{dB} - 12\text{dB}$
C	TEV level $> 20\text{dB}$ or Ultrasonic level $> 12\text{dB}$
D	- TEV level $> 20\text{dB}$ or Ultrasonic level $> 12\text{dB}$ - AND indicators of discharge are found: - o Presence of white residue - o Verdigris - o Smell of ozone - o Pulse count of measured TEV > 50
E	- TEV level $> 20\text{dB}$ or Ultrasonic level $> 12\text{dB}$ - AND at least one critical factor is found: - o Discharge audible by ear - o Discharge emanating between cable terminations - Any significant carbon tracking.

8.3.3 HV cable termination

Condition Rating	Description
A	- HV terminations are tight and free from corrosion. - No visible evidence of tracking. - No visible evidence of overheating. - Cable connections are not exposed and correct clearances are maintained.
B	HV cable termination shows normal signs of wear.
C	Some corrosion and evidence of tracking or overheating.
D	- Severe corrosion and evidence of tracking or overheating. - Cable connection is exposed.
E	HV terminations are damaged / degraded beyond repair.

8.3.4 HV switchgear internal condition

8.3.4.1 Cast resin

Components:

Condition Rating	Description
A	- Compound level is cable box within 125mm from top of box. - Arcing contacts and arc chamber show no visible signs of burning/ discolouration. - Switch caps, fuse holder caps free from cracks/damage or overheating.
B	HV switchgear shows normal signs of wear.
C	- Compound in cable box requires top up every maintenance interval. - Arcing contacts and arc chamber have minor discolouration. - Switch caps, fuse holder caps have minor cracks and discolouration.
D	- Compound in cable box requires top up more frequent than every maintenance interval. - Arcing contacts and arc chamber have major burning or discolouration. - Switch caps, fuse holder caps have major cracks and discolouration.
E	- Compound in cable box requires frequent topping up. - HV switchgear is damaged / degraded beyond repair.

Resin aging:

Condition Rating	Description
A	- Resin and plastics show no visible signs of tracking. - Resin and plastic are free from contamination and cracks.
B	Resin and plastic shows normal signs of wear.
C	Some tracking and minor cracks.
D	Severe tracking and major cracks.
E	Resin insulation is damaged / degraded beyond repair.

8.3.4.2 Safelink

Condition Rating	Description
A	- The SF6 gas density gauge is in the green region. - No signs of moisture ingress. - Contacts, indicators and busbar chamber are in functional condition.
B	HV switchgear shows normal signs of wear.
C	- SF6 requires top up every maintenance interval. - Contacts and busbar chambers have minor discolouration.
D	- SF6 requires top up more frequent than every maintenance interval. - Some evidence of moisture ingress. - Contacts and busbar chambers have major discolouration.
E	- SF6 requires frequent topping up or cannot hold pressure. - Clear signs of moisture ingress. - HV switchgear is damaged / degraded beyond repair.

8.3.4.3 ABB RGB12

Condition Rating	Description
A	- Truck primary circuit resistance: 120 – 150 micro-ohms for switch unit or 250 – 300 micro-ohms for switch fuse unit, adding 16 milliohms if fuse is inserted. - Switch chambers and main fixed contact tubes show no signs of overheating, burning, distortion, burs or other defects. - Upper insulation block show no signs of discharge, cracks, fractures, deformities or other defects. - Contacts free from defective plating, broken springs, discolouration, signs of arcing or other defects. - Nozzles and O-rings are not distorted or deteriorated.
B	HV switchgear shows normal signs of wear.
C	- Switch chambers and main fixed contact tubes show minor signs of overheating, burning, distortion, burs or other defects. - Upper insulation block show minor signs of discharge, cracks, fractures, deformities or other defects. - Contacts show minor signs of defective plating, broken springs, discolouration, arcing or other defects. - Nozzles and O-rings show signs of minor distortion or deterioration.

D	- Switch chambers and main fixed contact tubes show major signs of overheating, burning, distortion, burs or other defects. - Upper insulation block show major signs of discharge, cracks, fractures, deformities or other defects. - Contacts show major signs of defective plating, broken springs, discolouration, arcing or other defects. - Nozzles and O-rings show signs of major distortion or deterioration.
E	HV switchgear is damaged / degraded beyond repair.

8.3.4.4 Other sheet metal enclosed HV switch units

Condition Rating	Description
A	- Insulation is clean and shows no signs of deterioration. - No signs of moisture ingress. - Contacts, indicators and busbar chamber are in functional condition.
B	HV switchgear shows normal signs of wear.
C	- Insulation is clean and shows minor signs of deterioration. - Contacts and busbar chambers have minor discolouration.
D	- Insulation is clean and shows major signs of deterioration. - Some evidence of moisture ingress. - Contacts and busbar chambers have major discolouration.
E	- Clear signs of moisture ingress. - HV switchgear is damaged / degraded beyond repair.

8.3.4.5 HV oil switch and switch fuse units

Fuse components:

Condition Rating	Description
A	- No signs of moisture ingress or sweating or oil leaks. - Fixed and moving contacts show no signs of overheating, are loose, bent or other defects. - Fuse elements are clean and free from cracks and are not broken. - Fuse carriages are in functional condition.
B	Fuse components show normal signs of wear.
C	- Minor oil leaks. - Fixed and moving contacts show minor signs of overheating. - Fuse elements and carriages have minor cracks, but are not broken.
D	- Major oil leaks. - Some evidence of moisture ingress. - Fixed and moving contacts show major signs of overheating, are loose, bent or other defects. - Fuse elements and carriages have major cracks and are broken.
E	- Clear signs of moisture ingress. - Fuse components are damaged / degraded beyond repair.

Switch components:

Condition Rating	Description
A	- No signs of moisture ingress or sweating or oil leaks. - No cable box compound leaks. - Tank lining/inter phase barriers are clean and not damaged. - No visible evidence of treeing or tracking. - Bushings are free from abnormalities, cracks, chips, flange damage or other defects.
B	Switch components show normal signs of wear.
C	- Minor oil leaks. - Minor cable box compound leaks. - Some evidence of treeing or tracking. - Bushings have minor abnormalities, cracks, chips, flange damage or other defects.
D	- Some signs of moisture ingress. - Major oil leaks. - Major cable box compound leaks. - Clear evidence of treeing or tracking. - Bushings have major abnormalities, cracks, chips, flange damage or other defects.
E	- Clear signs of moisture ingress. - Switch components are damaged / degraded beyond repair.

8.3.5 HV switchgear external condition

8.3.5.1 Cast resin

Condition Rating	Description
A	- Steelwork and frame has no visible corrosion and bolts are secure. - Dust covers are not damaged or distorted. - Cam and leaf springs are in functional condition.
B	HV switchgear shows normal signs of wear.
C	- Steelwork and frame has some corrosion. - Dust covers have minor damage or distortion.
D	- Steelwork and frame has severe corrosion and bolts are loose. - Dust covers have major damage or distortion.
E	HV switchgear is damaged / degraded beyond repair.

8.3.5.2 Safelink

Condition Rating	Description
A	- No signs of paint degradation and corrosion. - Switch position indicators show correct display when performing test operations of the mechanism.
B	HV switchgear shows normal signs of wear.
C	Some paint degradation and corrosion.
D	- Severe paint degradation and corrosion. - Switch position indicators does not show correct display when performing test operations of the mechanism.
E	HV switchgear is damaged / degraded beyond repair.

8.3.5.3 ABB RGB12

Condition Rating	Description
A	- Main switch is in functional condition manually and electrically. - Equipment frame and exterior casing free from paint degradation, and signs of corrosion. - No tracking or cracks on fiberglass drive rod. - Fuse handle, operating mechanism, auxiliary switches, coil, motor and heater are in functional condition.
B	HV switchgear shows normal signs of wear.
C	- Some paint degradation and corrosion. - Some tracking or cracks on fiberglass drive rod.
D	- Main switch is in poor condition manually and electrically. - Major paint degradation and corrosion. - Major tracking or cracks on fiberglass drive rod. - Fuse handle, operating mechanism, auxiliary switches, coil, motor and heater are in poor condition.
E	HV switchgear is damaged / degraded beyond repair.

8.3.5.4 Other sheet metal enclosed HV switch units

Condition Rating	Description
A	- No signs of paint degradation and corrosion. - Operating mechanism, auxiliary switches, coil, motor and heater are in functional condition.
B	HV switchgear shows normal signs of wear.
C	Some paint degradation and corrosion.
D	- Major paint degradation and corrosion. - Operating mechanism, auxiliary switches, coil, motor and heater are in poor condition.
E	HV switchgear is damaged / degraded beyond repair.

8.3.5.5 HV oil switch and switch fuse units

Condition Rating	Description
A	- No signs of paint degradation and corrosion. - Tank chamber shows no signs of temperature rise, distortion or other defects. - Operating mechanism, gaskets and damping device are in functional condition.
B	HV switchgear shows normal signs of wear.
C	- Some paint degradation and corrosion. - Tank chamber shows some signs of temperature rise, distortion or other defects.
D	- Severe paint degradation and corrosion. - Tank chamber shows sever signs of temperature rise, distortion or other defects. - Operating mechanism, gaskets and damping device are in poor condition.
E	HV switchgear is damaged / degraded beyond repair.

8.3.6 Overall LV distribution board condition

Condition Rating	Description
A	• Labelling is present and legible. • No evidence of moisture / condensation, excessive dirt, dust, overheating, tracking or arcing. • Encapsulation and barriers are free from cracks, fractures or deformities. • Contacts and contact finger springs show no signs of discolouration or damage. • Steelwork and hardware are free from rust or corrosion and are secure.
B	• LV distribution board shows normal signs of wear.
C	• Encapsulation and barriers have minor cracks, fractures or deformities. • Contacts and contact finger springs show some signs of discolouration or damage. • Steelwork and hardware have minor rust or corrosion.
D	• Some moisture / condensation, excessive dirt, dust, overheating, tracking or arcing. • Encapsulation and barriers have major cracks, fractures or deformities. • Contacts and contact finger springs show severe signs of discolouration or damage. • Steelwork and hardware have major rust or corrosion.
E	• Clear signs of moisture ingress. • LV distribution board is damaged / degraded beyond repair.

8.3.7 LV termination and hotspot

Condition Rating	Description
A	• LV terminations are tight, free from corrosion and show no visible evidence of tracking or overheating. • Cable connections are not exposed and correct clearances are maintained. • No hot spot or temperature rise measured.
B	• LV terminations show normal signs of wear. • Hot spot detected, temperature rise < 20°C.
C	• Some corrosion and evidence of tracking or overheating. • Hot spot detected, temperature rise between 20°C – 30°C.
D	• Severe corrosion and evidence of tracking or overheating. • Some cable connections are exposed. • Hot spot detected, temperature rise between 31°C – 60°C.
E	• LV terminations are damaged / degraded beyond repair. • Hot spot detected, temperature rise < 60°C. • Annealed or oxidised metal contacts must be replaced immediately.

8.3.8 Enclosure, base or building and signage

Padmounts, kiosk and switching stations:

Condition Rating	Description
A	- Enclosure and doors show no evidence of corrosion, misalignment, obstruction, security or incorrect operation. - Substation base free from signs of alterations to ground level or foundation erosion. - Identification, danger and warning signs are present, legible and correct.
B	Enclosure, doors and base show normal signs of wear.
C	- Enclosure and doors show some evidence of corrosion, misalignment, obstruction, security or incorrect operation. - Substation base show some signs of alterations to ground level or foundation erosion.
D	- Enclosure and doors show severe evidence of corrosion, misalignment, obstruction, security or incorrect operation. - Substation base show severe signs of alterations to ground level or foundation erosion.
E	Enclosure, doors and base are damaged / degraded beyond repair.

Indoor, ground and cottage substations:

Condition Rating	Description
A	- No evidence of poor paintwork, rainwater leaks or any structural damage. - Identification, danger and warning signs are present, legible and correct. - Substation foundation free from signs of alterations to ground level or erosion. - Doors, gates or fences show no evidence of corrosion, misalignment, obstruction, security or incorrect operation.
B	Enclosure, doors, gates, fence and base show normal signs of wear.
C	- Some poor paintwork, rainwater leaks or any structural damage. - Substation foundation show some signs of alterations to ground level or erosion. - Doors, gates or fences show some evidence of corrosion, misalignment, obstruction, security or incorrect operation.
D	- Severe poor paintwork, rainwater leaks or any structural damage. - Substation foundation show severe signs of alterations to ground level or erosion. - Doors, gates or fences show severe evidence of corrosion, misalignment, obstruction, security or incorrect operation.
E	Enclosure, doors, gates, fence and base are damaged / degraded beyond repair.

8.3.9 Transformer condition

Condition Rating	Description
A	- Transformer free from signs of corrosion or oil leaks. - HV bushing shrouds are present and correctly seated. - HV bushing free from signs of contamination, tracking, heating or corrosion.

B	Transformer shows normal signs of wear.
C	- Some corrosion or oil leaks. - HV bushing show some signs of contamination, tracking, heating or corrosion.
D	- Severe corrosion or oil leaks. - HV bushing shrouds are damaged or missing. - HV bushing show severe signs of contamination, tracking, heating or corrosion.
E	Transformer is damaged / degraded beyond repair.

8.3.10 Transformer loading

Condition Rating	Description
A	Transformer load less than 95% of cyclic rating.
B	- Transformer load is greater than 95% of cyclic rating. - Measured temperature less than 82°C.
C	- Transformer load is greater than 95% of cyclic rating. - Measured temperature between 82°C and 93°C.
D	- Transformer load is greater than 95% of cyclic rating. - Measured temperature greater than 93°C.
E	- Transformer load is greater than 95% of cyclic rating. - Maximum top oil temperature is greater than 105°C OR - Maximum hotspot temperature is greater than 135°C.

8.3.11 Earthing condition

Condition Rating	Description
A	- Earth connections, earthing bar termination crimps are secure and free of corrosion. - Continuity between HV and LV earth systems. - Step and touch potential voltages are not exceeded.
B	Earthing shows normal signs of wear.
C	Some corrosion of earthing connections and earthing bar termination crimps.
D	Severe corrosion of earthing connections and earthing bar termination crimps and are loose.
E	Earthing is damaged / degraded beyond repair.

8.3.12 Inherent Safety Issues

Condition Rating	Description
A	No risk to safety, environment or network.
B	Minor risk to safety, environment or network.
C	Moderate risk to safety, environment or network.
D	Major risk to safety, environment or network.
E	Severe risk to safety, environment or network.

8.4 Health index formulation

The distribution substation is rated against set criteria for each condition parameter. The ratings are converted to a factor and multiplied by the given weight to obtain a health index score. The following tables contain the associated weight for each condition criterion:

8.4.1 Cast resin

#	Condition Criteria		Weight (W _i)	Condition Rating	Factors (S _i)	Maximum Score (T _i)
1	HV switchgear partial discharge level		6	A, B, C, D, E	4, 3, 2, 1, 0	24
2	HV cable termination partial discharge level		2	A, B, C, D, E	4, 3, 2, 1, 0	8
3	HV cable termination		2	A, B, C, D, E	4, 3, 2, 1, 0	8
4	HV switchgear internal condition	Components	4	A, B, C, D, E	4, 3, 2, 1, 0	56
		Resin aging	10			
5	HV switchgear external condition		4	A, B, C, D, E	4, 3, 2, 1, 0	16
6	Overall LV distribution board condition		6	A, B, C, D, E	4, 3, 2, 1, 0	24
7	LV termination and hotspot		3	A, B, C, D, E	4, 3, 2, 1, 0	12
8	Enclosure, base or building and signage		5	A, B, C, D, E	4, 3, 2, 1, 0	20
9	Transformer condition		10	A, B, C, D, E	4, 3, 2, 1, 0	40
10	Transformer loading		30	A, B, C, D, E	4, 3, 2, 1, 0	120
11	Earthing condition		3	A, B, C, D, E	4, 3, 2, 1, 0	12
12	Inherent safety issues		15	A, B, C, D, E	4, 3, 2, 1, 0	60
			100			400

All 12 scores are entered into the formula below to convert to a rating out of 100:

$$HI = \left(\frac{\sum_{i=1}^N (S_i \times W_i)}{\sum_{i=1}^N T_i} \right) \times 100$$

where: $\sum_{i=1}^N T_i = 400$

$N = 12$

8.4.2 Safelink

#	Condition Criteria	Weight (W _i)	Condition Rating	Factors (S _i)	Maximum Score (T _i)
1	HV switchgear partial discharge level	10	A, B, C, D, E	4, 3, 2, 1, 0	40
2	HV cable termination partial discharge level	2	A, B, C, D, E	4, 3, 2, 1, 0	8
3	HV cable termination	2	A, B, C, D, E	4, 3, 2, 1, 0	8
4	HV switchgear internal condition	10	A, B, C, D, E	4, 3, 2, 1, 0	40
5	HV switchgear external condition	4	A, B, C, D, E	4, 3, 2, 1, 0	16
6	Overall LV distribution board condition	6	A, B, C, D, E	4, 3, 2, 1, 0	24
7	LV termination and hotspot	3	A, B, C, D, E	4, 3, 2, 1, 0	12
8	Enclosure, base or building and signage	5	A, B, C, D, E	4, 3, 2, 1, 0	20
9	Transformer condition	10	A, B, C, D, E	4, 3, 2, 1, 0	40
10	Transformer loading	40	A, B, C, D, E	4, 3, 2, 1, 0	160
11	Earthing condition	3	A, B, C, D, E	4, 3, 2, 1, 0	12
12	Inherent safety issues	5	A, B, C, D, E	4, 3, 2, 1, 0	20
		100			400

All 12 scores are entered into the formula below to convert to a rating out of 100:

$$HI = \left(\frac{\sum_{i=1}^N (S_i \times W_i)}{\sum_{i=1}^N T_i} \right) \times 100$$

where: $\sum_{i=1}^N T_i = 400$

$N = 12$

8.4.3 ABB RGB12 and other sheet metal enclosed HV switch units

#	Condition Criteria	Weight (W _i)	Condition Rating	Factors (S _i)	Maximum Score (T _i)
1	HV switchgear partial discharge level	8	A, B, C, D, E	4, 3, 2, 1, 0	32
2	HV cable termination partial discharge level	2	A, B, C, D, E	4, 3, 2, 1, 0	8
3	HV cable termination	2	A, B, C, D, E	4, 3, 2, 1, 0	8
4	HV switchgear internal condition	12	A, B, C, D, E	4, 3, 2, 1, 0	48
5	HV switchgear external condition	4	A, B, C, D, E	4, 3, 2, 1, 0	16
6	Overall LV distribution board condition	6	A, B, C, D, E	4, 3, 2, 1, 0	24
7	LV termination and hotspot	3	A, B, C, D, E	4, 3, 2, 1, 0	12
8	Enclosure, base or building and signage	5	A, B, C, D, E	4, 3, 2, 1, 0	20

9	Transformer condition	10	A, B, C, D, E	4, 3, 2, 1, 0	40
10	Transformer loading	40	A, B, C, D, E	4, 3, 2, 1, 0	160
11	Earthing condition	3	A, B, C, D, E	4, 3, 2, 1, 0	12
12	Inherent safety issues	5	A, B, C, D, E	4, 3, 2, 1, 0	20
		100			400

All 12 scores are entered into the formula below to convert to a rating out of 100:

$$HI = \left(\frac{\sum_{i=1}^N (S_i \times W_i)}{\sum_{i=1}^N T_i} \right) \times 100$$

where: $\sum_{i=1}^N T_i = 400$

$N = 12$

8.4.4 HV oil switch and switch fuse units

#	Condition Criteria		Weight (W _i)	Condition Rating	Factors (S _i)	Maximum Score (T _i)
1	HV switchgear partial discharge level		4	A, B, C, D, E	4, 3, 2, 1, 0	16
2	HV cable termination partial discharge level		2	A, B, C, D, E	4, 3, 2, 1, 0	8
3	HV cable termination		2	A, B, C, D, E	4, 3, 2, 1, 0	8
4	HV switchgear internal condition	Fuse components	12	A, B, C, D, E	4, 3, 2, 1, 0	64
		Switch components	4			
5	HV switchgear external condition		4	A, B, C, D, E	4, 3, 2, 1, 0	16
6	Overall LV distribution board condition		6	A, B, C, D, E	4, 3, 2, 1, 0	24
7	LV termination and hotspot		3	A, B, C, D, E	4, 3, 2, 1, 0	12
8	Enclosure, base or building and signage		5	A, B, C, D, E	4, 3, 2, 1, 0	20
9	Transformer condition		8	A, B, C, D, E	4, 3, 2, 1, 0	32
10	Transformer loading		27	A, B, C, D, E	4, 3, 2, 1, 0	108
11	Earthing condition		3	A, B, C, D, E	4, 3, 2, 1, 0	12
12	Inherent safety issues		20	A, B, C, D, E	4, 3, 2, 1, 0	80
			100			400

All 12 scores are entered into the formula below to convert to a rating out of 100:

$$HI = \left(\frac{\sum_{i=1}^N (S_i \times W_i)}{\sum_{i=1}^N T_i} \right) \times 100$$

where: $\sum_{i=1}^N T_i = 400$

$N = 12$

8.5 Health index results and condition assessment

An overall health index for a Distribution Substation can be derived from the above methodology. The overall health index is then compared to the Health index scale in Section 2.3 to determine the overall condition of the asset. The resultant overall condition will dictate the strategic asset management requirements of the asset.