32 Testing a metal-enclosed bus system

Contents

Testing a bus system is generally along similar lines to those for a switchgear assembly, discussed in Chapter 14. In this chapter we discuss additional tests that are specifically for a metal-enclosed bus system.

32.1 Philosophy of quality systems

This has been covered in Section 11.1.

32.1.1 Quality assurance

To fulfil the quality requirements, the material inputs going into the making of a bus system must be properly checked as soon as they are received,

- Aluminium or copper sections and sheets (for their cross-sectional areas, thickness of sheet, surface finish, bending properties and conductivity etc.)
- Hardware (for proper size, quality of threads and tensile strength etc.)
- Insulators and supports (for sizes and quality of material)
- Other materials, components or equipment used for making, inter-connections and bondings of such systems
- Cooling systems (in large current rating systems).

All these items must be properly checked and recorded according to the manufacturer's internal quality checks and formats before they are used in the manufacture of a bus system. This will eliminate any inconsistency in a material or component at the initial stage. Similarly, stage inspections are necessary during the course of manufacturing to ensure quality at every stage and to eliminate incorrect construction and assembly or poor workmanship. And thus assure a product of desired specifications and quality.

32.1.2 Purpose of testing

The purpose of testing of a bus system is to ensure its compliance with design parameters, material inputs and manufacturing consistency.

32.2 Recommended tests

The following are the recommended tests that may be carried out on a completed bus duct, as in IEC 62271-200, ANSI C-37/20C, IEC 60694 and BS 159 for both LV and HV systems.

32.2.1 Type tests

Type tests are conducted on the first assembly (bus system) of each voltage, current rating and fault level to demonstrate compliance with the electrical and constructional design parameters. The tests provide a standard reference for any subsequent assembly with similar ratings and constructional details. The following tests are conducted:

1 Verification of insulation resistance or measurement of the leakage current, both before and after the dielectric test (no longer a prescribed test but can be retained as an in-house screening test)
2 Verification of dielectric properties:
   (i) Power frequency voltage withstand or HV test
   (ii) Impulse voltage withstand test for all LV and HV system voltages
3 Verification of temperature rise limits (for rated continuous current capacity)
4 Verification of short-circuit strength:
   (a) For straight lengths and tap-offs
   (b) For the tap-offs in a power-generating station, connecting a UAT through the main bus section between the generator and the generator transformer.
   (c) For the ground bus in isolated phase bus (IPB) systems
5 Verification of momentary peak or dynamic current
6 Verification of protective circuit
7 Verification of clearance and creepage distances
8 Verification of degree of protection:
   (a) Enclosure test
   (b) Watertightness test – for all outdoor parts of any bus system (but for outdoor as well as indoor parts for isolated phase bus (IPB) systems)
   (c) Air leakage test, for isolated phase bus (IPB) systems
9 Measurement of resistance and reactance
10 Endurance of trunking system with trolley type tap-off facilities

As safety measures new tests added in the latest Standards,

11 Verification of structural strength
12 Verification of crushing resistance (force)
13 Verification of resistance of the insulating materials to abnormal heat
14 Verification of resistance to flame propagation
15 Verification of fire barriers in building penetration
16 Electromagnetic compatibility (EMC) or immunity test and electromagnetic interferences (EMI) or emission test.
17 Additional test on an IPB enclosure to satisfy electromagnetic interference (EMI) requirements (Section 23.18) for radio influence as in *NEMA-107. The maximum radio influence voltage (RIV) should not exceed 100 μV at 1000 kHz. For test equipment and test procedure refer to the Standard.

32.2.2 Routine tests

Routine tests are conducted on each completed bus system, irrespective of voltage, current, fault level and constructional details and whether or not it has undergone type tests. The following will form routine tests:

1 To check for any human error
2 General inspection of the bus assembly
3 Inspection of electrical wiring if there is any (such as for space heaters, cold or hot air blowing, enclosure pressurizing or any other protective circuit)

* NEMA – National Environmental Management Act (South Africa).

4 Verification of insulation resistance or measurement of the leakage current, both before and after the dielectric HV test. This test may be conducted only on partially type tested (PTT) bus systems
5 Verification of dielectric properties – similar to item 2 under type tests
6 Additional tests for an IPB system are:
   (a) Partial discharge test: On all cast resin components such as instrument transformers, bushings and insulators to ensure that the insulation is free from defects and voids.
   (b) Checking of welded joints: as in GDCD-198, norms for aluminium welding (CEGB, UK)*: All shop-welded joints will be subjected to dye penetration examination and 10% of butt-welded joints, including joints on flexibles, enclosures and conductors, will be subjected to radiographic (X-ray) examination.

32.2.3 Seismic disturbances

In Section 14.6 we have provided a brief account of such disturbances as well as the recommended tests and procedures to verify the suitability of critical enclosures and bus systems for locations that are earthquake-prone. For this the user is required to provide the manufacturer with the intensity of seismic effects at site of the installation in the form of response spectra (RS). (See Section 14.6.)

32.2.4 Field tests

These are to be conducted after the installation and before energizing the bus assembly at site:

1 Checking for any human error
2 Visual inspection of the bus assembly
3 Inspection of electrical wiring if there is any (such as for space heaters, cold or hot air blowing or enclosure pressurizing or any other protective circuit)
4 Verification of insulation resistance or measurement of the leakage current, both before and after the dielectric HV test, if the HV test is to be carried out.
5 Verification of dielectric properties – limited to power frequency voltage withstand or HV test (usually not recommended)
6 Watertightness and air leakage test for isolated phase bus systems.

32.3 Procedure for type tests

Below we briefly outline the procedure for conducting type tests at the manufacturer's works.

32.3.1 Verification of insulation resistance or measurement of the leakage current

The procedure and test requirements will remain the same as that discussed in Section 14.3.2, for metal-enclosed switchgear and controlgear assemblies.

*CEGB – Central Electricity Generating Board, U.K.

32.3.2 Verification of dielectric properties

Power frequency voltage withstand or HV test

The test voltage may be applied for one minute as shown in Tables 32.1(a) or (b) for series I and Table 32.2 for series II voltage systems. Any disruptive discharge or insulation breakdown during the application of high voltage will be considered to be dielectric failure.

The tap-offs in a power-generating station connecting a UAT through the main bus section between the generator and the generator transformer which are under the cumulative influence of two separate power sources, must be subjected to a higher withstand voltage as prescribed by IS 8084 and indicated in column 4, Table 32.1(a).

32.3.3 Impulse voltage withstand test

(i) **For LV system**
IEC 60439-1 has now stipulated impulse voltage withstand test for LV power as well as control and auxiliary circuits. Test procedures noted in Section 14.3.3 and Tables 14.3 (a and b) are applicable for bus systems also that are tested as per IEC Standards.
(ii) **For HV systems**

The procedure for testing will be the same as that discussed for switchgear assemblies in Section 14.3.4. The impulse test voltage is applied as in Table 32.1(a) for series I and Table 32.2, for series II voltage systems with a full wave standard lightning impulse of 1.2/50 μs (Section 17.6.1). There should be no disruptive discharge or insulation breakdown.

32.3.4 Verification of temperature rise limits (or rated continuous current capacity)

(Recommended for systems having a current rating of more than 400 A)

This will be carried out under similar parameters of room condition and the type of test voltage wave to those for a switchgear assembly (Section 14.3.5). The current in each phase should be within 2% of the specified test value (rated current).

For LV bus systems: The length of the test piece will be a minimum 6 m formed of two pieces of straight lengths as in IEC 60439-2 with at least two joints. The joints must be both in the conductor and in the enclosure in each phase. If the total length of the bus section is less than specified, the entire length of the bus system in the fully assembled form will then be tested.

For HV bus systems: The entire length of the bus system manufactured for a particular installation in the fully assembled form will be tested. Each end of the bus enclosure will be properly sealed to eliminate any heat leakage.

The bus sample is located 600 mm above floor level. The ambient temperature should be within 10–40°C as measured by the average value of at least four thermometers, two placed on each side of the enclosure on the centre line, at least 300 mm from it, and 600 mm from the ends. The bus sample must be a three-phase unit as well as the test equipment for a three-phase system to account for the proximity effect. This effect will not be reflected if a three-

Table 32.1(a) For series I voltage systems: Insulation levels, power frequency and impulse withstand voltages for metal-enclosed bus systems

Nominal system voltage V_r	*Rated max. system voltage* V_m	*One-minute power frequency voltage withstand at a frequency between 45 and 65 Hz for LV and 25 and 100 Hz for HV systems*		*Standard lightning impulse, 1.2/50 μs voltage withstand (phase to ground)*
1	*2*	*3*	*4*	*5*
		For a switchgear assembly and a bus system (phase to ground)	For the tap-offs in a power-generating station, connecting a UAT through the main bus section between the generator and the generator transformer (Figure 31.1) (phase to ground)	(a) We consider here only List II, which is more prevalent. For List I, refer to Table 13.2. (b) For impulse voltage withstand across the contact gaps of an interrupting device refer to IEC 60694
*kV (r.m.s.)	kV (r.m.s.)	kV (r.m.s.)	kV (r.m.s.)	kV (peak)
0.415	0.44	2.5	–	–
0.6	0.66	2.5	–	–
3.3	3.6	10	21	40
6.6	7.2	20	27	60
11	12	28	35	75
15	17.5	38	–	95
22	24	50	55	125
33	36	70	75	170

Based on IEC 60439-2 LV, IEC 60694 for HV and IS 8084 for tap-offs.
*For new voltage systems as per IEC 60038 see Introduction.

Notes

1 Busbars above 36 kV are presently not possible in air insulation, hence not covered above. At higher voltages the power transfer is usually achieved through XLPE cables, gas insulated busbar systems (GIBs) or partially isolated phase bus systems (PIPBs) as discussed in Section 28.2.6.

2 Field tests (power frequency voltage withstand) after erection at site, if required, may be conducted at 85% of the values indicated above in LV and 80% in HV systems.

Table 32.1(b) For series I voltage systems: Power frequency voltage withstand levels for metal-enclosed bus systems

Nominal system voltage V_r	*Rated maximum system voltage* V_m	*One-minute power frequency withstand voltage at any frequency between 25 and 100 Hz (phase to ground)*	*Field test after erection at site (phase to ground)*	
			A.C. test (for one minute at any frequency between 25 and 100 Hz)	*D.C test*[a]
1	*2*	*3*	*4*	*5*
*kV (r.m.s.)	kV (r.m.s.)	kV (r.m.s.)	kV (r.m.s.)	kV
0.415	0.44	2.0	2.0	3.0
0.6	0.66	2.0	2.0	3.0
3.3	3.6	9.5	8.6	5.0
6.6	7.2	17.0	15.2	10.5
11	12	27.0	24.0	18.0
15	17.5	36.0	32.0	25.0
22	24	52.0	46.0	37.5
33	36	76.0	68.0	60.0
			$(2V_r + 2)$ for HV systems	

Based on BS 159
* For new voltage systems as per IEC 60038 see Introduction.
[a] In the absence of a.c. test voltage at site, a d.c. test can also be conducted, the duration of which will be 15 minutes.

Notes

1 Busbars above 36 kV are presently not possible in air insulation, hence not covered above. At higher voltages the power transfer is usually achieved through XLPE cables, gas insulated busbar systems (GIBs) or partially isolated phase bus systems (PIPBs) as discussed in Section 28.2.6.

Table 32.2 For series II voltage systems: Insulation levels, power frequency and impulse withstand voltages for metal-enclosed bus systems

Nominal system voltage V_r	*Rated maximum system voltage* V_m	*One-minute power frequency voltage withstand at a frequency not less than the rated, 60 Hz (phase to ground)*		*Standard lightning impulse (1.2/50 μs) voltage withstand (phase to ground)*	*One-minute d.c. voltage withstand (phase to ground)*
1	*2*	*3*		*4*	*5*
*kV (r.m.s.)	kV (r.m.s.)	kV (r.m.s.)		kV (peak)	kV
		Dry (1 minute)	Dew (10 seconds)		
0.6	0.635	2.2	–	–	3.1
4.16	4.76	19.0	15.0	60	27.0
13.8	15.00	36.0	24	95	50.0
14.4	15.50	50.0	30	110	70.0
23.0	25.80	60.0	40	125	
34.5	38.00	80.0	70	150	1
69.0	72.50	160.0	140	350	
For application of isolated phase bus to generator, the following voltage ratings will apply.					
14.4 to 24[2]	–	50.0	50.0	110	70

Based on ANSI C-37/20C
*For new voltage systems as per IEC60038 see Introduction.

Notes

1 (a) The procedure for a d.c. test is the same as for an a.c. one. Due to variable voltage distribution encountered when conducting d.c. tests, the ANSI Standard recommends that the matter be referred to the manufacturer for system voltages 25.8 kV and above.
(b) For a power frequency voltage withstand test a d.c. test is generally not recommended on a.c. equipment, unless only d.c., test voltage is available at the place of testing. The d.c. test values, as above, are therefore for such eventualities only and are equivalent to power frequency a.c. voltage withstand test values.

2 These ratings are applicable to generators which are directly connected to the transformers without intermediate breakers and where adequate surge protection is provided. The requirements are in line with or in excess of the required withstand values of the generator.

3 Field tests after erection at site, if required, may be conducted at 75% of the values indicated above. Also refer to field tests (Table 14.8).

phase system is tested on a single-phase one. Similarly, a single-phase unit and single-phase test equipment should be used for a single-phase system (such as from the neutral side of the generator up to the neutral grounding transformer).

The test will be conducted at the rated current until a near-stable condition is reached and three successive readings at not less than one-hour intervals for an LV system and 30 minutes for an HV system do not show a maximum variation of more than 1°C. To shorten the test, the current may be increased during the initial period. The test may be conducted at a reduced voltage, as the emphasis is on heating due to current. For a successful test, the hottest spot temperature should not exceed the values in Table 32.3.

Effect of solar radiation

The effect of solar radiation must be considered in the outdoor part of a bus enclosure exposed to solar heat. This effect may be observed for all LV and HV bus enclosures, as all are influenced equally by such radiations, particularly IPB enclosures, as discussed in Section 31.4.4.

32.3.5 Verification of short-circuit strength

For straight lengths and tap-offs

The test procedure is generally the same as that discussed for switchgear assemblies (Section 14.3.6). It is carried out on a similar section to that used for the temperature rise test. Now the power supply can be single-phase or three-phase. If three-phase, the bus conductors are shorted at one end while the other ends are connected to the power source. If a single-phase power is used, the circuit should be so arranged that the current flows through the two adjacent phase conductors. The force due to a three-phase fault would be approximately 86.6% of this.

Therefore, for single-phase tests, the current would be $\sqrt{86.6}$ or approximately 93% of that prescribed in Table 13.10. The test results should show no sign of undue deformation. Slight deformation may be acceptable, provided that the clearance and the creepage distances are complied with and the degree of protection is not impaired. The insulators and mounting supports, however, must show no signs of deterioration.

For the tap-offs in a power-generating station, connecting a UAT through the main bus section between the generator and the generator transformer

As discussed in Section 13.4.1(5), these sections are under the cumulative influence of two power sources and may

Table 32.3 Hottest spot temperature rise limits for metal-enclosed bus systems

Component	*Limit of hottest spot temperature rise over an ambient of 40°C – in °C*	
	As in IEEE-C37.20 (our Table 28.2)	*As in IEC-60439-2 (our Table 14.5)*
1 Bus conductors		
(i) Bolted plain joints	30[a]	50
(ii) Bolted joints silver plated	65[b]	65[b]
(iii) Aluminium welded joints	65[b]	65[b]
2 Enclosure and support structures		
(i) Easily accessible	40	30[c]
(ii) Not accessible	70	50
3 Bus conductors in contact with insulating materials	50[d]	50[d]
	(or higher, as limited by insulation class, Table 14.6[e])	
4 Terminations at generator or transformer end	Same as for bus conductors noted above	
5 Termination at cables with plain connections	30	50[d]
6 Termination at cables with silver surfaced or equivalent connections	45	50[d]

Notes
[a] A very low temperature rise at the main joints is a measure to prevent the joints from overheating due to corrosion.
[b] Unless limited by insulation (e.g. for a class *Y* insulation, Table 14.6 this will be 50).
[c] If the enclosure and covers not to be touched during normal operation the temperature rise limit can be considered to be 40°C.
[d] For the class of insulation, not supposed to exceed a total temperature of 90°C during normal operation.
[e] Subject to the insulation class of the cables.

be tested for a higher short-time rating, which would be the algebraic sum of the two fault levels, one of the generator and the other of the generator transformer as noted in Table 13.8. Also refer to Figures 31.1 and 13.18 for more clarity.

For the ground bus

In an isolated phase bus (IPB) system, the ground bus must be capable of carrying the same short-time current as for the main conductors for 2 seconds, for both discontinuous and continuous grounding systems.

32.3.6 Verification of momentary peak or dynamic current

The test method and test results will generally be the same as for a switchgear assembly, discussed in Section 14.3.7.

For the tap-offs, connecting a UAT through the main bus section between the generator and the generator transformer, however, as discussed above, the momentary peak current will depend upon the short-time rating of such tap-offs. The likely ratings are noted in Table 13.8.

32.3.7 Verification of protective circuits

All the protective circuits will be checked for continuity and operational requirements.

32.3.8 Verification of clearance and creepage distances

The clearance will be verified as in Table 28.4 while for creepages Table 28.5 may be followed as per BS 159.

IEC 60439-1 has corroborated this with the dielectric impulse and power frequency voltage withstand levels (Section 14.3.9).

32.3.9 Verification of degree of protection

Enclosure test

The types of protection and their degrees are generally the same as those defined for motors in Section 1.15, Tables 1.10 and 1.11. The test requirements and methods of conducting such tests are also almost the same as for motors, discussed in Section 11.5.3.

Watertightness test

This test is applicable to all outdoor parts of any bus system and on both indoor and outdoor parts of an isolated phase bus (IPB) system. Each enclosure to be tested (such as the enclosure of one phase in an isolated phase bus system) should be complete in all respects with all its fittings and mounts in place. The length of the test piece must be the same as that considered for the temperature rise test (Section 32.3.4).

As in ANSI C-37/20C and IS 8084 water under a head of 11 m through a hose of 25 mm diameter held at 3 m from the enclosure will be impinged at an angle of at least 45° from the horizontal on all sides and the entire length of the enclosure for a period of 5 minutes. No water should enter the enclosure.

Air leakage test

This test is prescribed by ANSI C-37/20C for isolated phase bus systems after they have been assembled at site. The test is conducted by filling the enclosure with air up to a pressure of 15 cm of water (1500 N/m^2). After the air supply is shut off, the pressure must not drop to less than 7.5 cm of water in 15 seconds. All breathers and drain holes must be sealed before the test.

32.3.10 Measurement of resistance and reactance

The mean values of the resistance and reactance per phase are determined on at least two trunking units, including the joints, from a total length of 6 m. If the total length of the bus section is less than this, the values may be determined on the entire length of the bus system.

If V_{d_1}, V_{d_1} and V_{d_3} are the voltage drops in the three phases, then the average voltage drop

$$V_d = \frac{V_{d_1} + V_{d_2} + V_{d_3}}{3} \text{ volts per phase and}$$

average current $I_{\text{ph}} = \dfrac{I_{\text{R}} + I_{\text{Y}} + I_{\text{B}}}{3}$ Amps per phase

where I_{R}, I_{Y}, I_{B} are the phase currents in the three phases

$$\therefore \text{ Impedance, } Z = \frac{V_{\text{d}}}{I_{\text{ph}} \cdot L}\ \Omega \text{ per phase/m}$$

and $$R = \frac{P}{3 I_{\text{ph}}^2 \cdot L}\ \Omega \text{ per phase/m}$$

and $$X = \sqrt{Z^2 - R^2}\ \Omega \text{ per phase/m}$$

where

P = total power input in watts

L = length of the bus section on which the voltage drop has been measured in metres

32.3.11 Endurance of trunking system with trolley-type tap-off facilities

This test is generally applicable to an LV overhead busbar system or rising mains which have sliding-type plug-in boxes for outgoing terminations (Figures 28.3 and 28.4(a)). The sliding contacts carrying their rated current at rated voltage must be able to operate at least 10 000 times to and fro with the trunking conductors. A successful test should reveal no mechanical or electrical defect such as pitting, burning or welding of contacts.

32.3.12 Safety measures–new tests by IEC

For test procedures under serial no. 11-15 one may refer to IEC 60439-2.

32.3.13 EMC / EMI tests

This test is required when EMC/EMI and radio frequency interferences may adversely influence the sensitive electronic equipment and devices like diagnostic and monitoring devices or communication network operating in the vicinity (Section 23.18). IEC 60439-2 has prescribed for power frequency magnetic field test. For procedure one may refer to the said Standard.

32.4 Routine tests

The tests against step numbers 1, 2 and 3 are of a general nature and no test procedure is prescribed for these. The remainder have already been covered under type tests. The procedure for tests and the requirements of the test results will remain the same as for the type tests.

32.5 Field tests

1,2,3 These tests are of general nature.

4 Verification of insulation resistance or measurement of leakage current: The procedure remains the same as described in Section 14.5(4).

5 Verification of dielectric properties: No field test as regards the power frequency voltage withstand or HV test is normally prescribed on a bus system, which has already been tested at the manufacturer's works.

Repeated application of high voltage may deteriorate the insulating properties of the insulation system and its life unless modification has been carried out at site or where the insulation of joints between the busbars can be completed only after erection at site. In such cases, if this test becomes essential it can be conducted,

- At 85% of the test values in Table 32.1(a) for LV systems, applied for 1 minute.
- Or at 80% of the test values for MV systems for 1 minute.
- Or a d.c. voltage as in Table 32.1(b) applied for 15 minutes as in IS 8084.
- Or at 75% of the test values in Table 32.2, for series II voltage systems according to ANSI C-37/20C.

Note

If it is not possible to carry out the test at 75%, 80% or 85% of the test values, as prescribed above or for some reasons the test duration may have to be increased by more than one minute, then it is permissible for the test voltage to be further reduced to suit the site and instead, the test duration increased. The reduced test voltages for longer test durations are provided in Table 14.8.

6 Water tightness and air leakage test for isolated phase bus systems: The procedure described in Section 32.3.9 may be followed.

Relevant Standards

IEC	*Title*	*IS*	*BS*	
60439-2/2000	Low voltage switchgear and controlgear assemblies. Particular requirements for busbar trunking systems.	8623-2/1998	BS EN 60439-2/2000	–
60694/2001	Common specifications for high voltage switchgear and controlgear Standards.	12729/2000	BS EN 60694/1997	–
62271-200/2003	A.C. metal enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV.	12729/2000	BS EN 60298/1996	–
–	Specification for hard anodic coatings on aluminium and aluminium alloys.	6057/2001	–	–
–	Interconnecting busbars for a.c. voltage above 1 kV up to and including 36 kV.	8084/2002	BS 159/1992	–

Relevant US Standards ANSI/NEMA and IEEE

ANSI/IEEE-C37.23/1992	Metal enclosed bus and Guide for calculating losses in isolated phase bus.
ANSI/IEEE-C37.24/1986	Guide for evaluating the effect of solar radiation on outdoor metal enclosed switchgear.
NEMA*-107/1993	Method of measurement of Radio Influence Voltage (RIV) of HV apparatus.

** NEMA – National Environmental Management Act (South Africa)*

Notes

1 In the table of relevant Standards while the latest editions of the Standards are provided, it is possible that revised editions have become available or some of them are even withdrawn. With the advances in technology and/or its application, the upgrading of Standards is a continuous process by different Standards organizations. It is therefore advisable that for more authentic references, one may consult the relevant organizations for the latest version of a Standard.

2 Some of the BS or IS Standards mentioned against IEC may not be identical.

3 The year noted against each Standard may also refer to the year it was last reaffirmed and not necessarily the year of publication.