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(Revision of ANSI/IEEE C37.23-1969)

American National Standard

guide for metal-enclosed bus and calculating losses in isolated-phase bus

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Change the title to: **IEEE Standard for Metal-Enclosed Bus and Calculating Losses in Isolated-Phase Bus,** each time it appears within the document.

The Institute of Electrical and Electronics Engineers, Inc
345 East 47th Street, New York, NY 10017, USA

ANSI/IEEE C37.23-1987
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An American National Standard

IEEE Guide for Metal-Enclosed Bus and Calculating Losses in Isolated-Phase Bus

Sponsor

Switchgear Committee of the
IEEE Power Engineering Society

Cosecretariats

Institute of Electrical and Electronics Engineers, Inc
National Electrical Manufacturers Association

Approved December 8, 1983

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Foreword

(This Foreword is not a part of ANSI/IEEE C37.23-1987, IEEE Guide for Metal-Enclosed Bus and Calculating Losses in Isolated-Phase Bus.)

This revision of ANSI/IEEE C37.23-1969, IEEE Guide for Calculating Losses in Isolated-Phase Bus, includes updated information from ANSI/IEEE C37.20-1969, Switchgear Assemblies Including Metal-Enclosed Bus, and additional data concerning flexible bus (cable).

The major work in preparing this standard was accomplished by a working group of the National Electrical Manufacturers Association (NEMA) Power Switchgear Assemblies Technical Committee.

The initial work on Section 8 of this standard, Calculating Losses in Isolated-Phase Bus, was accomplished over a period of years by a working group of the IEEE Switchgear Assemblies Subcommittee of the IEEE Power Engineering Society and published as ANSI/IEEE C37.23-1969. Section 8 reflects changes made since the 1969 edition. These changes are those that were issued to 1970 as corrections and clarifications, and the working group included Fig 5: Curves For Skin Effect of Isolated Round Rod and Tubular Conductors.

The Standards Committee on Power Switchgear, C37, which reviewed and approved this standard, had the following personnel at the time of approval:

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An American National Standard

IEEE Guide for Metal-Enclosed Bus and Calculating Losses in Isolated-Phase Bus

1. Scope

This standard covers assemblies of metal-enclosed conductors along with associated interconnections, enclosures, and supporting structures. When switches and disconnecting links are included, they shall conform to this standard.

Basically, this standard is concerned with performance characteristics of enclosed, rather than open, conductor assemblies. It does not pertain to busyways or bus assemblies for distribution of electric power less than 600 V consisting of enclosed sectionalized prefabricated bus bars or associated structures and fittings, such as feeder busways (indoor or outdoor) and plug-in busways (indoor only). It does not include enclosed bus assemblies utilized at voltages in excess of 38.0 kV (see ANSI/UL 857-1981 [9]).[1]

2. Definitions

2.1 The definitions of terms contained in this document, or in other standards referred to in this document, are not intended to embrace all legitimate meanings of the terms. They are applicable only to the subject treated in this standard.

2.1.1 Metal-Enclosed Bus. An assembly of conductors with associated connections, joints, and insulating supports within a grounded metal enclosure. The conductors may be either rigid or flexible.

2.1.1.1 Types of Metal-Enclosed Bus Assemblies. (See Fig 1.) In general, three basic types of construction are used: nonsegregated-phase, segregated-phase, and isolated-phase.

(1) *nonsegregated-phase bus.* One in which all phase conductors are in a common metal enclosure without barriers between the phases.

When associated with metal-clad switchgear, the primary bus and connections shall be covered with insulating material equivalent to the switchgear insulation system.

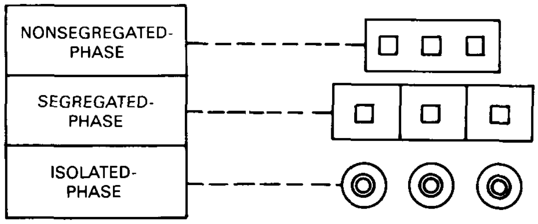
(2) *segregated-phase bus.* One in which all phase conductors are in a common metal enclosure but are segregated by metal barriers between phases.

(3) *isolated-phase bus.* One in which each phase conductor is enclosed by an individual metal housing separated from adjacent conductor housing by an air space.

The bus may be self-cooled or may be forced-cooled by means of circulating a gas or liquid.

2.1.2 Metal-Enclosed (As Applied to Metal-Enclosed Bus). Surrounded by a metal case or housing, with provisions for grounding.

Fig 1
Types of Bus Assemblies



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[1] The numbers in brackets correspond to those of the references listed in Section 3; when preceded by B, they correspond to the bibliography in Section 10.

2.1.3 Enclosure. A surrounding case or housing used to protect the contained conductor and prevent personnel from accidentally contacting live parts.

2.1.3.1 Ventilated Enclosure. An enclosure so constructed as to provide for the circulation of external air through the enclosure to remove heat, fumes, or vapors.

2.1.3.2 Nonventilated Enclosure. An enclosure so constructed as to provide no intentional circulation of external air through the enclosure.

2.1.3.4 Dripproof Enclosure. An enclosure usually for indoor application, so constructed or protected that falling drops of liquid or solid particles that strike the enclosure at any angle not greater than 15 degrees from the vertical shall not interfere with the successful operation of the metal-enclosed bus.

2.1.4 Ambient Air Temperature. The temperature of the surrounding air that comes in contact with equipment.

NOTE: Ambient air temperature, as applied to enclosed bus asemblies, is the average temperature of the surrounding air that comes in contact with the enclosure.

2.1.5 Design Tests. Those tests made to determine the adequacy of a particular type, style, or model of metal-enclosed bus or its component parts to meet its assigned ratings and to operate satisfactorily under normal service conditions or under special conditions, if specified.

NOTE: Design tests are made only on representative apparatus to substantiate the ratings assigned to all other apparatus of basically the same design. These tests are not intended to be used as a part of normal production. The applicable portion of these design tests may also be used to evaluate modifications of a previous design and to assure that performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate.

2.1.6 Field Tests. Tests made after the assembly has been installed at its place of utilization.

2.1.7 Termination (Terminal Chamber). A metal enclosure that contains all necessary mechanical and electrical items to complete the connections to other equipment.

2.1.8 Rated Short-Time Current (Rated for Isolated-Phase Bus). The maximum symmetrical current that the bus must carry without exceeding a specified total temperature in a given time interval.

2.1.9 Rated Short-Circuit Withstand Current. The rated short-circuit withstand current of metal-enclosed bus is the maximum rms total current that it can carry momentarily without electrical, thermal, or mechanical damage or permanent deformation. The current shall be the rms value, including the direct-current (dc) component, at the major peak of the maximum cycle as determined from the envelope of the current wave during a given test time interval.

2.1.10 Dew Withstand Voltage Test. A test to determine the ability of the insulating system to withstand specified overvoltages for a specified time without flashover or puncture while completely covered with dew.

2.1.11 Support Components. The components that add additional strength and rigidity or both to the bus enclosure and are basic subassemblies of the enclosure.

2.2 The following terms are defined in ANSI/IEEE C37.100-1981 [5], and the user is referred to the definitions given therein. For additional definitions, see ANSI/IEEE Std 100-1984 [7].

barrier
basic impulse insulation level (BIL)
bus
bus structure
conducting mechanical joint
conformance tests
continuous-current tests
control bus
dielectric withstand voltage tests
direct-current component (of a total current)
fault bus
ground bus
ground contact
impulse withstand voltage
live parts
production tests
silver-surfaced or equivalent
symmetrical component (of a total current) (ac component)
terminal
total (asymmetrical) current
withstand voltage

3. References

The following publications shall be used in conjunction with this standard:

[1] ANSI C29.1-1982, American National Standard Test Methods for Electrical Power Insulators.[2]

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[2] ANSI publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[2] ANSI Z55.1-1967 (R 1973), American National Standard Gray Finishes for Industrial Apparatus and Equipment.

[3] ANSI/IEEE C37.20.2-1987, IEEE Standard for Metal-Clad and Station-Type Cubicle Switchgear.

[4] ANSI/IEEE C37.24-1971 (R 1984), IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Clad Switchgear.

[5] ANSI/IEEE C37.100-1981, IEEE Standard Definitions for Power Switchgear.

[6] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.[3]

[7] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.

[8] ANSI/UL 857-1981, Safety Standard for Busways and Associated Fittings.[4]

[9] ASTM D1535-80, Method for Specifying Color by the Munsell System.[5]

[10] Federal Specification No A-A-1492, Tape, Gummed, Mending and Reinforcing (Paper and Cloth), General Services Administration.[6]

4. Service Conditions

4.1 Usual Temperature and Altitude Service Conditions. Metal-enclosed bus assemblies conforming to this standard shall be suitable for operation at the nameplate rating provided that

(1) Ambient air temperature is within the limits of minus 30 °C and plus 40 °C.

(2) The altitude does not exceed the value for which the voltage and current correction factors (shown in 4.2.1) are equal to 1.00.

(3) The effect of solar radiation can be neglected.

4.2 Unusual Temperature and Altitude Service Conditions. The application of metal-enclosed bus assemblies at higher or lower ambient temperatures or at higher altitudes than specified in 4.1 shall be considered as special.

Standard assemblies may be applied at higher ambient temperatures or at higher altitudes than specified in 4.1 but performance may be affected and special consideration should be given to these applications, some of which are stated below.

4.2.1 Altitudes. Metal-enclosed bus that depends on air for an insulating and cooling medium will have a higher temperature rise and a lower dielectric strength when operated at altitudes above 3300 ft (1000 m) or 6600 ft (2000 m), as shown below.

For application at higher altitudes, the rated 1 min power frequency withstand voltage, the impulse withstand voltage, and continuous current rating of the assemblies shall be multiplied by the following correction factors to obtain the modified ratings:

For bus with rigid conductors, in air

	Correction Factors	
Altitude in Feet	Voltage	Current
3 300 (1000 m)*	1.00	1.00
5 000 (1500 m)	0.95	0.99
10 000 (3000 m)	0.80	0.96

For bus with insulated flexible conductors

	Correction Factors	
Altitude in Feet	Voltage	Current
6 600 (2000 m)*	1.00	1.00
8 500 (2600 m)	0.95	0.99
13 000 (3900 m)	0.80	0.96

NOTES: (1) Intermediate values may be obtained by interpolation.

(2) Correction factors for higher voltages are under study.

*And below

4.3 Other Conditions That May Affect Design and Application. Where other conditions exist, they should be brought to the attention of those responsible for the design and application of the metal-enclosed bus. Among such conditions are

(1) Exposure to damaging fumes or vapors, steam, salt air, oil vapors, hot or humid climate, excessive dust, abrasive dust, dripping water, falling dirt, explosive mixtures of dust or gases, or extreme high or low temperature.

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[3] ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Service Center, The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

[4] ANSI/UL publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018 or from Publication Stock, Underwriters Laboratories, Inc, 333 Pfingsten Rd, Northbrook, IL 60020.

[5] ASTM publications can be obtained from Sales Service, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

[6] Federal Specifications can be obtained from the Standardization Division, Federal Supply Service, General Services Administration, Washington, DC 20406.

(2) Unusual installation requirements, space or ventilation limitations, special duty, frequency or other operating requirements, difficulty of maintenance, building construction, abnormal vibration, shocks, or seismic disturbances.

NOTE: The ability of a bus to withstand seismic disturbances, vibration, or shock is generally dependent on the building structure and relative motion between support points, and these considerations should be evaluated.

(3) High wind, ice loads, and snow loads.

(4) Installations accessible to the general public.

(5) Refer to ANSI/IEEE C37.24-1971 [4] for solar radiation effects.

(6) Temperature limits of connected equipment. (See Table 1.)

(7) Installations where the rated short-circuit withstand or rated short-time current ratings or both, specified in Tables 2A and 2B, may be exceeded.

5. Ratings

5.1 General. The ratings of metal-enclosed bus are designations of operating limits under specified conditions of ambient temperature, temperature rise, etc.

Metal-enclosed bus shall have the following ratings shown on a nameplate:

(1) Maximum voltage
(2) Rated continuous current
(3) Insulation (BIL) level
(4) Frequency
(5) Rated short-time current (where applicable)
(6) Rated short-circuit withstand current
(7) Temperature rise of conductor and enclosure

For force-cooled bus, both the force-cooled and the self-cooled continuous current rating for the same rated temperature rise shall be given.

5.2 Voltages, Current, Temperature Limits, and Insulation (BIL) Levels.

5.2.1 Voltages. Maximum operating voltages and corresponding insulation levels, for ac metal-enclosed bus for general applications are listed in Tables 3A, 3B, and 3C. (For dc ratings, refer to Table 3D.)

5.2.2 Rated Continuous Current. The continuous self-cooled current ratings for metal-enclosed bus are listed in Tables 4A and 4B.

Table 1
Metal-Enclosed Bus
Limitations of Hottest-Spot Temperature Rise
Over Outside Average Ambient

Part of Metal-Enclosed Bus	Limit of Hottest-Spot Temperature Rise (°C)	Limit of Hottest-Spot Total Temperature (°C)
Bus conductor		
Unplated bus joints	30	70
Silver-surfaced (or equivalent) Bolted joints	65 (unless limited by insulation)	105
Welded joints	65 (unless limited by insulation)	105
Enclosure and support structure*		
(1) For bus conductor rated 65 °C rise	40	80
(2) For bus conductor rated 30 °C rise	20	60
Insulation	As limited by material classification (see Table 5)	—
Terminations Machine, transformer, etc	Same as conductor and enclosure of bus except when modified by connected equipment bushing. In such cases, maximum temperature rise is to be specified by bus purchaser.	
Terminations (cable)		
Unplated bolted joints	30	70
Silver-surfaced (or equivalent)	45	85

*Where enclosure and support structure are inaccessible, 70 °C rise and 110 °C total temperature are permissible.

5.2.3 Short-Circuit Withstand Current. The short-circuit withstand current ratings of metal-enclosed bus are listed in Tables 2A and 2B.

5.2.4 Temperature Limitations.

5.2.4.1 Limitations of Hottest-Spot Temperature Rise Over Outside Average Ambient. (See Tables 1 and 5.)

5.2.4.2 Temperature Limitations for Ambient Air. See service conditions in 4.1 and 4.2.

6. Tests

6.1 General. This section establishes physical and electrical conditions for tests and methods of determining temperature and test values. All apparatus and devices applicable for testing of the metal-enclosed bus shall be mounted in their normal locations during tests.

Tests may be classified as design tests, production tests, conformance tests, and field tests. (Refer to definitions in Section 2.)

NOTE: Except for the main switching and interrupting device, other devices, such as instrument transformers, which are mounted in the bus assemblies, should be disconnected during dielectric tests. Such devices are individually tested in accordance with standards applying to them.

6.2 Design Tests. The equipment to be tested shall be in a new and clean condition. Tests shall be made at the factory or manufacturer's test laboratory, unless otherwise specified. The bus conductors may be extended out of the enclosure to permit the attachment of test connections.

6.2.1 Dielectric Tests. The dielectric withstand tests and, where applicable, conductor insulation tests shall be made to determine the adequacy of the insulation. See 6.2.1.4 for conductor insulation tests.

The dielectric withstand tests shall consist of the application of a voltage with a value at least equal to the voltages in Table 3A, 3B, and 3C.

Dielectric withstand tests shall be made under the temperature and humidity conditions normally obtained under conditions of commercial testing with appropriate correction factors applied as outlined in ANSI/IEEE Std 4-1978 [6].

Dielectric withstand tests shall be made as follows:

(1) For isolated-phase and segregated-phase bus, these tests shall be made from each phase to ground.

(2) For other types of bus, the tests shall be made phase-to-phase and from each phase-to-ground.

Table 2A
Isolated-Phase Bus
Rated Short-Circuit Withstand Current and Rated Short-Time Current

Rated Short-Circuit Withstand Current* (kA asymmetrical) 167 ms Duration	Rated Short-Time Current† (kA symmetrical) 1 s Duration
As required by connected equipment.	The symmetrical current value will be that measured at the end of 1 s.

Table 2B
Segregated- and Nonsegregated-Phase Bus
Rated Short-Circuit Withstand Current†
(kA asymmetrical) 167 ms Duration

Nominal Voltage (kV)	Nonsegregated	Segregated
0.635 ac and all dc	75; 100; 150	—
4.76	39; 58; 78	—
13.8	37; 58; 77	—
14.4	—	60; 80; 100
23.0	32; 56; 64	60; 80; 100
34.5	32; 56; 64	60; 80; 100

NOTE: The power factor of the test circuit shall be 4-5% lagging (X/R ratio of 25 to 6.6) with X and R in series connection.

*For definition of rated short-circuit withstand current, see 2.1.9.

†For definition of rated short-time current, see 2.1.8.

Table 3A
Isolated-Phase Bus
Voltage Ratings

(Ratings for application to generator leads)*

Maximum Operating Voltage (kV rms)	Insulation Level (kV)			
	Rated Frequency Withstand (rms)		dc Withstand Dry‡	Impulse Withstand
	Dry (1 min)	Dew (10 s)†		
24.5	50	50	70	110
29.5	60	60	—	125
34.5	80	70	—	150

NOTE: These ratings are compatible with or in excess of required withstand values of the generators.

(Ratings for applications other than generator leads)

Maximum Operating Voltage (kV rms)	Insulation Level (kV)			
	Rated Frequency Withstand (rms)		dc Withstand Dry‡	Impulse Withstand
	Dry (1 min)	Dew (10 s)†		
15.5	50	50	70	110
25.8	60	60	—	125
38.0	80	70	—	150

Table 3B
Nonsegregated-Phase Bus
Voltage Ratings

Maximum Operating Voltage (kV rms)	Insulation Level (kV)			
	Rated Frequency Withstand (rms)		dc Withstand Dry‡	Impulse Withstand
	Dry (1 min)	Dew (10 s)†		
0.635	2.2	—	3.1	—
4.760	19.0	15.0	27.0	60
15.000	36.0	24.0	50.0	95
25.800	60.0	40.0	85.0	125
38.000	80.0	70.0	—	150

Table 3C
Segregated-Phase Bus
Voltage Ratings

Maximum Operating Voltage (kV rms)	Insulation Level (kV)			
	Rated Frequency Withstand (rms)		dc Withstand Dry‡	Impulse Withstand
	Dry (1 min)	Dew (10 s)†		
15.5	50	30	70	110
25.8	60	40	85	125
38.0	80	70	—	150

Table 3D
DC Bus Duct
Voltage Ratings

Operating Voltage (V)	Insulation Level (kV)	
	60 Hz Withstand (rms)	dc Withstand[‡]
300	2.2	3.1
800	3.7	5.2
1200	4.6	6.5
1600	5.4	7.6
3200	8.8	12.4

[*] For generator leads with intermediate breakers, surge protection may be required. The breaker manufacturer should be contacted for recommendations.

[†] The 10 s dew rating does not apply to insulation systems containing organic materials. Dew withstand voltage tests shall be made in accordance with 6.2.1.3.

[‡] The presence of the column headed "dc Withstand" does not imply any requirement for a dc withstand test on ac equipment. This column is given as a reference only for those using dc tests and represents values believed to be appropriate and approximately equivalent to the corresponding power frequency withstand test values specified for each class of bus. *Direct-current withstand tests are recommended for flexible bus to avoid the loss of insulation life that may result from the dielectric heating that occurs with rated frequency withstand testing.*

Because of the variable voltage distribution encountered when making dc withstand tests and variances in leakage currents associated with various insulation systems, the manufacturer should be contacted for recommendations before applying dc withstand tests to this equipment.

Table 4A
Isolated-Phase Bus
Continuous Self-Cooled Current Ratings (Amperes)

Current Ratings Based Upon Temperature Rise Shown in Table 1	
1200	10 000
2000	12 000
3000	14 000
4000	16 000
5000	18 000
6000	20 000
7000	22 000
8000	24 000
9000	

Table 4B
Segregated- and Nonsegregated-Phase Bus
Continuous Self-Cooled Current Ratings (Amperes)

Nominal Voltage (kV)					
0.635 ac and All dc	2.4 and 4.16	13.8	14.4	23.0	34.5
600	—	—	—	—	—
1 200	1200	1200	1200	1200	1200
1 600	—	—	—	—	—
2 000	2000	2000	2000	2000	2000
—	—	—	2500	2500	2500
3 000	3000	3000	3000	3000	3000
—	—	—	3500	3500	—
4 000	4000	4000	4000	4000	—
—	—	—	4500	4500	—
5 000	—	—	5000	5000	—
—	—	—	5500	5500	—
6 000	—	—	6000	6000	—
10 000	—	—	—	—	—

6.2.1.1 Rated Frequency Withstand Tests. Alternating-current voltage shall have a crest value equal to 1.41 times the rms value specified in Tables 3A, 3B, and 3C. The wave shape shall be as close to a sine wave as practicable. The test voltage shall be applied for 1 min.

NOTE: For the test across the open gap of switches or links at 10% higher voltage, an intermediate point of the voltage source may, if practicable, be connected to ground and to the frame of the assembly in order that the voltage between any live part and the frame will not exceed that specified in Tables 3A, 3B, and 3C. If this is not practicable, the frame may be insulated from ground.

6.2.1.2 Impulse Withstand Tests. Impulse withstand tests are made to determine the ability of the bus assembly to withstand momentary overvoltage surges from lightning or momentary system disturbances.

Metal-enclosed bus shall pass a full wave 1.2/50 μs impulse voltage test series. The wave shall have a virtual front time, based on the rated full wave impulse voltage (T_1 of Fig 2) equal to or less than 1.2 μs with a crest voltage equal to or exceeding the rated full wave impulse withstand voltage (Tables 3A, 3B, and 3C), and with a time to the 50% value of the crest voltage (T_2 of Fig 2) equal to or greater than 50 μs.

NOTE: In previous editions of standards where the impulse voltage limits of 1.5/40 μs were defined, this is the same as 1.2/50 μs in terms of the parameters of the curve as defined below. Metal-enclosed bus assemblies designed and tested in accordance with the previous 1.5/40 μs impulse wave may be assigned a 1.2/50 μs rating on the basis of a prior design tested with a 20% tail tolerance.

If the capacitance of a test sample is too high for test equipment to be able to produce a virtual front time as short as the 1.2 μs, while maintaining the crest value, the most rapid rise possible may be used in the design test.

In these tests, three positive and three negative impulse voltages shall be applied without causing damage or flashover.

If flashover occurs on only one test during any group of three consecutive tests, three more tests shall be made. If the equipment successfully withstands all three of the second group of tests, the flashover in the first group shall be considered as a random flashover and the equipment shall be considered as having successfully passed the tests.

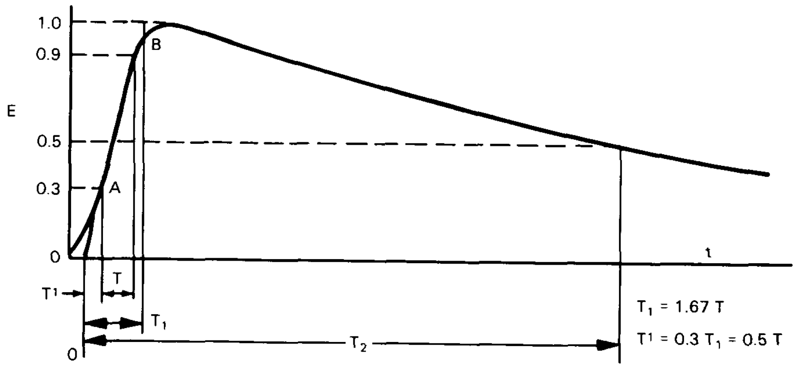
Table 5
Temperature Limits for Insulating Materials*

Class of Insulating Material	Limit of Hottest-Spot Temperature Rise (°C)	Limit of Hottest-Spot Total Temperature (°C)
Class 90	50	90
Class 105	65	105
Class 130	90	130
Class 155	115	155
Class 180	140	180
Class 220	180	220

NOTE: For additional information on temperatures, see ANSI/IEEE Std 1-1986 [B6].

* These temperature limits for insulating materials may not apply to insulation in circuit breakers or other devices. For temperature limits on devices, refer to the appropriate standards for the devices.

Fig 2
Impulse Test Wave Shape



The basic wave shape to define the impulse test limits is shown in Fig 2.

The wave shape (Fig 2), used to define the limits, is described by four parameters—the 0.3*E*, 0.5*E*, 0.9*E*, and 1.0*E* per unit values of a crest voltage. The time between the 0.3*E* and the 0.9*E* values (*T* of Fig 2) is 0.75 μs and the time to the 0.5*E* value (T_2 of Fig 2) is 50 μs as measured from the virtual zero. The virtual zero is established by the intersection of a line drawn through 0.3*E* and 0.9*E* points on the front of the wave, and the zero line (0_1 of Fig 2). The virtual front time (T_1 of Fig 2) is defined as 1.67 times the time interval between the 0.3*E* and the 0.9*E* points.

6.2.1.3 Dew Withstand Voltage Test.

6.2.1.3.1 Preparation of Test Specimen. The test specimen shall be placed in a chamber having a temperature of from -10 °C to -15 °C until the specimen is thoroughly cooled. (Cooling may take 10-12 h.)

6.2.1.3.2 Mounting Arrangement. The test specimen shall be mounted in accordance with ANSI C29.1-1982 [1], Section 3, in a test chamber having a temperature of approximately 25 °C. The relative humidity in the test chamber shall not be less than 80%. This may be obtained by passing live steam at atmospheric pressure into the chamber.

6.2.1.3.3 Resistance Measurement and Voltage Application. The resistance-to-ground of the test specimen shall be measured at 5 min intervals. The measurement shall be made with a megohmeter with an output voltage between 500 and 1000 V. The voltage shall be applied only long enough to read the resistance. When a reading equals or exceeds the immediately preceding reading, transfer the leads to a hi-pot set as quickly as possible (less than 5 min). Five minutes after the last resistance reading, the voltage shall be raised rapidly to the dew withstand voltage. The time to raise the voltage shall not be more than 20 s.

NOTE: The resistance measurement shall be made with the same megohmeter voltage throughout. The megohmeter reading will normally rise to a maximum and then drop fairly rapidly to a relatively stable value. The stable value shall be deemed the resistance value.

6.2.1.3.4 Test Voltage and Time. The test voltage, which is the rated dew withstand voltage, with appropriate atmospheric correction applied, shall be held on the test specimen for the time indicated in Tables 3A, 3B, 3C, and 3D.

6.2.1.3.5 Corrections. Corrections shall be made in accordance with 4.5.6 in ANSI C29.1-1982 [1].

6.2.1.4 Test for Bus Bar Insulation. The insulated bus bar sample shall have a rated frequency voltage applied from the conductor to an electrode effectively covering the outer surface of the insulation. The alternating-current test voltage shall have a value not less than the rated maximum voltage as shown in Tables 3A, 3B, and 3C. For alternating current, test voltage shall have a crest value equal to 1.41 times the rms value and the wave shape shall be as close to a sine wave as practicable. The test voltage shall be applied for 1 min. The bus bar sample shall include typical elbows and joints.

NOTE: Suggested external electrodes are conductive paint, lead foil, or equivalent.

6.2.2 Rated Continuous-Current Tests. Tests shall be conducted to demonstrate the ability of the bus assemblies to meet the temperature rise limitations specified in Table 1 while carrying rated continuous current.

NOTE: In the following paragraphs, the word *bus* is used to denote *bus assembly*.

The bus shall be at least 24 in (60 cm) from the floor, exclusive of structural supports. The test shall be made at an ambient air temperature between the limits of 10 °C and 40 °C. The ambient air temperature shall be determined by taking the average of the readings of at least four temperature measuring devices, such as thermometers or thermocouples, placed on the side of the bus on the centerline at least 12 in (30 cm) from the bus enclosure and 24 in (60 cm) from the ends of the bus enclosure.

The thermometers should be immersed in oil in a cup as follows: A convenient form for such an oil cup consists of a metal cylinder with a hole drilled partly through it. This hole is filled with oil and the thermometer is placed therein with its bulb immersed. The response of the thermometer to various rates of temperature change will depend largely upon the size, kind of material, and mass of the containing cup and may be further regulated by adjusting the amount of oil in the cup. The larger the apparatus under test, the larger should be the metal cylinder that is employed as an oil cup in the determination of the cooling air temperature. The smallest size oil cup employed, in any case, shall be a metal cylinder 1 in (2.5 cm) in diameter and 2 in (5 cm) high.

Thermocouples may be used to measure the hottest-spot temperatures even though this process may involve drilling holes that destroy some parts used in a design test.

The bus sample shall be a three-phase unit having a minimum length of 19 ft (6 m). It shall have at least one joint (conductor and enclosure) per phase (bolted, clamped, or welded). Single-phase applications shall be tested single-phase. Supply leads (connections) shall be of proper size to prevent heat interchange. Ends of the bus shall be sealed.

Current shall be of sine wave shape and shall flow through all three phases with the current in each phase within 2% of the specified test current value. The test current shall be applied continuously until the temperature of all bus parts and supports is substantially constant. (Three successive readings at not less than 30 min intervals of hottest-spot temperatures shall show a maximum variation of ±1 °C.)

6.2.3 Short-Circuit Withstand Current Tests. Short-circuit withstand current tests shall be made to determine the electrical, thermal, and mechanical adequacy of buses and connections. Short-circuit withstand tests of metal-enclosed bus shall be made with a three-phase section of equipment—a minimum of 19 ft (6 m). The power supply may be three-phase or single-phase. If three-phase, the bus conductors shall be connected together at one end, while the other ends are connected to the power source. If single-phase power is used, the circuit shall be arranged so current flow is through two adjacent phase conductors. The force due to a three-phase fault is approximately 86.6% of that due to a single-phase fault of the same current. Therefore, for single-phase testing, the current shall be 7.0% below that shown in Tables 2A and 2B. The minimum duration of tests shall be 167 ms at rated frequency.

6.2.4 Watertight Tests. The enclosure of a watertight bus assembly shall prevent the entrance of water when a stream from a 1 in (2.5 cm) diameter hose under a head of 35 ft (11 m) (under flow conditions) and with the nozzle 10 ft (3 m) from the equipment, is directed downward on it over the full length at an angle of at least 45 degrees from the horizontal. The test shall be made for 5 min.

6.2.5 Weatherproof Test. The enclosure of a weatherproof bus assembly shall be tested in accordance with the rain test as described in ANSI/IEEE C37.20.2-1987 [3].

6.2.6 Short-Time Current Tests. Short-time current tests shall be made for isolated-phase bus to determine that the buses and connections can carry the test current without exceeding a total temperature of 300 °C for copper and 260 °C for aluminum.

Requirements and conditions are the same as for momentary current tests (6.2.3) except the minimum duration of the test is 1 s.

6.2.7 Flame-Retardant Tests for Applied Insulation. Applied insulation shall be tested as follows:

6.2.7.1 Test Apparatus. The test apparatus shall consist of the following: (See Fig 3.)

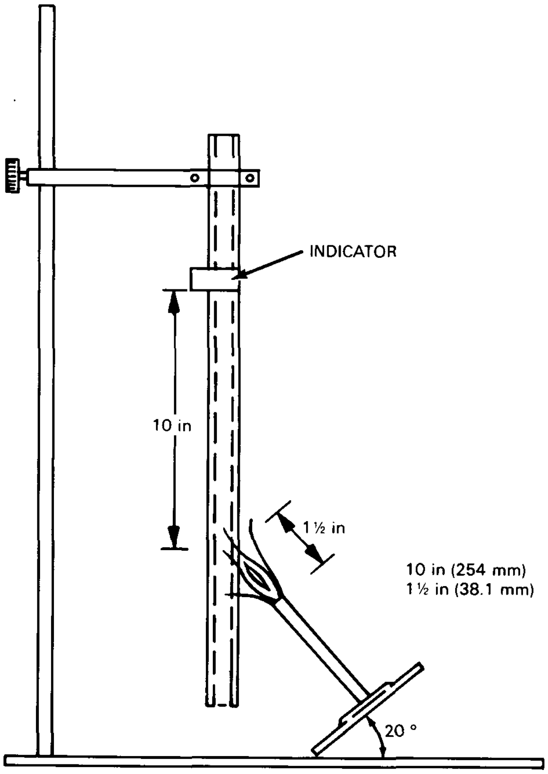
(1) Test chamber of sheet metal 12 in (305 mm) wide, 14 in (356 mm) deep, and 24 in (610 mm) high, which is open at the top and which is provided with means for clamping the test specimen at the upper end and supporting it in a vertical position.

(2) Means for adjusting the position of the test specimen.

(3) Tirrill burner with an attached pilot light and mounted on a 20-degree angle block. The burner shall have a nominal bore of ⅜ in (9.5 mm) and a length of approximately 4 in (102 mm) above the primary air inlets.

(4) An adjustable steel angle (jig) attached to the bottom of the chamber to ensure the correct location of the burner with relation to the test specimen.

Fig 3
Test Apparatus



(5) Gas — a supply of ordinary illuminating gas or equivalent at normal pressure.

(6) Watch or clock with a hand that makes one complete revolution per minute.

(7) Flame indicators consisting of strips of gummed kraft paper having a nominal thickness of 0.05 in (1.27 mm) and a width of ½ in (12.7 mm).

NOTE: The paper used for the indicators is known to the trade as 60 lb stock and is material substantially the same as that described in Federal Specification No A-A-1492 [10].

6.2.7.2 Preparation of Sample. Prepare a copper rod approximately ¾ in (19.0 mm) in diameter, 22 in (559 mm) in length, with the necessary covering to be tested to a thickness of approximately 0.06-0.125 in (1.5-3.17 mm).

6.2.7.3 Procedure. The test shall be made in a room that is reasonably free from drafts, although a ventilated hood may be used if air currents do not affect the flame. One end of the test specimen approximately 22 in (559 mm) in length shall be clamped in position at the upper end of the chamber. A paper indicator shall be applied to the specimen so that the lower edge is 10 in (254 mm) above the point at which the inner blue cone of the test flame is to be applied. The indicator shall be wrapped once around the specimen with the gummed side toward the conductor.

The ends shall be pasted evenly together and shall project ¾ in (19.0 mm) from the specimen on the side opposite to that which the flame is to be applied. The paper tab shall be moistened only to the extent necessary to permit proper adhesion. The height of the flame with the burner vertical shall be adjusted to 5 in (127 mm) with an inner blue cone 1½ in (38.1 mm) high.

6.2.7.4 Test. The burner, with only the pilot lighted, shall be placed in front of the sample so that the vertical plane through the stem of the burner includes the axis of the specimen. The angle block shall rest against the jig, which shall be adjusted so that there is a distance of 1½ in (38.1 mm) along the axis of the burner stem between the tip of the stem and the surface of the specimen. The valve supplying the gas to the burner proper shall then be opened and the flame automatically applied to the sample. This valve shall be held open for 15 s and then closed for 15 s. This process shall be repeated four times. During each application of the flame the specimen shall be adjusted, if necessary, so that the top of the inner blue cone touches the surface of the specimen. If more than 25% of the extended portion of the indicator is burned after the five applications of the flame, the specimen is considered to have conveyed flame. The duration of burning of the specimen after the fifth application of the flame shall be noted, and any specimen that continues to burn for more than 1 min shall be considered to have failed this test.

6.3 Production Tests. Production tests for metal-enclosed bus shall be power frequency dielectric tests, mechanical tests, grounding of instrument transformer case tests, and electrical operation and control wiring check.

Rated frequency withstand tests shall be made at the factory, as described in 6.2.1.1.

6.4 Field Tests. In addition to the following, manufacturer's recommendations should be consulted.

6.4.1 Tightness. A watertight bus installation may be tested in the field to determine the adequacy of field welds, assembly of bus sections, covers, gaskets, etc. The tightness can be determined by either the watertightness design test method as described in 5.2.4 or by the air tightness method described herein.

Fill the bus (or section) to be tested with air to a pressure of 6 in (15 cm) of water (approximately ¼/in^2 gauge or 1500 N/m^2). Cover the field (and factory) welds and joints with soap bubbles to detect escaping air. If the amount of air leaking at a point is excessive, the area should be checked for watertightness.

6.4.2 Dielectric Tests. Rated frequency withstand tests or dc tests made in the field shall not exceed 75% of the values shown in Tables 3A, 3B, and 3C.

6.4.3 Forced-Air Cooled Bus. Inspection of and measurements on a forced-air cooled bus should be made and the parameters checked against the manufacturer's specifications. These should include

(1) Fan rotation and speed

(2) Fan and motor vibration

(3) Motor operating voltage and load current (as a check against brake horsepower)

(4) Heat exchange coolant flow rate and temperature

(5) Air balance within the bus system

NOTE: Most systems utilize turbulent air flow which makes air measurements difficult. Generally, air balance is checked by measuring the temperature rise of the bus under load conditions. However, the manufacturer's recommendations for the specific installation should be followed.

(6) Alarm and indicating device settings and/or calibration (thermostats, thermometers, pressure switches, etc).

7. Construction

7.1 Finishes and Color. All steel surfaces to be painted shall receive a phosphatizing treatment or equivalent prior to application of paint. External and internal surfaces shall be coated with at least one coat of corrosion-resisting paint.

The preferred color for the finish on metal-enclosed bus shall be light gray #61 (see ASTM D1535-80 [9]).

NOTES: (1) See gray finishes for industrial apparatus equipment in ANSI Z55.1-1967 [2].
(2) Internal detail parts may have metallic plating or equivalent in lieu of paint finish.

7.2 Grounding. A continuous ground conductor shall be provided in parallel with the bus to ensure that all enclosures are grounded. The ground bus may take the form of a separate bar (copper or aluminum), it may be the enclosure itself, or it may be the supporting structure if a continuous electrical path can be provided of the same short-circuit withstand current rating as the main bus conductors. The ground bus shall be capable of carrying the rated short-circuit current of the bus.

The ground conductor is preferably connected to the station ground at one point only, although more connection points are satisfactory if induced current loops have been avoided. Induced voltages across insulated joints in the housing should be kept as low as possible and preferably below 2 V during rated current operation.

7.3 Adjacent and Supporting Structure. For high-current installations, consideration should be given to the problem of induced circulating current in nearby metallic members, such as support beams, reinforcing rods, etc. Suitable insulated gaps in the steel work to eliminate closed loops and amortisseur bands around steel members will aid in solving the problem.

It is recommended that the suggested procedures be followed to the extent that ground currents in any adjacent metallic material be kept below 10% of the bus phase currents or low enough so temperature rise is within the limits shown in Table 1.

7.4 Ventilation. Widely fluctuating ambient air temperatures for any one section of bus necessitate consideration of the resulting enclosure air temperature; form of ventilation with filtered breathers or means for air circulation should be provided. If the insulation system is organic, heaters may be used to control condensation inside the bus enclosure.

7.5 Force-Cooled. Auxiliary equipment may be used to force-cool the metal-enclosed bus. Either a gas, a liquid, or combination of these media are satisfactory for force-cooled bus. The system may be of the open or of the recirculatory type. Precautions shall be taken to prevent transmittal of arc products between phases. A force-cooled bus will carry a lower-than-normal current when the cooling medium is not being circulated, and both the force- and self-cooled values of current shall be indicated in the rating.

7.5.1 Forced-Air-Cooled, Isolated-Phase Bus. Forced-air-cooled, isolated-phase bus generally consists of the following components.

7.5.1.1 Isolated-Phase Bus Structure with Provisions for Connection to a Cooling Unit. Connections between the bus structure and the cooling unit should provide for vibration isolation. Electrical insulation shall be provided at such connections to prevent circulating currents between the two components.

7.5.1.2 Cooling Unit with Necessary Air Duct and Connections to the Bus Structure.[7] Cooling units may be of the recirculatory type, the nonrecirculatory or "once through" type, or of a type convertible from recirculatory to nonrecirculatory.

7.5.1.2.1 Recirculatory Cooling Units. Recirculatory cooling units consist of a motor-driven fan;[8] a suitable heat exchanger (generally air-to-water);[9] and provisions to admit air lost by leakage into the system through filtered openings in the air duct.

Cooling air is circulated through the bus assembly by the motor-driven fan. After completing the circulation, the cooling air is returned to the cooling unit through the air duct, is cooled by being

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[7] Additional indicating devices, fans, motors, and heat exchanger may be added to the basic equipment outlined to provide redundancy.

[8] Special consideration shall be given to the drive motor, such that under any operating conditions it will not exceed its horsepower rating.

[9] The heat exchanger construction shall be such that possible condensation will not be carried into the fan.

passed through the heat exchanger, and returns to the motor-driven fan for recirculation through the bus.

7.5.1.2.2 Nonrecirculatory or "Once Through" Cooling Units. Nonrecirculatory cooling units consist of a motor-driven fan[10] and provisions to admit filtered ambient air into the system. The filtered cooling air is circulated through the bus assembly by the motor-driven fan and, after completing the circulation, is exhausted to the atmosphere.

7.5.1.2.3 Convertible-Type Cooling Units. Convertible cooling units have provisions to convert from a recirculatory cooling system to a nonrecirculatory or "once through" system when the heat exchanger is out-of-service.

7.5.1.3 Indicating Devices. Suitable devices on the bus system and cooling units shall be provided to perform the following functions:

(1) Indicate the bus conductor temperature at possible hot spots.

(2) Indicate, for alarm purposes, bus overtemperature at possible hot spots.

(3) Indicate, for alarm purposes, loss of cooling air to the bus system.

(4) Indicate, for alarm purposes, insufficient or excessive coolant flow to the heat exchanger.

(5) Indicate, for alarm purposes, accumulation of water in the heat exchanger drain pan.

7.5.1.4 Means to Transfer Cooling Air Between Phases. When cooling air is transferred between phases, means shall be provided to reduce the possibility of the transfer of ionized air between phases due to a phase-to-ground fault in the bus. Grounded deionizing baffles, grids, or similar means shall be provided for this purpose. If necessary for air balancing, adjustable dampers shall be provided. Such dampers shall have provisions for locking in any position, and their *open* and *closed* positions shall be indicated.

7.6 Vapor Barriers. Self-cooled metal-enclosed bus having sections located inside and outside a building, so that ambient temperature may be appreciably different at the same moment, shall include sealing means or baffles to prevent an interchange of air between the sections or have a suitable air drying system.

7.7 Fire Barriers. Self-cooled buses may propagate smoke and fire from one part of the building to another unless barriers are installed at strategic locations. Fire barriers to prevent passage of fire and smoke may be required at all floor-lines of vertical buses and in horizontal runs of buses whenever the buses pass through walls designated as "fire walls."

7.8 Insulating Materials for Covering Buses and Connections. If insulation is provided on the bus conductors, it shall be tested for dielectric strength and flame resistance as outlined in 6.2.1 and 6.2.7. Where joints are required to be made up on the job site, insulating materials shall be supplied for application in accordance with the manufacturer's instructions.

7.9 Terminations. The bus is electrically attached to the studs of generators or transformer bushings or switch terminal pads, usually with flexible braid or multiple laminations depending on the degree of flexibility required.

Similar flexible connections may be required in long, straight runs of bus to provide for temperature expansion or contraction, or where the bus crosses building vibration isolation joints.

The terminating equipment at the generator may require seal-off bushings or baffles with provision for escape to the atmosphere of hydrogen from leaks in or around the generator bushings.

7.10 Switches or Links for Station-Service Transformers. Generator bus frequently has tap connections to station-service transformers through group-operated switches or disconnecting links. Switches shall be designed to interrupt only the magnetizing current of the transformer and should not be operated to close onto an energized bus unless designed for closing duty. Links should be easily removable, but should only be removed when the bus is de-energized. The switches and links shall be capable of carrying the rated short-circuit current in that section of bus.

7.11 Secondary Wiring. Secondary devices and their wiring shall be isolated by grounded metal barriers from all primary circuit elements except for short lengths of wire, such as at instrument transformer terminals.

8. Miscellaneous Accessories

Metal-enclosed bus equipment installations will usually include such accessories or auxiliaries as potential transformers, compartments, surge equipment, and generator neutral connections. Current

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[10] See Footnote 8.

transformers may also be mounted in the bus. High-current rated bus will usually include bushings having provision for mounting a current transformer.

All such accessories shall conform to the dielectric test requirements of this standard. In addition, the connections shall be arranged with seals or baffles to prevent faults in the units from reaching the main conductors. Otherwise, cubicles are constructed in accordance with the requirements for station-type equipment. Devices such as instrument transformers, however, may not withstand the dielectric tests of the equipment and should be disconnected when such tests are made.

Locations of current transformers shall be coordinated with joints in the bus so that current transformers are accessible.

9. Calculating Losses in Isolated-Phase Bus

9.1 General. The information in this standard is applicable to all forms of isolated-phase buses operating in ac power systems. It is not meant to apply to other forms of open or enclosed buses, although some of the material will be useful in most bus applications.

All conductors carrying electric current will produce power losses. This standard covers methods for calculating conductor and enclosure losses at bus operating temperatures, including skin effect. In making power loss calculations, the I^2R losses in the enclosure are considered. Means for determining such losses for various bus configurations are included. If the bus is force-cooled, the power requirements of the cooling equipment will be included in the total power loss.

For high-current installations, consideration should be given to the problem of induced magnetic heating and induced circulating current in nearby metallic members such as support beams and reinforcing rods. The standard also contains references to assist in the estimation of heating effects of adjacent structural members. Such induced currents should be minimized to reduce extraneous losses. Methods of reducing eddy current and hysteresis losses and eliminating losses due to circulating currents are indicated.

9.2 Conductor Losses

9.2.1 General. The loss in each conductor is

$$P_c = I^2 R_c$$

where

R_c = conductor resistance at the appropriate temperature with skin effect corrections for the applicable frequency

I = conductor current

It is convenient for the purpose of this standard to determine the losses per unit length of conductor. Thus, if R_c is expressed in microhms per foot ($\mu\Omega$/ft) and I in kiloamperes rms (kA rms), P_c will be expressed in watts per foot (W/ft).

The conductor resistance may be obtained from tables or calculated from its dimensions and resistivity. Equation 11 may be used to calculate the resistance of round hollow conductors.

The current for which the loss is calculated shall be the rated continuous current.

9.2.2 Temperature Effects

9.2.2.1 Conductor Operating Temperature. The losses should be calculated for the operating temperature of the conductor. The maximum operating temperature limit set by this standard for isolated-phase bus conductors follows:

	Maximum Temperature Limit of Hottest Spot (°C)
Bus conductor with plain connection joints	70
Bus conductor with silver, or equivalent, contact surfaces	105

The maximum temperature limit is based on 40 °C ambient. The total temperature of the bus conductor at current below full load and at other ambients can be approximated by using the following

For a 105 °C bus:

Bus temperature (°C at % load)

$$= \text{ambient} + \left[\left(\frac{\%\ \text{load}}{100}\right)^n \cdot 65\right] \qquad \text{(Eq 1)}$$

For a 70 °C bus:

Bus temperature (°C at % load)

$$= \text{ambient} + \left[\left(\frac{\%\ \text{load}}{100}\right)^n \cdot 30\right] \qquad \text{(Eq 2)}$$

The suggested value of exponent n is 1.7 for self-cooled buses and 2.0 for force-cooled buses.

9.2.2.2 Change in DC Resistance with Temperature. Most tables list the dc resistance of conductors at 20 °C. The resistance at other temperatures may be determined from the following formula:

$$R_t = R_{20}\left[1 + \propto_{20}(t - t_0)\right] \qquad \text{(Eq 3)}$$

where

$\propto_{20}$ = temperature resistance coefficient at 20 °C
t_0 = 20 °C

The temperature resistance coefficient depends upon the material used for the bus conductor and its conductivity. For 100% conductivity copper, $\alpha_{20} = 0.00393$; for 98% conductivity copper, $\alpha_{20} = 0.00385$. The above equation may be written

$$R_t = R_{20}\left[1 + k_3\gamma(t - t_0)\right] \qquad \text{(Eq 4)}$$

where

γ = conductivity
k_3 = constant depending upon material

For aluminum, and when γ is expressed in percent of the annealed copper standard, $k_3 = 0.000066$.

9.3 Skin Effects. In the curves shown in Figs 4 and 5 (for round conductors and enclosures) and Fig 6 (for square conductors), the skin effect factor R_{ac}/R_{dc} is plotted against $\sqrt{(f \cdot 10^3)/R_{dc}}$ for various conductor thickness/diameter ratios where the resistances are in microhms per foot. The data in Figs 4 and 5 for values of t/d of 0.03 and greater and all data in Fig 6 are derived from formulas given in Dwight [B10]. In Figs 4 and 5, data for values of t/d of 0.025 and less have been calculated to extend the range of $\sqrt{(f \cdot 10^3)/R_{dc}}$ to cover values for large-diameter enclosures. Figure 6 can also be used in conjunction with two channels arranged to form a square conductor without introducing appreciable error. These curves apply for both copper and aluminum conductors. The curves can be used for all temperatures within operating ranges.

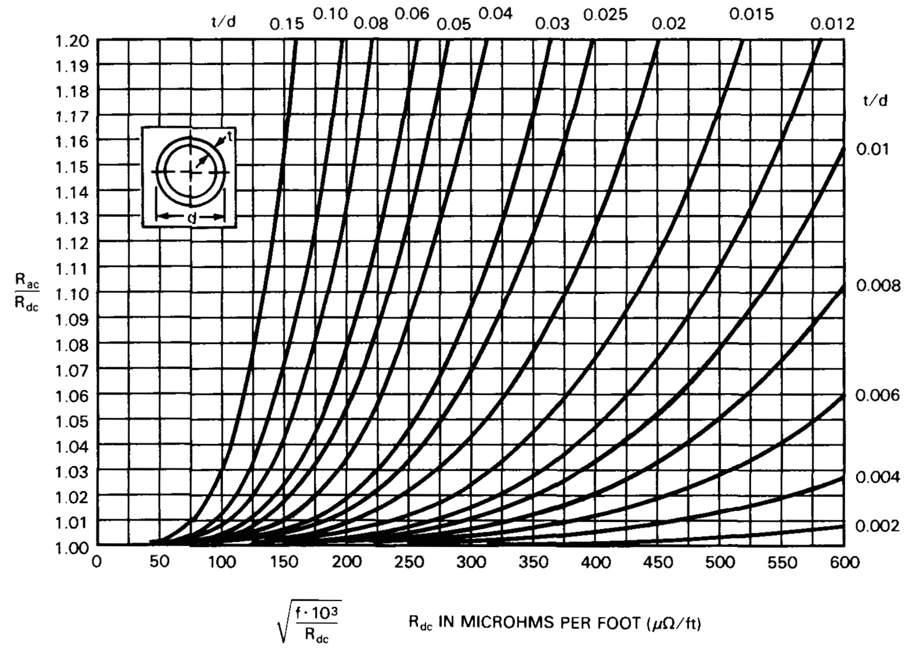
The heat loss, in watts per single-phase foot, generated in bus conductors is

$$P_c = I^2 R_c \qquad \text{(Eq 5)}$$

where

R_c = conductor resistance at the appropriate temperature with skin effect corrections for the applicable frequency
I = conductor current

Fig 4
Curves for Skin Effect of Isolated Tubular Conductors



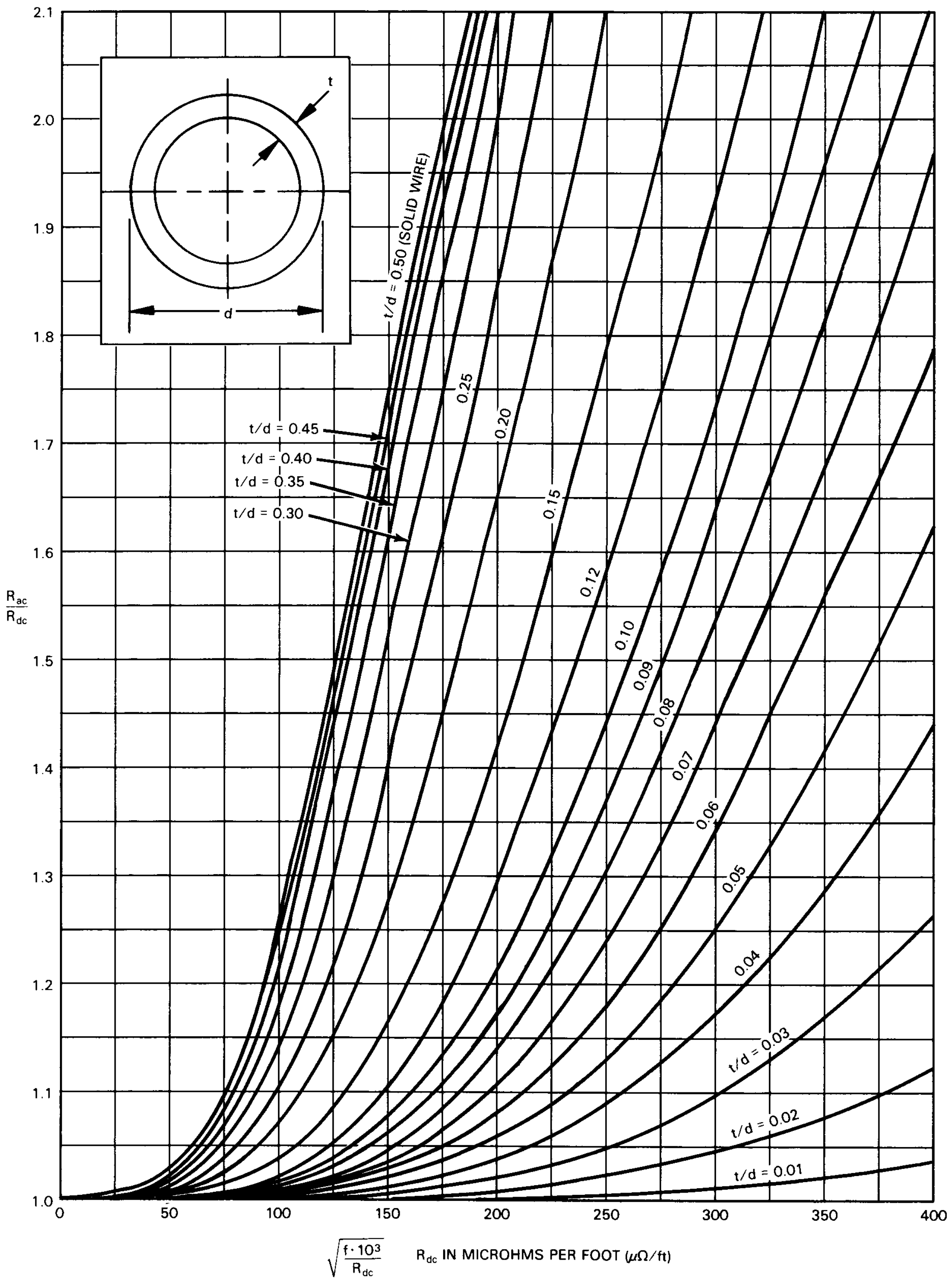


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Fig 5
Curves for Skin Effect of Isolated Round Rod and Tubular Conductors [B10]

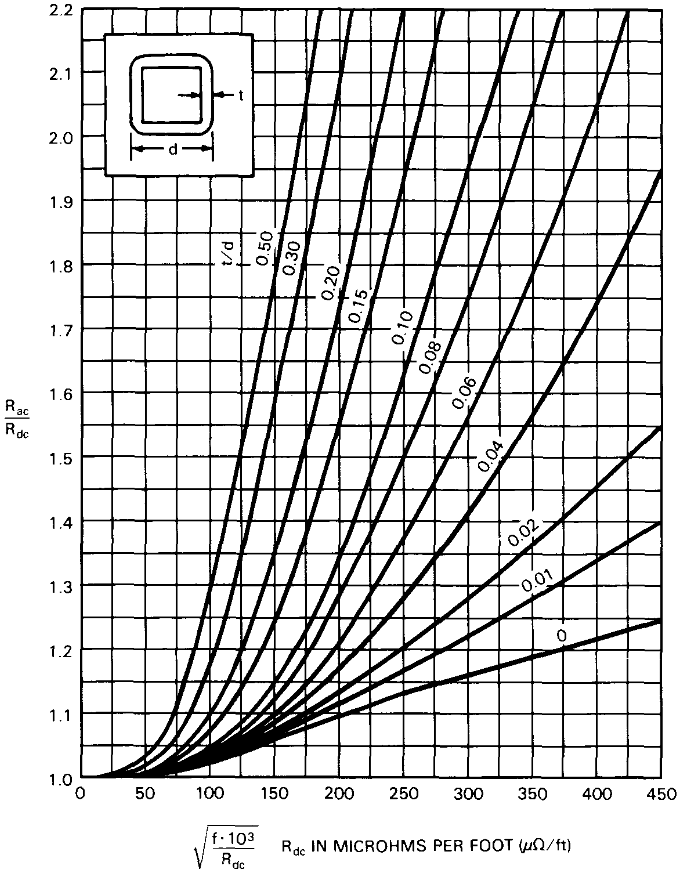

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Fig 6
Curves for Skin Effect of Isolated Square Rod and Square Tubular Conductors [B10]

It is convenient for the purposes of this standard to determine the losses per unit length of conductor. Thus, if R is expressed in microhms per foot (μΩ/ft) and I in kiloamperes (kA) rms, P_c will be expressed in watts per foot (W/ft).

9.4 Enclosure Losses

9.4.1 Definitions. A *continuous isolated-phase bus enclosure* (see Fig 7) is one in which the consecutive sections surrounding the same phase conductor are electrically connected to each other over the length of the installation and cross-connected to the enclosures of the other phases at the extremities of the installation, so as to permit longitudinal current flow in the enclosures. Electric connection-to-ground may be made at any convenient point. (This type of enclosure is referred to as a *bonded* enclosure.)

A noncontinuous isolated-phase bus enclosure (see Fig 8) is one in which the consecutive enclosure sections surrounding the same phase conductor are electrically insulated from each other so as to prevent longitudinal current flow across the enclosure joints. Each enclosure section is connected to a ground bus at one point only. (This type of enclosure is referred to as an *insulated* enclosure.)

The enclosure factor is a parameter defined as follows:

$$l^2 = \frac{k_5 \pi D t \omega}{\rho} \qquad \text{(Eq 6)}$$

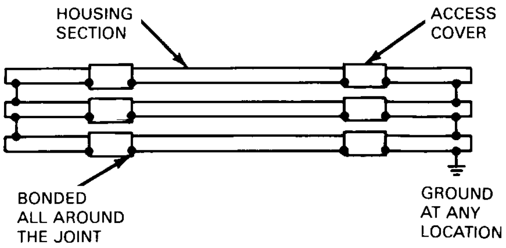


Fig 7
Continuous Isolated-Phase Bus Enclosure

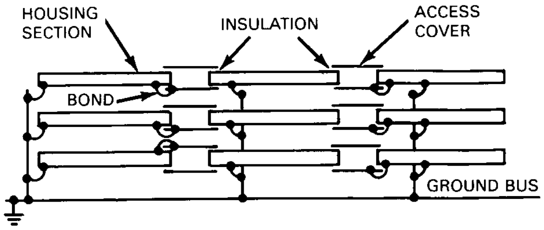


Fig 8
Noncontinuous Isolated-Phase Bus Enclosure

where

D = enclosure mean diameter = $d - t$
d = enclosure outside diameter
t = enclosure wall thickness
ω = $2\pi f$
f = frequency
ρ = resistivity of the enclosure material
k_5 = constant depending on units used (for units of the SI system, $k_5 = 10^{-7}$)

For practical computations, l^2 may be expressed in the following alternate form:

$$l^2 = \frac{k_6 f}{R_e} \qquad \text{(Eq 7)}$$

where

R_e = resistance of enclosure per unit length
k_6 = constant (if R_e is expressed in $\mu\Omega$/ft and f in Hz, $k_6 = 0.1915$)

The *spacing factor* is the ratio D/S, where D is the enclosure mean diameter and S is the spacing of conductor centerlines, with D and S in the same units.

The *virtual enclosure loss* is a fictitious loss, based upon the assumption that the enclosure current is the same as the conductor current, expressed by I^2R_e, where R_e is the enclosure longitudinal resistance and I is the conductor current.

The *loss factor* K is a number relating the actual enclosure loss to the virtual loss defined previously. The value of K depends on the installation parameters, the type of enclosure (continuous or noncontinuous), and the relative magnitudes and phase angles of the conductor currents in each particular arrangement.

9.4.2 Power Loss in Enclosures. Currents flowing in the main conductors induce voltage in the enclosures. The voltages cause currents that flow in patterns, depending on how the enclosures are interconnected. Current flow in the enclosures produces heat loss, which may be expressed in the form

$$P_e = KI^2R_{(ac)e} \qquad \text{(Eq 8)}$$

where

K = loss factor, for the total loss in all three enclosures of a three-phase run or both enclosures of a single-phase tap for the particular enclosure and arrangement. (A single-phase tap refers to the connections to one transformer of a three-phase bank as shown in Fig 9.)
$R_{(ac)e}$ = ac resistance of the particular enclosure corrected to the operating temperature of the enclosure
I = line current in the main conductors of the bus run. (Even when the losses in single-phase taps are unbalanced, three-phase balanced runs are considered.)

9.4.3 Temperature Effects

9.4.3.1 Enclosure Operating Temperature. The loss should be calculated at the assumed operating temperature of the enclosure, or at the maximum temperature specified by this standard, as is appropriate for the installation. The maximum limit of total temperature set by this standard for the bus enclosure is

Accessible parts	80 °C
Nonaccessible parts	110 °C

The interpretation given here is that those portions of the enclosure in which currents are induced will be accessible. The effects of local hot spots due to current crowding and deviations due to normal ventilation and external heat sources and heat sinks may be ignored in loss calculations.

9.4.3.2 Continuous Enclosures. The temperature rise of each of the continuous enclosures in a three-phase installation and for force-cooled buses will be relatively uniform. The total temperature at conductor currents below full load and at ambients other than 40 °C can be approximated by the following:

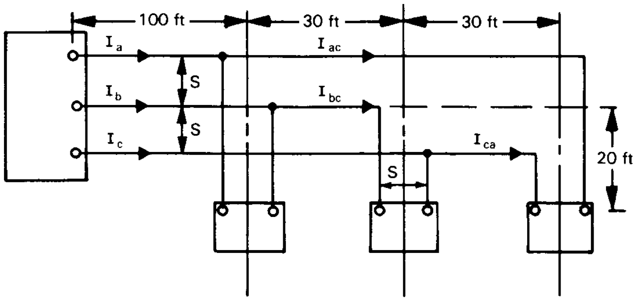


Fig 9
Layout of Isolated-Phase Bus Installation

enclosure temperature (°C at % load)

$$= \text{ambient} + \left[\left(\frac{\%\ \text{load}}{100}\right)^n \cdot 40\right] \qquad \text{(Eq 9)}$$

The suggested value of n is 1.7 for self-cooled buses and 2.0 for force-cooled buses.

9.4.3.3 Noncontinuous Enclosures. In the case of noncontinuous construction, the temperature rise of one of the enclosures will exceed that of the other two. Therefore, the average temperature of the three enclosures at full load will be less than the limit set by this standard. For loss calculations, the operating temperature of noncontinuous enclosures at conductor currents below full load and at ambients other than 40 °C may be approximated by use of Eq 2 if the average temperature rise of the enclosures at full load is assumed to be 30 °C.

9.4.3.4 Enclosure Resistance. The resistance of a large-diameter enclosure with a thin-wall section may be closely approximated by the expression

$$R_{e(20)} = \rho \frac{L}{\pi D t} \qquad \text{(Eq 10)}$$

where

ρ = resistivity of enclosure material at 20 °C
L = length of bus enclosure
D = enclosure mean diameter
t = enclosure wall thickness

Enclosures are generally made of aluminum of specified conductivity. Since losses are usually determined per unit length, it is convenient to determine $R_{e(20)}$ for unit length in the units used. For a length of one foot, with D and t in inches, and conductivity expressed in percent, Eq 9 becomes

$$R_{e(20)} = \frac{259}{Dt\gamma} \ (\mu\Omega/\text{ft}) \qquad \text{(Eq 11)}$$

Since the temperature at which the losses are desired is generally different from 20 °C, R_e as determined by Eqs 10 or 11 must be adjusted to the appropriate temperature. Formulas for temperature corrections are given in 9.2.2.2.

9.4.4 Skin Effect. In many cases, skin effect correction will not be necessary for the enclosure. However, it should be checked by use of factors obtained in the curves shown in Figs 4, 5, and 6.

9.4.5 Loss Factor

9.4.5.1 Continuous Circular Enclosures. The voltage induced in a circular enclosure by the current in the conductor that it surrounds causes a longitudinal current flow in the continuous enclosure. This current returns through the enclosures of adjacent phases. The enclosure longitudinal current is very nearly equal in magnitude to the conductor current, lagging by somewhat less than 180 degrees. Due to the opposite polarities of conductor and enclosure currents, the magnetic flux is mainly contained within the enclosure. The sum of the conductor and enclosure current is equal to the effective magnetizing current, which establishes the magnetic field external to the enclosure. The effective mangetizing current will vary from 2-10% of the conductor current. For this reason, and because the magnetizing and enclosure currents are very nearly 90 degrees apart, for most installations the magnitude of the enclosure current will equal that of the conductor current.

As shown in Niemoller [B13], neglecting the impedance of cross connections, the current I_e in the continuous enclosure is related to the conductor current I in the following manner:

$$\frac{I_e}{I} = \cos\left[\cot^{-1}\left(4.61\ l^2 \log\frac{2S}{D}\right)\right] \qquad \text{(Eq 12)}$$

where

l^2 = enclosure factor

S/D = reciprocal of the spacing factor

If l^2 is greater than 7, the value of I_e/I as calculated from Eq 12 will fall between 0.995 and 1.000. However, the actual value of I_e/I will be somewhat less due to the impedance of cross connections. If it is assumed that the impedance of the cross connection is equivalent to the impedance of an enclosure of length S

$$\frac{I_e}{I} = k_c \cos\left[\cot^{-1}\left(4.61\ l^2 \log\frac{2S}{D}\right)\right] \qquad \text{(Eq 13)}$$

where k_c is derived empirically as follows:

$$k_c = \frac{L}{L+S} + \left(1 - \frac{L}{L+S}\right)\left(\frac{D}{S}\right) = \left(\frac{L+D}{L+S}\right) \qquad \text{(Eq 14)}$$

where

L = length of bus enclosure

D = enclosure mean diameter

S = spacing of conductor center lines

and L, D, and S should be expressed in the same units in this equation.

Under such conditions, the loss factor K for use in Eq 8 is given in the following:

For the total loss in the three enclosures of a balanced three-phase run

$$K = 3\left(\frac{I_e}{I}\right)^2$$

For the total loss in the three enclosures of an unbalanced three-phase run where the current in one conductor is I and $I/\sqrt{3}$ in the other two

$$K = \frac{5}{3}\left(\frac{I_e}{I}\right)^2$$

For the total loss in the two enclosures of a single-phase power tap

$$K = \frac{2}{3}\left(\frac{I_e}{I}\right)^2$$

9.4.5.2 Noncontinuous Circular Enclosures. Since there is no external return path, the voltage induced in a noncontinuous enclosure by the current in the conductor that is surrounds cannot cause longitudinal current flow; however, nonuniform voltages are induced in the adjacent enclosures. These nonuniform voltages cause local current flow in each insulated enclosure section.

The enclosure currents flow in nonuniform patterns. The magnitude and phase angle of the current density in the longitudinal direction are functions of the angular position of the enclosure filaments. The flow pattern depends on the magnitude and phase angle of the conductor currents, the spacing factor D/S, and the enclosure factor l^2.

The loss per unit length of enclosure is evaluated by integrating, over the circumference that constitutes its cross section, the I^2R losses produced in all the elementary filaments. The result of this integration is expressed as the loss factor K to be used with Eq 8.

The value of K depends principally on the parameter D/S and to a lesser extent on the parameter l^2. The extreme values of l^2 expected in practical installations are 5 and 55. The K versus D/S curves at l^2 = 10 and for different specified conditions are plotted in Fig 10. The curves are based on formulas given in Dwight [B10] and Conangla and White [B9]. The loss factors shown in Fig 10 may be used for installations when the conductor center lines are parallel and coplanar, and the enclosure factor l^2 lies between 5 and 55.

Curves A, B, and C of Fig 10 cover three-phase installations. For these curves, the K factor involves the total loss in all three enclosures and is related to the full-line current I.

Curve A is applicable to a three-phase run carrying balanced currents. Curves B and C are applicable to that portion of a three-phase installation falling between single-phase taps, where one conductor carries the full-line current I and the other two conductors carry the phase current $I/\sqrt{3}$. Curve B applies when one of the outside conductors carries the line current I; curve C applies when the center conductor carries the line current I.

Curve D of Fig 10 is applicable to a two-conductor, single-phase tap and involves the total loss in both enclosures. For the convenience of grouping calculations as shown in the sample solution included in this standard, the K factors of Curve D are also related to the full-line current

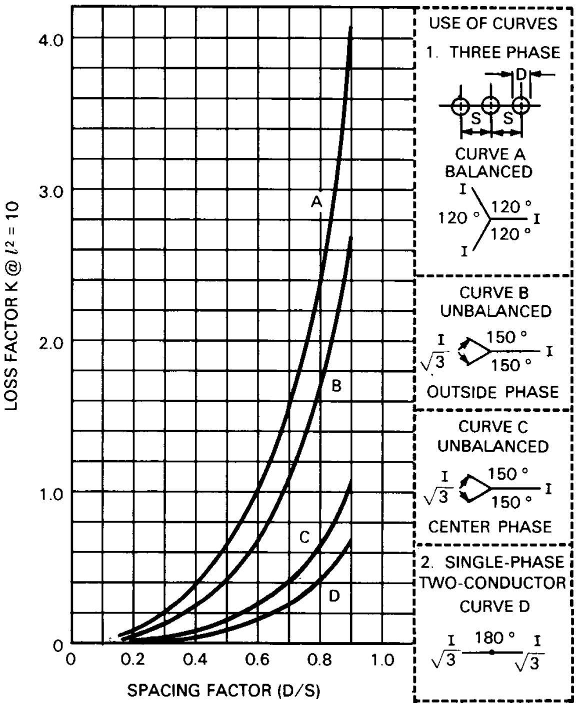


Fig 10
Loss Factors for Noncontinous Bus Enclosures

I. To relate Curve D to the actual single-phase current, the K factor must be multiplied by three.

Percent deviation of K versus D/S curves are also plotted in Fig 11. Curve E is applicable to balanced three-phase installations and is used in conjunction with Curve A. The curves show the percent that the value of K at $l^2 = 5$ and 55 deviates from the value of K at $l^2 = 10$. Deviation of K at other intermediate values of l^2 can be approximated by interpolation. Curve E can also be used in conjunction with Curves B and D with only slight error. Curve F should be used in conjunction with Curve C.

9.5 Power Consumption of Cooling Equipment. The power consumed by blowers, fans, circulating pumps, etc, used for force-cooling the buses should be considered a power loss in the evaluation of designs. Power requirements for cooling equipment should be stipulated by the manufacturer.

9.6 Sample Solutions. An isolated-phase bus installation is considered extending from the terminals of the 330 MVA, 20 kV generator to three single-phase, step-up transformers. The overall dimensions of the layout (Fig 9) are given in the following:

Conductor:
Round-tube 61% conductivity aluminum
Main three-phase bus: 14.5 inch outside diameter, 0.47 inch wall
Transformer taps: 8.5 inch outside diameter, 0.375 inch wall

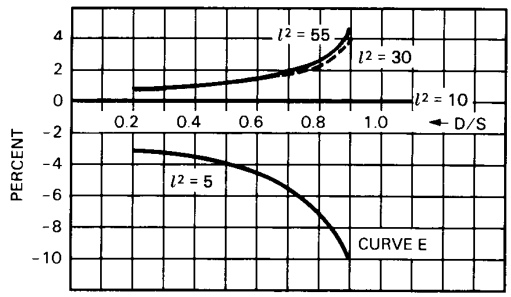
Enclosure:
Round 57% conductivity aluminum
29.5 inch outside diameter, 0.25 inch wall

Phase spacing:
$S = 41$ inch

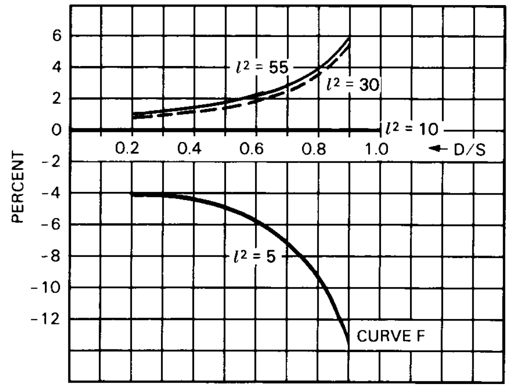
Construction:
Noncontinuous enclosure

Ratings:
Self-cooled, based on conductor 65 °C rise over 40 °C ambient
Main bus, 10 kA; taps, 6 kA

Losses are to be calculated assuming operation at the full-load rating of the generator, 9500 A, and a 40 °C ambient temperature.



DEVIATION OF K FROM VALUES SHOWN ON CURVES A, B, AND D



DEVIATION OF K FROM VALUES SHOWN ON CURVE C

Fig 11
Loss Factor Deviation Curves for Noncontinuous Bus Enclosures

9.6.1 Percent Loading

Main conductors:

$$\frac{9\,500}{10\,000} \cdot 100 = 95\%$$

Single-phase taps:

$$\frac{9500/\sqrt{3}}{6000} \cdot 100 = 91.4\%$$

9.6.2 Estimated Operating Temperatures. For conductors, Eq 1 is used.

Main conductors:
Temperature $= 40 + [(0.95)^{1.7} \cdot 65] = 99.6$ °C

Single-phase taps:
Temperature $= 40 + [(0.914)^{1.7} \cdot 65] = 95.8$ °C

For enclosures, Eq 9 is used.

Main conductors:
Temperature $= 40 + [(0.95)^{1.7} \cdot 40] = 76.7$ °C

Single-phase taps:
Temperature $= 40 + [(0.914)^{1.7} \cdot 40] = 74.3$ °C

9.6.3 DC Resistances. Eq 11 is used.

Main conductor:
d = 14.5 in; t = 0.47 in; γ = 61 (at 20 °C)

$$R_{\mathrm{dc}(20)} = \frac{259}{(14.5 - 0.47) \cdot 0.47 \cdot 61}$$
$$= 0.644\ \mu\Omega/\mathrm{ft}\ \text{at}\ 20\ °\mathrm{C}$$

Single-phase taps:
d = 8.5 in; t = 0.375 in; γ = 61 (at 20 °C)

$$R_{\mathrm{dc}(20)} = \frac{259}{(8.5 - 0.375) \cdot 0.375 \cdot 61}$$
$$= 1.394\ \mu\Omega/\mathrm{ft}\ \text{at}\ 20\ °\mathrm{C}$$

Enclosures:
d = 29.5 in; t = 0.25 in; γ = 57 (at 20 °C)

$$R_{\mathrm{dc}(20)} = \frac{259}{(29.5 - 0.25) \cdot 0.25 \cdot 57}$$
$$= 0.621\ \mu\Omega/\mathrm{ft}\ \text{at}\ 20\ °\mathrm{C}$$

9.6.4 Corrections for Operating Temperature. Eq 4 is used.

Main conductor:
Temperature = 99.6 °C; 61% conductivity

$$R_{\mathrm{dc}(99.6)} = R_{\mathrm{dc}(20)}\ [1 + 0.000066 \cdot 61(99.6 - 20)]$$
$$= 0.644\ (1.320)$$
$$= 0.850\ \Omega/\mathrm{ft}\ \text{at}\ 99.6\ °\mathrm{C}$$

Single-phase taps:
Temperature = 95.9 °C; 61% conductivity

$$R_{\mathrm{dc}(95.9)} = R_{\mathrm{dc}(20)}\ [1 + 0.000066 \cdot 61(95.9 - 20)]$$
$$= 1.394\ (1.306)$$
$$= 1.821\ \Omega/\mathrm{ft}\ \text{at}\ 95.9\ °\mathrm{C}$$

Enclosures:
Average temperature = 76.7 °C; 57% conductivity

$$R_{\mathrm{dc}(76.7)} = R_{\mathrm{dc}(20)}\ [1 + 0.000066 \cdot 57(76.7 - 20)]$$
$$= 0.621\ (1.213)$$
$$= 0.753\ \Omega/\mathrm{ft}\ \text{at}\ 76.7\ °\mathrm{C}$$

9.6.5 Skin Effect Correction

Main conductor:

$$\frac{t}{d} = \frac{0.47}{14.5} = 0.0324; \sqrt{\frac{f \cdot 10^3}{R_{\mathrm{dc}}}} = \sqrt{\frac{60 \cdot 10^3}{0.851}} = 265.5$$

From Fig 4:

$$\frac{R_{ac}}{R_{dc}} = 1.08$$

$$\begin{aligned} R_{ac} &= 1.08\, R_{dc(99.6)} \\ &= 1.08 \cdot 0.850 \\ &= 0.918\ \Omega/\text{ft at } 99.6\ ^\circ\text{C} \end{aligned}$$

Single-phase taps:

$$\frac{t}{d} = \frac{0.375}{8.5} = 0.0441; \sqrt{\frac{f \cdot 10^3}{R_{dc}}} = \sqrt{\frac{60 \cdot 10^3}{1.821}} = 181.5$$

From Fig 4:

$$\frac{R_{ac}}{R_{dc}} = 1.04$$

$$\begin{aligned} R_{ac} &= 1.04\, R_{dc(95.9)} \\ &= 1.04 \cdot 1.821 \\ &= 1.893\ \Omega/\text{ft at } 95.9\ ^\circ\text{C} \end{aligned}$$

Enclosures:

$$\frac{t}{d} = \frac{0.25}{29.5} = 0.0085; \sqrt{\frac{f \cdot 10^3}{R_{dc}}} = \sqrt{\frac{60 \cdot 10^3}{0.753}} = 282.3$$

From Fig 4:

$$\frac{R_{ac}}{R_{dc}} = 1.005$$

$$\begin{aligned} R_{ac} &= 1.005\, R_{dc(76.7)} \\ &= 1.005 \cdot 0.753 \\ &= 0.757\ \Omega/\text{ft at } 76.7\ ^\circ\text{C} \end{aligned}$$

9.6.6 Conductor Loss

Portion	$(kA)^2$	·	R_{ac}	·	*Length**	=	*Watts*
I_a	$(9.5)^2$		0.918		98.3		8 144
I_{a-b}	$(9.5/\sqrt{3})^2$		1.893		(23.4 + 20.0)		2 472
I_b	$(9.5)^2$		0.918		101.7		8 426
I_{b-c}	$(9.5/\sqrt{3})^2$		1.893		(46.6 + 16.6)		3 599
I_c	$(9.5)^2$		0.918		131.7		10 911
I_{c-a}	$(9.5/\sqrt{3})^2$		1.893		(43.2 + 86.8)		7 403
Total conductor loss, P_c:							40 955 W

*See Fig 9.

9.6.7 Enclosure Loss

Enclosure factor: Eq 7 is used.

$$l^2 = \frac{0.1915 \cdot 60}{0.757} = 15.18 \quad \text{(which lies between 5 and 55)}$$

Spacing factor:

Three-conductor runs and single-phase taps (see Fig 9):

$$\frac{D}{S} = (29.5 - 0.25) \div 41 = 0.713$$

Two-conductor, single-phase run (see Fig 9):

$$\frac{D}{S} = (29.5 - 0.25) \div (2 \cdot 41) = 0.357$$

9.6.8 Continuous Enclosure Construction

Cross-Connection Factor: Eq 14 is used.

Three-conductor, balanced-current run:
length = 100 ft, spacing = 41 in, $D/S = 0.713$

$$k_c = \frac{100 \cdot 12}{100 \cdot 12 + 41} + \left[\left(1 - \frac{1200}{1241}\right) \cdot 0.713\right]$$

$$= 0.967 + [(0.033)\,(0.713)] = 0.991$$

Three-conductor, unbalanced-current run:
length = 30 ft, spacing = 41 in, $D/S = 0.713$

$$k_c = \frac{30 \cdot 12}{(30 \cdot 12) + 41} + \left[\left(1 - \frac{360}{401}\right) \cdot 0.713\right]$$

$$= 0.898 + [(0.102)\,(0.713)] = 0.971$$

Two-conductor, single-phase run:
length = 30 ft, spacing = $2 \cdot 41$ = 82 in, $D/S = 0.357$

$$k_c = \frac{30 \cdot 12}{(30 \cdot 12) + 82} + \left[\left(1 - \frac{360}{442}\right) \cdot 0.357\right]$$

$$= 0.814 + [(0.186)\,(0.357)] = 0.880$$

Two-conductor, single-phase taps:
length = $30 \cdot 20$ = 60 ft, spacing = 41 in, $D/S = 0.713$

$$k_c = \frac{60 \cdot 12}{(60 \cdot 12) + 41} + \left[\left(1 - \frac{720}{761}\right) \cdot 0.713\right]$$

$$= 0.946 + [(0.054)\,(0.713)] = 0.985$$

Loss Factor:

Since $l^2 = 15.18$, from Eq 12

$$\cos\left[\cot^{-1}\left(4.61\, l^2 \log 2 \frac{S}{D}\right)\right] = 1$$

and

$$\frac{I_e}{I} = k_c$$

Three-conductor, balanced-current run:

$$K = 3\left(\frac{I_e}{I}\right)^2 = 3\,(0.991)^2 = 2.946$$

Three-conductor, unbalanced-current run:

$$K = \frac{5}{3}\left(\frac{I_e}{I}\right)^2 = \frac{5}{3}(0.971)^2 = 1.571$$

Two-conductor, single-phase run:

$$K = \frac{2}{3}\left(\frac{I_e}{I}\right)^2 = \frac{2}{3}(0.880)^2 = 0.516$$

Two-conductor, single-phase taps:

$$K = \frac{2}{3}\left(\frac{I_e}{I}\right)^2 = \frac{2}{3}(0.985)^2 = 0.647$$

For each portion, the enclosure loss is KI^2R_eL

$$I^2R_e = (9.5)^2 \cdot 0.757 = 68.3 \text{ W/ft}$$

Portion	I^2R_{ac} ·	K ·	*Length*	= *Watts*
Three-conductor, balanced	68.3	2.946	100	= 20 121
Three-conductor, unbalanced	68.3	1.571	30	= 3 219
Two-conductor, single-phase	68.3	0.516	30	= 1 057
Single-phase taps	68.3	0.647	60	= 2 651
Total enclosure loss, P_e:				27 048 W

Total Operating Loss at 9.5 kA (with Continuous Enclosure Construction):

$$P_{\text{total}} = P_c + P_e = 40\,955 + 27\,048 = 68\,003 \text{ W}$$

9.6.9 Noncontinuous Enclosure Construction.

Equation 7 is used, with K to suit, as follows:

Three-conductor, balanced-current run:
length = 100 ft; D/S = 0.713. Figure 10, Curve A: K = 1.65; Curve E: deviation = 1%, ∴ K = 1.65 (1.01) = 1.67. (Factor K covers total loss in three enclosures.)

Three-conductor, unbalanced-current run with line current in outside conductor:
length = 30 ft; D/S = 0.713. Figure 10, Curve B: K = 1.125; Curve E: deviation = 1%, ∴ K = 1.125 (1.01) = 1.14. (Factor K covers total loss in three enclosures.)

Two-conductor, single-phase run:
length = 30 ft; D/S = 0.357. Figure 10, Curve D: K = 0.025; Curve E: deviation, less than 1%, can be ignored. (Factor K covers total loss in two enclosures.)

Two-conductor, single-phase taps:
length = 3 · 20 = 60 ft; D/S = 0.713. Figure 10, Curve D: K = 0.28; Curve E: deviation = 1%, ∴ K = 0.28 (1.01) = 0.283. (Factor K covers total loss in two enclosures.)

For each portion, the enclosure loss is $P_e = KI^2R_eL$

$$I^2R_e = 0.757 \cdot (9.5)^2 = 68.3 \text{ W/ft}$$

Portion	I^2R_e ·	K ·	*Length*	= *Watts*
Three-conductor, balanced	68.3	1.67	100	= 11 406
Three-conductor, unbalanced	68.3	1.14	30	= 2 336
Two-conductor, single-phase	68.3	0.025	30	= 51
Single-phase taps	68.3	0.283	60	= 1 160
Total enclosure loss, P_e:				14 953 W

Force-Cooling Loss: In this case, there is none.

Total Operating Loss at 9.5 kA (with Continuous Enclosure Construction)

$$P_{\text{total}} = P_c + P_e = 40\,955 + 14\,953 = 55\,908 \text{ W}$$

9.7 Structural Steel Losses. This section is included to point out additional losses that could occur if due consideration is not given to the relationship of the bus to nearby structural members and piping. The data will assist the user in determining where corrective measures are required or in estimating the magnitude of losses in existing installations. If a troublesome condition is suspected during the design stage, it is recommended that corrective measures be adopted at that time. Losses in structures external to the bus installation should be excluded from loss calculations used in economic evaluations, since such heat losses cannot be predicted with any great accuracy.

Losses in structural steel near conductors carrying heavy currents are caused by:

(1) Circulating currents flowing in closed metallic loops that link the magnetic flux associated with the conductor currents. These loops usually include structural members running in a direction parallel to the longitudinal axis of the bus run. The circulating current loss is avoided by breaking the electrical continuity of the loops, by physical gaps, or with insulation inserted at some convenient point.

(2) Hysteresis and eddy currents due to flux contained in magnetic material members. Steel supports or pipes in close proximity, and running in a direction normal to the longitudinal axis of the bus run, are likely to heat up due to this effect.

The magnetic flux in such members is minimized by using low-resistance short-circuited bands at locations where they pass over the main conductors.

The supporting structure furnished as part of an isolated-phase bus installation should include insulated joints and short-circuited bands in the proper locations to avoid or minimize losses due to these effects. With such measures, the losses in the supporting structure are negligible and should not be considered in overall loss evaluation.

The continuous enclosure construction constitutes a means for minimizing losses in nearby structures. Other recognized means are the opening of closed conductive loops to avoid circulating currents, the installation of short-circuited bands around steel members to reduce the magnetic flux in them, and the interposition of amortisseur grids or plates to shield the structural members from the flux produced by the conductor currents.

10. Bibliography

10.1 Standards. The following pertinent standards are suggested for further study and better understanding of this standard:

[B1] ANSI C37.11-1979, American National Standard Requirements for Electrical Control for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis or a Total Current Basis.

[B2] ANSI C84.1-1982, American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz).

[B3] ANSI/IEEE C37.13-1981, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

[B4] ANSI/IEEE C37.26-1972, IEEE Guide for Methods of Power Factor Measurements for Low-Voltage Inductive Test Circuits.

[B5] ANSI/IEEE C57.13-1978, IEEE Standard Requirements for Instrument Transformers.

[B6] ANSI/IEEE Std 1-1986, IEEE Standard General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation.

[B7] ANSI/IEEE Std 142-1982, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.

[B8] ANSI/NFPA 70-1987, National Electrical Code.

10.2 Other Publications. It is recommended that those responsible for the layout of isolated-phase bus, study the material listed, particularly [B14] to circumvent possible troublesome conditions in the early stages of design:

[B9] CONANGLA, A. and WHITE, H. F. Isolated-Phase Bus Enclosure Loss Factors. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-87, pp 1622-1628, July 1968.

[B10] DWIGHT, H. B. *Electrical Coils and Conductors*. New York: McGraw-Hill, 1945.

[B11] DWIGHT, H. B. Some Proximity Effect Formulas for Bus Enclosures. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-83, pp 1167-1172, Dec 1964.

[B12] ELGAR, E. C., REHDER, R. H. and SWERDLOW, N. Measured Losses in Isolated-Phase Bus and Comparison With Calculated Values. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-87, 1724-1730, Aug 1968.

[B13] NIEMOLLER, A. B. Isolated-Phase Bus Enclosure Currents. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-87, pp 1714-1718, Aug 1968.

[B14] SWERDLOW, N. and BUCHTA, M. A. Practical Solutions of Inductive Heating Problems Resulting from High-Current Buses. *AIEE Transactions on Power Apparatus and Systems*, vol 78, part IIIB, pp 1736-1746, 1959 (Feb 1960 section).

NOTE: Swerdlow and Buchta give data for estimating the average temperature rise due to hysteresis and eddy currents in steel members in proximity to unenclosed buses carrying large currents. They also give data on the effects of shielding devices and on methods for determining power losses by determination of the energy loss from the steel by radiation and convection. Although primarily concerned with unenclosed buses, they include rules for application of the data to isolated-phase buses.

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