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Electric Power Connection for Substations

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CONTENTS

Page

Foreword iv

Section 1 GENERAL

1.1 Scope 1
1.2 References 1
1.3 Definitions 1

Section 2 RATING STANDARDS

2.1 Current Ratings for Bare Copper Conductors 5
2.2 Current Ratings for Bare Aluminum Conductors 7
2.2.1 The 60-Hertz Current Ratings of Aluminum Conductors When Used Indoors 7
2.2.2 The Current Ratings for the Aluminum Tubing Conductivities 8
2.3 Ratings for HV, EHV, and UHV Power Connectors 9
2.4 Rated Frequency 9
2.5 Basis of Temperature Rise 9
2.5.1 Temperature Rise of the Conductor 9
2.5.2 Temperature Rise of the Conductor Having the Highest Temperature Rise 9
2.5.3 Average Temperature of an Expansion Electric Power Connector 9
2.6 Pullout Strength 10
2.7 Cantilever Strength of Bus Supports 10
2.8 Torque Strength of Bolted Connector 10
2.9 Aluminum Weldment Couplers 10

Section 3 TESTING STANDARDS

3.1 Temperature Rise Tests 11
3.1.1 Temperature Rise Tests Conducted either Indoors or Outdoors 11
3.1.2 Eliminate Heat Sinks or Hot Spots on the Test Loop 11
3.1.3 The Values of the Current to be Used in Making Temperature Rise Tests 11
3.1.4 Expansion Connectors Measurements 12
3.2 Pullout Strength Tests 12
3.3 Corona and RIV Tests 12
3.3.1 Connectors shall be Tested while Assembled with the Conductor 12
3.3.2 Tests Performed under Single-Phase Conditions 12
3.3.3 Observations for Visual Corona 13
3.3.4 RIV Measurements 13
3.4 Cantilever Strength of Bus Supports 13
3.5 Torque Strength Test of Bolted Connectors 14
3.6 Tensile Test of Welded Couplers 14
3.7 Bending Test of Welded Couplers 14

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Section 4 MANUFACTURING STANDARDS

4.1 Clamping Fasteners for Connectors 16
4.1.1 Clamping Fasteners for Copper Electric Power Connectors 16
4.1.2 Clamping Fasteners for Aluminum Electric Power Connectors 16
4.2 Identification Marking 16
4.3 Designation of Connector Sizes 16
4.4 Thread Dimensions for Stud<R>Terminal Connectors 16
4.5 Bolt Holes for Terminal Connectors with Single Tangs or Multiple Flat Bar Tangs 17
4.6 Number and Diameter of Conductor Clamping Bolts for Connectors 17
4.6.1 Number and Diameter of Conductor Clamping Bolts Illustration 17
4.6.2 Examples Illustrating the Use of the Table in 4-1 22
4.7 Expansion Connectors 23
4.8 Terminal Connectors 23
4.9 Flat Plain Washers 23
4.10 Height of Aluminum and Copper Bus Support Clamps (Fittings) 24
4.11 Height of Aluminum Side Formed Terminal Connectors for Tubular Bus 24
4.12 Recommendation for Making Connections 25
4.13 Tongue Mounting Fasteners 25

Tables

Table 2-1 Current Ratings for Bare Copper Conductors 5
Table 2-2 Current Ratings for Bare Copper Conductors 6
Table 2-3 Current Ratings for Bare Aluminum Conductors 7
Table 2-4 Current Ratings for Bare Aluminum Conductors 8
Table 4-1 Connector Clamping Bolts for Connectors 20
Table 4-2 Nominal Torque Values 22
Table 4-3 Height of Aluminum and Copper Bus Support Clamps (Fittings) 24
Table 4-4 Height of Aluminum Side Formed Terminal Connectors for Tubular Bus 24
Table A-2 Dimensions in MM 27
Table A-3 Dimensions in MM 28
Table A-4 9 Hole, Dimensions in MM 29

Figures

Figure 3-1 Thermocouple Locations 12
Figure 3-2 Conductor Voltage Gradient for Single Conductor 13
Figure 3-3 Conductor Voltage Gradient for Bundled Conductor 14
Figure 3-4 Line to Ground Voltage for Single Conductor (Three Phase) 14
Figure 3-5 Line to Ground Voltage for Bundled Conductor (Three Phase) 15
Figure 4-1 Bolt Holes for Terminal Connectors 18
Figure 4-2 Bolt Holes for Terminal Connectors 18
Figure 4-3 Bolt Holes for Terminal Connectors 18
Figure 4-4 Bolt Holes for Terminal Connectors 18
Figure 4-5 Bolt Holes for Terminal Connectors 19

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Figure 4-6 Bolt Holes for Terminal Connectors 19
Figure 4-7 Typical Spacing for Multiple Flat Bar Tangs 19
Figure 4-8 Typical Spacing for Multiple Flat Bar Tangs 19
Figure 4-9 Typical Spacing for Multiple Flat Bar Tangs 19
Figure A-1 Bolt Holes for Terminal Connectors 26
Figure A-2 Bolt Holes for Terminal Connectors, Dimensions in MM 27
Figure A-3 Germany 8 Holes Bolt for Terminal Connectors, Hole Dimensions in MM 28
Figure A-4 Bolt for Terminal Connectors 29

Appendix

Appendix A Bolts for Terminal Connectors 26

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Foreword

The purpose of this publication is to provide standard test methods and performance requirements for the electrical and mechanical characteristics of connectors under normal operating conditions.

User needs in the development of this Standards Publication have been recognized through the normal marketing determination of customer acceptance done by individual NEMA members, and through the procedures inherent in its approval as an American National Standard.

The Electrical Connector Section of NEMA, in its constant review of the publication, continues to seek out the views of responsible users which will contribute to the development of better standards.

These standards are periodically reviewed by the Electrical Connector Section for any revisions necessary to keep them up to date with advancing technology. Proposed or recommended revisions are welcome and should be submitted to:

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Rosslyn, Virginia 22209

This Standards Publication was developed by the Electrical Connector Section of the National Electrical Manufacturers Association. At the time it was approved, the Electrical Connector Section had the following members:

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Section 1
GENERAL

1.1 SCOPE

This Standards Publication covers uninsulated connectors and bus supports which are made of metal and intended for use in substations. Connectors which are supplied in equipment are covered by the appropriate equipment standards and are excluded from this Standards Publication.

1.2 REFERENCES

The following publications are adopted in part, by reference in this publication, and are available from the organizations below:

American National Standards Institute (ANSI)
11 West 42nd Street
New York, NY 10036

B18.2.1-1981	*Standard for Square and Hex Bolts and Screws including Askew Head Bolts, Hex Cap Screw and Lag Screws*
B18.2.2-1987	*Square and Hex Nuts*
B18.22.1-1981	*Standard for Plain Washers*
B18.21.1-1983	*Standard for Lock Washers*
738-1989	*Calculation of Bare Overhead Conductor Temperature and Ampacity for Steady-State Conditions*

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107-1987	*Methods of Measurements of Radio Influence Voltage of High Voltage Apparatus*

1.3 DEFINITIONS

angle connector: An angle connector joins two conductors end to end at a specified angle.

angle of a connector: The angle of a connector is: a) In the case of an angle connector, the deflected angle. b) In the case of a branch connector, the least angle between the branch and the main conductor.

bolted-type connector: In a bolted-type connector, the contact between the conductor and the connector is made by pressure exerted by one or more clamping bolts.

branch connector: A branch connector is an angle connector which joins a branch conductor to the main conductor at a specified angle.

bus support: A bus support is a metal member, usually mounted on an insulator, which supports a bus conductor.

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combined "t" and straight connector ("t" coupler): A combined "T" and straight connector joins two main conductors end to end and also joins a branch conductor to the main conductors at an angle of 90 degrees.

conductor: A conductor is constructed from conducting material so that it may be used as a carrier of electric current.

connector: A connector is a device which joins two or more conductors for the purpose of providing a continuous electrical path.

cross connector: A cross connector joins two branch conductors to the main conductor. The branch conductors are opposite to each other and perpendicular to the main conductor.

design tests: Design tests are made on the completion of the development of a new design to establish representative performance data. They need to be repeated only if the design is changed to modify its performance.

HV (high voltage), EHV (extra-high-voltage), and UHV (ultra-high-voltage), power connectors: A HV, EHV, or UHV power connector is a connector, bus support, or other device which, when installed on its conductor, does not generate corona or noise at nominal voltage.

expansion connector: An expansion connector provides a flexible connection between rigid conductors or between a rigid conductor and electrical apparatus.

hot-line clamp (live-line connector): A hot-line clamp is a connector which shall be permitted to be installed while the conductor is energized.

"L" connector: An "L" connector is an angle connector which joins two conductors end to end at an angle of 90 degrees.

main conductor (run): A main conductor is a continuous conductor from which other conductors branch.

pad (solid or laminated block) angle terminal connector: A pad (solid or laminated block) angle terminal connector joins a conductor to the terminal pad (solid or laminated block) of electrical apparatus at a specified angle.

pad (solid or laminated block) terminal connector: A pad (solid or laminated block) terminal connector joins a conductor to the terminal pad (solid or laminated block) of electrical apparatus.

parallel connector: A parallel connector joins two parallel conductors which may overlap each other.

pressed-tubular terminal connector: A pressed-tubular terminal connector is fabricated or pressed from tubing.

pressure-type connector: In a pressure-type connector the pressure to fix the connector to the electrical conductor is applied by integral screw, cone, or other mechanical parts.

range-taking (multisize) connector: A range-taking connector accommodates more than one conductor size.

routine tests: Routine tests are made to verify the quality and uniformity of the workmanship and materials used in the manufacture of electric power connectors.

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service connector: A service connector is a parallel connector in which the contact between the conductors is obtained by mechanically applied pressure.

shrink-fit-type connector: In a shrink-fit-type connector the contact between the conductor and the connector is made by a shrink fit.

single-size connector: A single-size connector accommodates only one conductor size.

soldered-type connector: In a soldered-type connector the contact between the conductor and the connector is made by a soldered joint.

split-sleeve connector: A split sleeve connector is of split-sleeve form and is tinned for soldering.

straight adapter connector (straight adapter): A straight adapter connector joins two conductors of different shapes end to end in a straight line.

straight connector: A straight connector joins two lengths of conductor end to end in a straight line.

straight coupler connector (coupler): A straight coupler connector joins two conductors of equal sizes end to end in a straight line.

straight reducer connector (reducer): A straight reducer connector joins two conductors of unequal sizes end to end in a straight line.

stud angle terminal connector: A stud angle terminal connector joins a conductor to the round terminal stud of electrical apparatus at a specified angle.

stud terminal connector: A stud terminal connector joins a conductor to the round terminal stud of electrical apparatus.

"T" connector: A "T" connector is a branch connector which joins a branch conductor to the main conductor at an angle of 90 degrees.

tang: A tang is that portion of a connector which is used to fasten a connector to a terminal pad.

tap conductor: A tap conductor branches off from a main conductor.

terminal connector: A terminal connector joins a conductor to a lead, terminal pad (solid or laminated block), or round terminal stud of electrical apparatus.

terminal pad: A terminal pad is the (usually) flat conducting part of a device to which a terminal connector is fastened.

threaded-type connector: In a threaded-type connector the contact between the conductor and the connector is made by pressure exerted on a threaded part.

twisted sleeve connector: A twisted sleeve connector is a parallel connector in which the contact between the conductors is obtained by forming a spiral twist in the connector and conductors after they are assembled.

"V" connector: A "V" connector joins two branch conductors to a main conductor. The branch conductors are perpendicular to the main conductor and have an included angle between them of less than 180 degrees.

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wedge-type connector: In a wedge-type connector the contact between the conductor and the connector is made by pressure exerted by a wedge.

"Y" connector: A "Y" connector joins two branch conductors to the main conductor at an angle. The three conductors are in the same plane.

weld-type connector: In a weld-type connector the contact between the conductor and the connector is made by welding.

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Section 2
RATING STANDARDS

2.1 CURRENT RATINGS FOR BARE COPPER CONDUCTORS

The 60-hertz current ratings of IACS copper conductors having a conductivity of 98 percent shall be in accordance with Tables 2-1 and 2-2 when used indoors. When conductors are used outdoors and are subjected to air currents, weathering, and so forth, the current rating shall be in accordance with Tables 2-1 and 2-2.

Table 2-1
CURRENT RATINGS FOR BARE COPPER CONDUCTORS

		Current Ratings, Amperes*	
(1)		(2)	(3)
Size of Conductors		Indoor**	Outdoor†
Solid Wire			
0 AWG	(54 mm^2)	160	250
00 AWG	(67 mm^2)	190	290
0000 AWG	(107 mm^2)	260	390
Stranded Wire			
0 AWG	(54 mm^2)	160	250
00 AWG	(67 mm^2)	190	300
0000 AWG	(107 mm^2)	270	400
250 MCM	(127 mm^2)	290	430
400 MCM	(203 mm^2)	410	580
500 MCM	(253 mm^2)	480	670
600 MCM	(304 mm^2)	540	750
750 MCM	(380 mm^2)	630	860
1000 MCM	(507 mm^2)	770	1030
1500 MCM	(760 mm^2)	1000	1310
2000 MCM	(1013 mm^2)	1190	1530

NOTES—Table 2-1 calculated according to ANSI/IEEE STD 738-11/89

*The distance between conductors shall be at least 18 inches (457 mm) but in the event it is less than 18 inches (457 mm) the proximity effect should be taken into consideration.

** Indoor ratings are calculated for a 30° rise above the ambient temperature of 40°C in still but unconfined air and a surface emissivity, e, equal to 0.35.

† Outdoor ratings are given for a wind velocity of 2 feet per second (0.6 meters per second), an ambient air temperature of 40°C and a conductor temperature of 70°C (30°C rise) emissivity, e, equal to 0.35.

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Table 2-2
CURRENT RATINGS FOR BARE COPPER CONDUCTORS

(1) Standard Pipe Size		Current Ratings, Amperes* (2) Indoor**		(3) Outdoor†	
		Schedule	Schedule	Schedule	Schedule
Inches	(mm)	40	80	40	80
1/2	(12.7)	380	420	510	580
3/4	(19.0)	540	590	710	780
1	(25.4)	650	750	850	1010
1-1/4	(31.8)	870	975	1120	1250
1-1/2	(38.1)	1020	1150	1280	1450
2	(50.8)	1250	1500	1550	1850
2-1/2	(63.5)	1700	1975	2000	2400
3	(76.2)	2175	2475	2550	2950
3-1/2	(88.9)	2575	2875	3050	3400
4	(101.6)	2850	3100	3400	3800
5	(127.0)	3450	3850	4100	4600
6	(152.4)	4000	4500	4700	5200

NOTES—*The distance between conductors shall be at least 18 inches (457 mm), but in the event it is less than 18 inches (457 mm), the proximity effect should be taken into consideration.

** Indoor ratings are calculated for a 30° rise above the ambient temperature of 40°C in still but unconfined air.

† Outdoor ratings are given for a wind velocity of 2 feet per second (0.6 meters per second), an ambient air temperature of 40°C and a conductor temperature of 70°C (30°C rise).

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2.2 CURRENT RATINGS FOR BARE ALUMINUM CONDUCTORS

2.2.1 The 60-Hertz Current Ratings of Aluminum Conductors When Used Indoors

The 60-hertz current ratings of aluminum conductors, when used indoors, shall be in accordance with Tables 2-3 and 2-4. When aluminum conductors are used outdoors and are subjected to air currents, weathering, and so forth, the current rating shall be in accordance with Tables 2-3 and 2-4.

Table 2-3
CURRENT RATINGS FOR BARE ALUMINUM CONDUCTORS

(1) Size of Conductors		Current Ratings, Amperes* (Based Upon 57-61 Percent Conductivity)** (2) Indoor††	(3) Outdoor††
	Solid Wire		
0 AWG	(54 mm^2)	120	190
00 AWG	(67 mm^2)	140	220
0000 AWG	(107 mm^2)	210	300
	Stranded Wire		
0 AWG	(54 mm^2)	130	200
00 AWG	(67 mm^2)	150	230
0000 AWG	(107 mm^2)	200	320
250 MCM	(127 mm^2)	240	350
400 MCM	(203 mm^2)	340	480
500 MCM	(253 mm^2)	400	550
600 MCM	(304 mm^2)	450	620
750 MCM	(380 mm^2)	530	720
1000 MCM	(507 mm^2)	650	870
1500 MCM	(760 mm^2)	850	1110
2000 MCM	(1013 mm^2)	1030	1320

NOTES—Table 2-3 calculated according to ANSI/IEEE STD 738-11/89

*The distance between conductors shall be at least 18 inches (457 mm), but in the event it is less than 18 inches (457 mm) the proximity effect should be taken into consideration.

** Tubing available in other conductivity values will affect this table. See 2.2.2 below.

† Indoor ratings are calculated for a 30°C rise above the ambient temperature of 40°C in still but unconfined air and a surface emissivity, e, equal to 0.35.

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2.2.2 The Current Ratings for the Aluminum Tubing Conductivities

For the aluminum tubing conductivities, the current ratings should be adjusted in accordance with the following formula:

$$I(\text{New Alloy}) = I\ (53\%)\ \frac{\text{Conductivity of New Alloy}}{0.53}$$

Table 2-4
CURRENT RATINGS FOR BARE ALUMINUM CONDUCTORS

(1) Standard Pipe Size		Current Ratings, Amperes* (Based Upon 53 Percent Conductivity)**			
		(2) Indoor**		(3) Outdoor†	
		Schedule	Schedule	Schedule	Schedule
Inches	(mm)	40	80	40	80
1/2	(12.7)	315	360	400	455
3/4	(19.0)	400	455	495	565
1	(25.4)	535	605	650	740
1-1/4	(31.8)	680	780	810	930
1-1/2	(38.1)	790	910	930	1070
2	(50.8)	1000	1175	1155	1355
2-1/2	(63.5)	1365	1570	1550	1780
3	(76.2)	1670	1935	1895	2195
3-1/2	(88.9)	1945	2265	2170	2530
4	(101.6)	2230	2605	2460	2880
4-1/2	(114.3)	2515	2955	2750	3230
5	(127.0)	2845	3355	3080	3635
6	(152.4)	3500	4205	3735	4490

NOTES—*The distance between conductors shall be at least 18 inches (457 mm), but in the event it is less than 18 inches (457 mm), the proximity effect should be taken into consideration.

** Indoor ratings are calculated for a 30° rise above the ambient temperature of 40°C in still but unconfined air.

† Outdoor ratings are given for a wind velocity of 2 feet per second (0.6 meters per second), an ambient air temperature of 40°C and a conductor temperature of 70°C (30°C rise).

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2.3 RATINGS FOR HV, EHV, AND UHV POWER CONNECTORS (See 3.4.)

The ratings of EHV power connectors shall be based on the following minimum design phase spacings and distances from ground plane. These are the maximum test conditions. The visual corona and audible noise extinctions test voltage shall be at least 10 percent greater than the nominal operating voltage. The radio influence voltage (RIV) level shall be below 200 microvolts at this voltage. All tests shall be conducted under laboratory conditions.

Nominal Operating Voltage	Minimum Phase Spacing		Minimum Distance from Ground plane	
kV	Feet	(meter)	Feet	(meter)
230	11	(3.4)	15	(4.6)
345	16	(4.9)	25	(7.6)
500	25	(7.6)	30	(9.1)
765	45	(13.7)	45	(13.7)
1100	55	(16.8)	55	(16.8)

high voltage (HV): A nominal system voltage not exceeding 230 kilovolts.

extra high voltage (EHV): A nominal system voltage that is greater than 230 kilovolts but less than 1100 kilovolts.

ultra high voltage (UHV): A nominal system voltage that is equal to or greater than 1100 kilovolts.

2.4 RATED FREQUENCY

The rated frequency of the power connectors covered by this publication shall be 60 hertz.

2.5 BASIS OF TEMPERATURE RISE (See 3.1.)

2.5.1 Temperature Rise of the Conductor

The temperature rise of an electric power connector shall not exceed the temperature rise of the conductor with which it is intended to be used.

2.5.2 Temperature Rise of the Conductor Having the Highest Temperature Rise

The temperature rise of an electric power connector which connects conductors of varying sizes shall not exceed the temperature rise of the conductor having the highest temperature rise.

2.5.3 Average Temperature of an Expansion Electric Power Connector

The average temperature of an expansion electric power connector shall be in accordance with 2.5.1. The hot-spot temperature rise shall not exceed the average temperature rise by more than 10°C.

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2.6 PULLOUT STRENGTH (See 3.2.)

The pullout strength of connector shall be as follows:

Wire or Cable Size AWG or MCM (mm^2)		Minimum Pullout Strength, Pounds (kg)	
6-1/0	(13-54)	300	(136)
2/0-4/0	(67-107)	500	(227)
250-500	(127-253)	1000	(454)
above 500	(above 253)	2000	(907)

2.7 CANTILEVER STRENGTH OF BUS SUPPORTS (See 3.3.)

The minimum cantilever strength of bus supports shall be as follows:

Bronze Pounds (kg)	Aluminum Pounds (kg)
500 (227)	2000 (907)

2.8 TORQUE STRENGTH OF BOLTED CONNECTOR

The connector shall withstand, without damage, a torque value 50 percent over the torque values given in Table 4-2, Nominal Torque Values. Damage is defined as any crack or opening detected by the naked eye.

2.9 ALUMINUM WELDMENT COUPLERS

The strength of the coupler shall be such that failure will occur in the annealed tubular bus when subjected to either a tensile or bending test.

The welded connections shall have an electrical conductivity equal to or greater than the original bus. The recommended welding methods are tungsten inert gas (TIG) or metallic inert gas (MIG).

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Section 3
TESTING STANDARDS

3.1 TEMPERATURE RISE TESTS

3.1.1 Temperature Rise Tests Conducted either Indoors or Outdoors

At the discretion of the manufacturers, temperature rise tests on electric power connectors shall be permitted to be conducted either indoors or outdoors. The temperature rise shall be determined at 100, 125, and 150 percent of the rated current, with equilibrium temperatures obtained at each level. Equilibrium temperature is defined as a constant temperature (2°C) between three successive measurements. Measurements are made at the end of the first 30 minutes and at one hour intervals thereafter until completion of the test. The current values used shall be based on the following:

	For Rated Current Values When Temperature Rise Test Is Conducted	
Type of Conductor	**Indoors**	**Outdoors**
Bare Copper	See Col. 2 of Tables 2-1 and 2-2	See Col. 3 of Tables 2-1 and 2-2
Bare Aluminum	See Col. 2 of Tables 2-3 and 2-4	See Col. 3 of Tables 2-3 and 2-4

This test is not intended to qualify the connectors for service higher than the normal rating (2.1, 2.2).

3.1.2 Eliminate Heat Sinks or Hot Spots on the Test Loop

Conductors of the correct size and type shall extend a minimum of 4 feet (1.2 meters) from each opening of the connector to the point where connection is made to the circuit, in order to eliminate heat sinks or hot spots on the test loop.

3.1.3 The Values of the Current to be Used in Making Temperature Rise Tests

The values of the current to be used in making temperature rise tests for the various general types of connectors shall be determined in accordance with the following:

a) Terminal Connectors - the values of rated current shall be selected on the basis of the rating of the equipment to which the connector is connected, or on the basis of the rating of the conductor for which the opening is designed, whichever is smaller.

b) Angle and Straight Connectors - the values of current shall be selected on the basis of the conductor which has the lower current-carrying value where the openings are of two sizes, and on the basis of the conductor which is common to both openings where the openings are of the same size.

c) "T" Connectors - the values of current shall be selected on the basis of the full-rated current in the tap conductor or in the run conductor if the run conductor is the smaller.

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3.1.4 Expansion Connectors Measurements

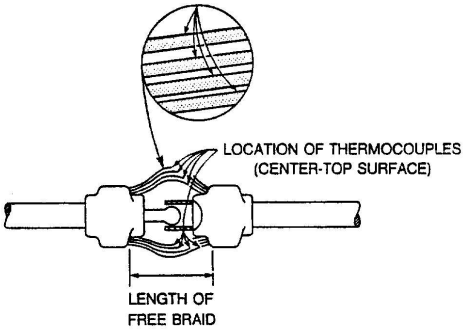


Figure 3-1
THERMOCOUPLE LOCATIONS

On expansion connectors measurements shall be made in accordance with the following:

a) Thermocouples shall be attached to the top surface of the individual flexible elements at the center of the free length. (See Figure 3-1.)
b) The temperature of each flexible element forming the entire connector shall be measured. The highest temperature shall be recorded and compared to the requirements given in 2.5.
c) All of the temperature measurements shall be averaged to obtain the average temperature rise of the expansion connector.

3.2 PULLOUT STRENGTH TESTS

The pullout strength test of connector fittings shall be made with both the maximum and minimum size of conductor, either aluminum or copper, which is normally used with each particular connector. The connector shall be fastened to the conductor and the clamping bolts tightened in accordance with the manufacturer's recommendation. The load shall be applied between the jaws at a crosshead speed not exceeding 1/4 inch per minute per foot of length (20.8 mm per minute per meter of length).

3.3 CORONA AND RIV TESTS

3.3.1 Connectors shall be Tested while Assembled with the Conductor

Connectors shall be tested while assembled with the conductor on which they are to be used. Dimensionally equivalent tubing shall be permitted to be substituted for stranded conductors. The connector and conductor to be tested shall be in a clean, dry, and new condition.

3.3.2 Tests Performed under Single-Phase Conditions

Tests shall be permitted to be performed under single-phase conditions but must be corrected to the connector rating at the center phase of the three-phase condition. This shall be done as follows:

a) Determine the conductor voltage gradient by using the corona-extinction test voltage and the test condition in the formulae in Figures 3-2 and 3-3.
b) Determine the line-to-ground voltage at which the connector will operate by using the voltage gradient determined in item 1 and the actual "operating rating" conditions in the formulae in Figures 3-4 and 3-5.

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Where:

h = distance from center of conductor to ground plane, centimeters.
r = radius of the individual conductor, centimeters.
s = conductor centerline spacing in the bundle, centimeters.
d = phase-to-phase spacing of bundle centerlines, centimeters.
V1 = line-to-ground corona-extinction test voltage, kV.
V2 = line-to-ground corona-extinction operating voltage, kV.
Ea = average voltage gradient at the surface of the conductor, kV/cm.
Em = maximum voltage gradient at the surface of a single conductor, kV/cm.
r_e = equivalent single-conductor radius of bundled conductors, centimeters.
n = number of conductors in the bundle.
g = for 1-, 2- and 3- conductor bundles, = 1; for 4-conductor bundles, = 1.12.
ln = natural logarithm.

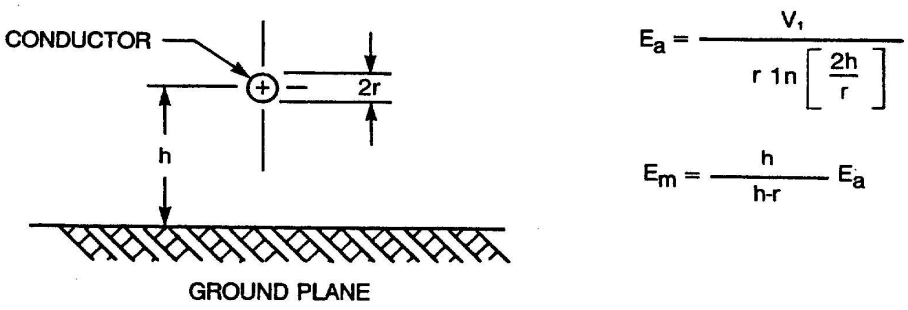


Figure 3-2
CONDUCTOR VOLTAGE GRADIENT
FOR SINGLE CONDUCTOR

3.3.3 Observations for Visual Corona

Observations for visual corona shall be made in a darkened area after the eye has adapted to the dark. Binoculars can be used to locate and observe presence or absence of positive corona, neglecting any negative glow corona, as only the positive corona contributes significantly to the radio noise. A voltage up to 30 percent overvoltage shall be applied to establish the critical corona location, if any. The corona extinction voltage shall be observed as the voltage is decreased.

3.3.4 RIV Measurements

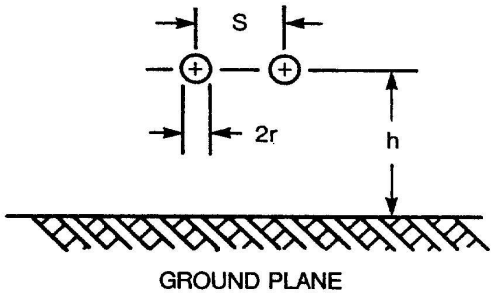
RIV measurements shall be made in accordance with the NEMA Standards Publications No. 107-1987, Methods of Measurements of Radio Influence Voltage (RIV) of High Voltage Apparatus. The RIV measurements shall be permitted to be omitted if the test set-up allows complete visual observation and all sources of corona have been identified.

3.4 CANTILEVER STRENGTH OF BUS SUPPORTS

The cantilever strength shall be determined by applying a load at the centerline of the conductor, transverse to the conductor longitudinal axis. The bus support shall be bolted to a flat surface, using the hardware recommended by the manufacturer.

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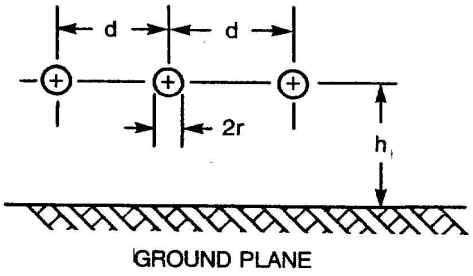
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$$E_a = \frac{V_1}{n\ r\ 1n\left[\frac{2h}{r_e}\right]}$$

$$r_e = r\left[\gamma\frac{s}{r}\right]^{\frac{n-1}{n}}$$

Figure 3-3
CONDUCTOR VOLTAGE GRADIENT FOR BUNDLED CONDUCTOR



$$V_2 = E_a\ r\ 1n\left[\frac{2hd}{r\sqrt{4h^2+d^2}}\right]$$

Figure 3-4
LINE TO GROUND VOLTAGE FOR SINGLE CONDUCTOR (THREE PHASE)

3.5 TORQUE STRENGTH TEST OF BOLTED CONNECTORS

The conductor(s) shall be assembled in the connector and the bolts torqued uniformly and alternately in 100 pound-inch (11.3 N-m) increments until 50 percent over the nominal torque value is achieved (4.6).

3.6 TENSILE TEST OF WELDED COUPLERS

The spliced conductor, with the coupler in between, shall be fastened in a tensile testing machine and a load shall be applied at a crosshead speed not exceeding 1/4 inch per minute per foot (20.8 mm per minute per meter).

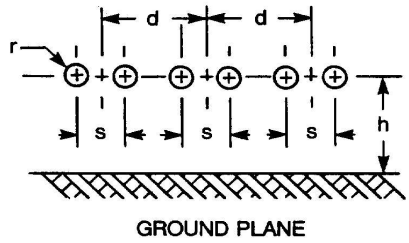
3.7 BENDING TEST OF WELDED COUPLERS

A load shall be applied at two points, at a distance of three inches (76.2 mm) from the weld transverse, to the conductor longitudinal axis.

The conductor shall be freely supported at each end.

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$$\dot{V}_2 = E_a \; n \; r \; 1n \left[\frac{2hd}{r_e \sqrt{4h^2+d^2}} \right]$$

$$r_e = r \left[\gamma \frac{s}{r} \right]^{\frac{n-1}{n}}$$

Figure 3-5
LINE TO GROUND VOLTAGE FOR BUNDLED CONDUCTOR (THREE PHASE)

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Section 4
MANUFACTURING STANDARDS

4.1 CLAMPING FASTENERS FOR CONNECTORS

4.1.1 Clamping Fasteners for Copper Electric Power Connectors

Clamping fasteners for copper electric power connectors shall meet the requirements of the American National Standard for Square and Hex Bolts and Screws, Including Askew Head Bolts, Hex Cap Screw and Lag Screws B18.2.1-1981, and Square and Hex Nuts B18.2.2-1987. Washers shall meet the requirements of the American National Standard for Plain Washers B18.22.1-1981. Lock washers are optional and, if used, shall meet the requirements of the American National Standard for Lock Washers B18.21.1-1983.

Copies of American National Standards are available from the American National Standards Institute, Inc., 11 West 42nd Street, New York, NY 10036.

4.1.2 Clamping Fasteners for Aluminum Electric Power Connectors

Clamping fasteners for aluminum electric power connectors shall meet the requirements of the American National Standard for Hex Bolts and Screws, Including Askew Head Bolts, Hex Cap Screw and Lag Screws B18.21.1-1983, and Square and Hex Nuts B18.2.2-1987. Flat washers shall meet the requirements of the American National Standard B18.22.1-1981. Lock washers shall meet the requirements of the American National Standard B18.21.1-1983.[1]

Bolts, nuts, or both, shall be treated to prevent galling.

4.2 IDENTIFICATION MARKING

The following minimum amount of information shall be given on all electric power connectors:

a) Manufacturer's designation.
b) Maximum size or range of sizes of the conductors with which the connector is intended to be used.

4.3 DESIGNATION OF CONNECTOR SIZES

The size of an electric power connector shall be designated in terms of the size, or other sizes of conductors which the connector accommodates.

The size of conductors shall be given in the following terms:

a) For wire and cable — in American Wire Gauge (AWG) sizes or thousands of circular mils.
b) For tubing—in nominal pipe size (NPS) or iron pipe size (IPS) which includes standard (SPS or SCH 40) and extra heavy (EHPS or SCH 80) sizes, except for expansion or internal connectors. The connector marked NPS or IPS indicates that it is designed to accommodate both SPS (SCH 40) or EHPS (SCH 80). Special marking is required if connector is limited to SPS (SCH 40) or EHPS (SCH 80) only.

4.4. THREAD DIMENSIONS FOR STUD<R>TERMINAL CONNECTORS

The thread dimensions for stud terminal connectors intended for use with electrical equipment shall be as follows:

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Stud Diameter		Number of Threads per	Connector Thread
In.	(mm)	In.	Class
3/4	(19.0)	16	UNF-2B
1-1/8	(28.6)	12	UNF-2B
1-1/4	(31.8)	12	UNF-2B
1-1/2	(38.1)	12	UNF-2B
2	(50.8)	12	UN-2B
2-1/2	(63.5)	12	UN-2B

4.5 BOLT HOLES FOR TERMINAL CONNECTORS WITH SINGLE TANGS OR MULTIPLE FLAT BAR TANGS

The dimensions and the arrangement of bolt holes in the tangs of electric power connectors intended for use with electrical equipment shall be as shown in Figure 4-1 through 4-6. Holes in Figure 4-2 through 4-6 are 9/16 inch (14.3 mm) in diameter. Figures 4-7 through 4-9 show the typical spacing for multiple flat bar tangs.

NOTE—Metric terminal pad spacing and sizes can be found in Appendix A.

4.6 NUMBER AND DIAMETER OF CONDUCTOR CLAMPING BOLTS FOR CONNECTORS

4.6.1 Number and Diameter of Conductor Clamping Bolts Illustration

The number and diameter of conductor clamping bolts for connectors are illustrated in Table 4-1.

4.6.1.1 U Bolts

Each U bolt shall count as two bolts.

4.6.1.2 Shackle Designs

For shackle design (single casting wrap-around conductor), each bolt shall count as two bolts.

4.6.1.3 When Two Different Sizes of Conductors are Involved

When two different sizes of conductors are involved, the bolts specified for the smaller conductor shall be permitted to be used.

4.6.1.4 When Three Bolts are Specified

When three bolts are specified, the following exceptions shall apply:

a) Terminal lugs shall have a minimum of four bolts or the equivalent for a single conductor.
b) Stud connectors shall have a minimum of four bolts or the equivalent for the stud portion.

4.6.1.5 Tensile Strength of Bronze Alloy Bolts

Bronze alloy bolts shall have a minimum tensile strength of 70,000 pounds per square inch (480 MPa) and aluminum alloy bolts shall have a minimum tensile strength of 55,000 pounds per square inch (380 MPa).

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4.6.1.6 When Bronze Alloy Bolts Shall be Used

Bronze alloy bolts shall be used on copper alloy connectors and aluminum alloy bolts shall be used on aluminum alloy conductors. Alternate alloy materials shall be permitted to be used for bolts if performance requirements are met.

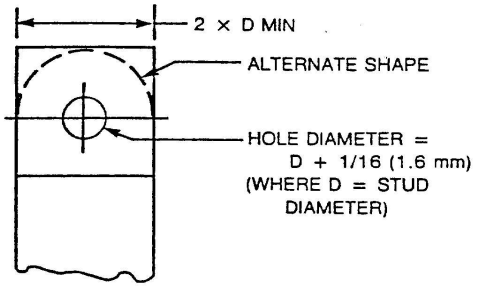


Figure 4-1
BOLT HOLES
FOR TERMINAL
CONNECTORS

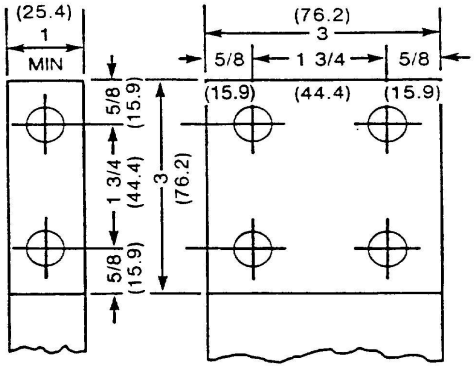
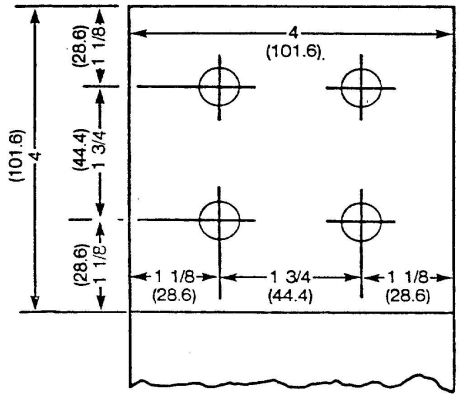


Figure 4-2
BOLT HOLES
FOR TERMINAL
CONNECTORS

Figure 4-3
BOLT HOLES
FOR TERMINAL
CONNECTORS



NOTE—All dimensions in inches and mm.

Figure 4-4
BOLT HOLES FOR TERMINAL CONNECTORS

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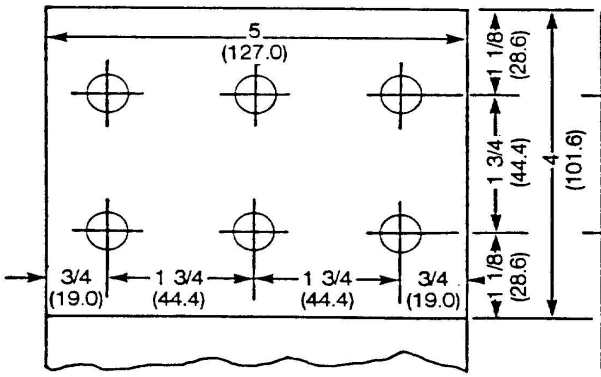


Figure 4-5
BOLT HOLES FOR TERMINAL CONNECTORS

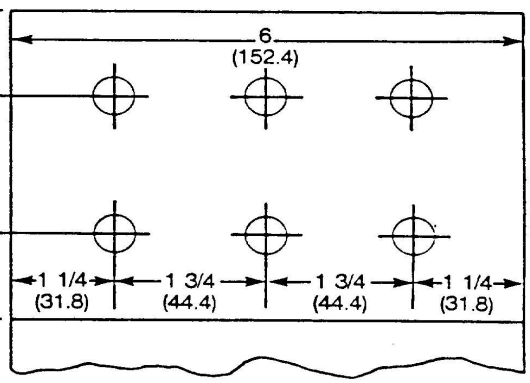


Figure 4-6
BOLT HOLES FOR TERMINAL CONNECTORS

NOTES—
All dimensions in inches and mm.
For tongue dimensions and drilling, see Figures 4-2 through 4-6.

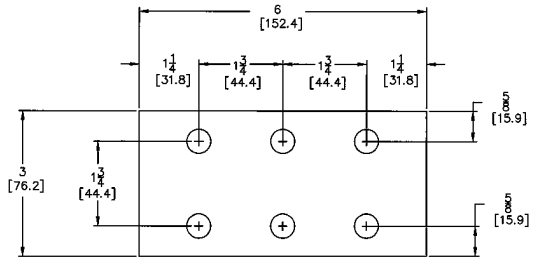


Figure 4-7
TYPICAL SPACING FOR
MULTIPLE FLAT BAR TANGS

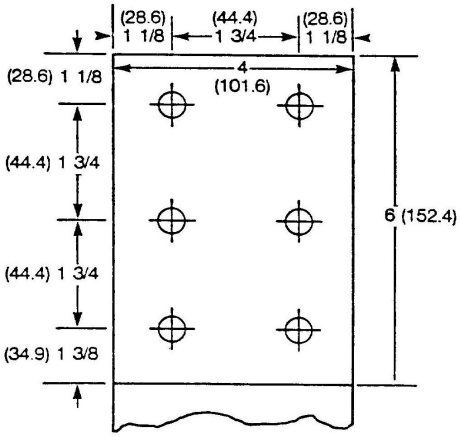


Figure 4-8
TYPICAL SPACING FOR
MULTIPLE FLAT BAR TANGS

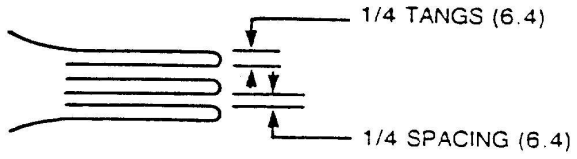


Figure 4-9
TYPICAL SPACING FOR
MULTIPLE FLAT BAR TANGS

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Table 4-1
CONNECTOR CLAMPING BOLTS FOR CONNECTORS
(Table shown in both customary and SI units)

Kind of Conductor				For Copper Conductors						For Aluminum or ACSR Conductors			
				Single Size Reg. Duty		Single Size Heavy Duty		Range Taking		Range Taking*		Single Size	
				Bolts Per Conductor		Bolts Per Conductor		Bolts Per Conductor		Bolts Per Conductor		Bolts Per Conductor	
Standard Pipe Size, Inches	Copper Cable, AWG or MCM	Aluminum or ACSR Cable Outside Diameter, Inches	Stud Diameter, Inches	Number	Diameter Inches	Number	Diameter Inches	Number	Diameter Inches	Number	Diameter Inches	Number	Diameter Inches
⅜	4 thru 2/0	0.200 thru 0.399	½	2	⅜	3	⅜	4	⅜	2	½	2	½
½	3/0 thru 500	…	⅝ thru 1⅛	3	⅜	3	½	4	⅜	4	½	4	½
¾ thru 1	550 thru 800	…	…	3	⅜	4	½	4	½	4	½	4	½
1¼ thru 2	900 thru 2000	0.400 thru 1.412	1¼ thru 2½	3	½	4	½	4	½	4	½	4	½
2½	900 thru 2000	0.400 thru 1.412	…	3	½	4	½	4	½	4	½	4	½
3 thru 4	2250 thru 3000	1.413 thru 1.850	2¾ thru 5	3	⅝	4	⅝	4	⅝	4	⅝	4	⅝
4½ thru 6	…	…	…	…	…	…	…	…	…	…	…	6	⅝

Customary Units

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Table 4-1
CONNECTOR CLAMPING BOLTS FOR CONNECTORS (Continued)

Kind of Conductor				For Copper Conductors						For Aluminum or ACSR Conductors			
				Single Size Reg. Duty		Single Size Heavy Duty		Range Taking		Range Taking*		Single Size	
				Bolts Per Conductor		Bolts Per Conductor		Bolts Per Conductor		Bolts Per Conductor		Bolts Per Conductor	
Standard Pipe Size, mm	Copper Cable, mm^2	Aluminum or ACSR Cable Outside Diameter, mm	Stud Diameter, mm	Number	Diameter mm	Number	Diameter mm	Number	Diameter mm	Number	Diameter mm	Number	Diameter mm
9.5	21 thru 67	5.08 thru 10.1	12.7	2	9.5	3	9.5	4	9.5	2	12.7	2	12.7
12.7	85 thru 253	…	15.9 thru 28.6	3	9.5	3	12.7	4	9.5	4	12.7	4	12.7
19.0 thru 25.4	279 thru 405	…	…	3	9.5	4	12.7	4	12.7	4	12.7	4	12.7
31.8 thru 50.8	456 thru 1013	10.2 thru 35.9	31.8 thru 63.5	3	12.7	4	12.7	4	12.7	4	12.7	4	12.7
63.5	456 thru 1013	10.2 thru 35.9	…	3	12.7	4	12.7	4	12.7	4	12.7	4	12.7
76.2 thru 101.6	1140 thru 1520	35.9 thru 47.0	69.8 thru 127.0	3	15.9	4	15.9	4	15.9	4	15.9	4	15.9
114.3 thru 152.4	…	…	…	…	…	…	…	…	…	…	…	6	15.9

SI Units

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Table 4-2
NOMINAL TORQUE VALUES

Diameter of Bolts		Nominal Torque Values		
Inch	(mm)	lb-ft	Lbf-in	(N-m)
¼ -SB	(6.3)	7	80	(9)
5/16-SB	(7.9)	15	180	(20)
3/8-SB	(9.5)	20	240	(27)
½-SB	(12.7)	40	480	(54)
5/8-SB	(15.9)	55	660	(75)
¾-SB	(19.1)	87	1050	(118)
3/8-LA	(9.5)	14	168	(19)
½-LA	(12.7)	25	300	(34)
5/8-LA	(15.9)	40	480	(54)
¾-LA	(19.1)	54	650	(73)

NOTES—
L-A = Lubricated-Aluminum
SB = Silicon bronze or steel
* See 4.5 for arrangement and sizes of bolts for terminal connectors.

4.6.2 Examples Illustrating the Use of the Table in 4-1

4.6.2.1 Example 1

A straight coupler connector or a 90-degree (1.57 rad) elbow connector is used to connect a conductor of 1½-inch (38.1 mm) copper pipe to another conductor of 1½-inch (38.1 mm) copper pipe. After locating the proper line for the 1½-inch (38.1 mm) copper pipe in the first column of the table, the total number of bolts required can be determined from the following information given for the connectors.

For standard-duty connectors:

3A X 2B = 6C
4A X 2B = 8C

Where:

A = ½-inch (12.7 mm) diameter bolts per conductor
B = Number of conductors
C = Number of ½-inch diameter bolts per fitting

4.6.2.2 Example 2

A single size "T" connector is used to connect a 3-inch (76.2 mm) Schedule 40 aluminum main to a 397.5 MCM ASCR (201 mm^2) tap (outside diameter = 0.743 inch, 18.87 mm).

After locating the proper line for the 3-inch (76.2 mm) pipe in the first column of the table, it can be seen that the connectors requires four 5/8-inch-diameter (15.9 mm) bolts per conductor.

After locating the proper line for the 0.743-inch-outside diameter (18.87 mm) ACSR tap in the third column of the table, it can be seen that the connectors require four 1/2-inch-diameter (15.9 mm) bolts per conductor.

In this case and in accordance with 4.6.1.3, the manufacturer has the choice of using either four 1/2-inch-diameter (12.7 mm) bolts per conductor or four 5/8-inch-diameter (15.9 mm) bolts per conductor.

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4.6.2.3 Example 3

A copper stud connector having a 1-1/8-inch (28.6 mm)-12 thread is connected copper cable ranging in size from 400 to 800 MCM (203 to 405 mm). This connector is considered a range taking connector. Using the fourth column for the stud and the second column for the copper cable, it can be seen that the connectors require the following bolts:

a) Four 3/8-inch-diameter (9.5 mm) bolts per conductor for the 1-1/8 stud, range taking column.
b) Four 1/2-inch-diameter (12.7 mm) bolts per conductor for the cable.

In this case and in accordance with 4.6.1.3, the manufacturer has the choice of using either four 3/8-inch-diameter (9.5 mm) bolts per conductor or four 1/2-inch-diameter (12.7 mm) bolts per conductor.

4.7 EXPANSION CONNECTORS

Expansion connectors shall permit a total movement of one conductor in relation to the other as follows:

a) For copper conductors—1-1/4 inches (31.8 mm) minimum.
b) For aluminum conductors or combination of aluminum and copper—2 inches (50.8 mm) minimum.

4.8 TERMINAL CONNECTORS

On bolted side formed terminals, there shall be a minimum clearance of 1/8-inch between the clamp bolts and the contact surface of the pad.

4.9 FLAT PLAIN WASHERS

The size of flat (plain) washers (silicon-bronze aluminum, steel) intended for use with 3/8-, 1/2-, and 5/8-inch (9.5-12.7-15.9-mm) bolts* for joining electric power connectors to flat contact surfaces shall be as follows:

Bolt Size		Washer Size inches (mm)		
		Inside Diameter		Maximum Outside
Inches	(mm)	Min.	Max.	Diameter
3/8	(9.5)	13/32 (10.3)	7/16 (11.1)	7/8 (22.2)
1/2	(12.7)	17/32 (13.5)	9/16 (14.2)	1-1/4 (31.7)
5/8	(15.9)	21/32 (17.4)	11/16 (17.4)	1-1/2 (38.1)

* See 4.5 for arrangement and sizes of bolts for terminal connectors.

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4.10 HEIGHT OF ALUMINUM AND COPPER BUS SUPPORT CLAMPS (FITTINGS)

Table 4-3
HEIGHT OF ALUMINUM AND COPPER BUS SUPPORT CLAMPS (FITTINGS)

Standard Pipe Size		Height in Inches (mm) of Centerline Conductor above Insulator Top	
		3-inch Bolt (76.2)	5 and 7 inch (127.0 and 177.8)
Inches	(mm)	Circle	Bolt Circles
1/2	(12.7)	1-3/4 ± 1/16 (44.4 ± 1.6)	2-1/8 ± 1/16 (54.0 ± 1.6)
3/4	(19.0)	2 ± 1/16 (50.8 ± 1.6)	2-1/4 ± 1/16 (57.2 ± 1.6)
1	(25.4)	2 ± 1/16 (50.8 ± 1.6)	2-1/4 ± 1/16 (57.2 ± 1.6)
1-1/4	(31.8)	2-1/4 ± 1/16 (57.2 ± 1.6)	2-3/8 ± 1/16 (60.3± 1.6)
1-1/2	(38.1)	2-1/2 ± 1/16 (63.5 ± 1.6)	2-1/2 ± 1/16 (63.5 ± 1.6)
2	(50.8)	2-3/4 ± 1/16 (69.8 ± 1.6)	2-3/4 ± 1/16 (69.8 ± 1.6)
2-1/2	(63.5)	3-1/8 ± 1/16 (79.4 ± 1.6)	3-1/8 ± 1/16 (79.4 ± 1.6)
3	(76.2)	3-5/8 ± 1/16 (92.1 ± 1.6)	3-5/8 ± 1/16 (92.1 ± 1.6)
3-1/2	(88.9)	4 ± 1/16 (101.6 ± 1.6)	4 ± 1/16 (101.6 ± 1.6)
4	(101.6)	4-1/2 ± 1/16 (114.3 ± 1.6)	4-1/2 ± 1/16 (114.3 ± 1.6)
5	(127.0)	5 ± 1/8 (127.0 ± 3.2)	5 ± 1/8 (127.0 ± 3.2)
6	(152.4)	5-1/2 ± 1/8 (139.7 ± 3.2)	5-1/2 ± 1/8 (139.7 ± 3.2)

NOTE—½" SPS (12.7) applies to copper clamps only.

4.11 HEIGHT OF ALUMINUM SIDE FORMED TERMINAL CONNECTORS FOR TUBULAR BUS

The distance from the centerline of the bus to the pad contact shall be as follows:

Table 4-4
HEIGHT OF ALUMINUM SIDE FORMED TERMINAL CONNECTORS FOR TUBULAR BUS

Pipe Size		Height in Inches		1/2' (13)	
Inches	(mm)	Bolted	(mm)	Welded	
1/2	(12.7)	1-3/8	(35)	15/16	(24)
3/4	(19.0)	1-3/8	(35)	1	(25)
1	(25.4)	1-3/8	(35)	1-1/8	(29)
1-1/4	(31.8)	1-1/2	(38)	1-1/4	(32)
1-1/2	(38.1)	1-5/8	(41)	1-1/2	(38)
2	(50.8)	1-3/4	(44)	1-3/4	(44)
2-1/2	(63.5)	2-1/8	(54)	2-3/8	(51)
3	(76.2)	2-3/8	(60)	2-3/8	(60)
3-1/2	(88.9)	2-5/8	(67)	2-5/8	(67)
4	(101.6)	3-1/8	(79)	2-7/8	(73)
5	(127.0)	3-3/4	(95)	3-3/8	(86)
6	(152.4)	4-3/8	(111)	4	(102)

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4.12 RECOMMENDATION FOR MAKING CONNECTIONS

The connector and conductor surfaces should be vigorously cleaned with a wire brush or emery cloth. A shiny, bright surface is needed. A contact compound should be applied immediately following the cleaning of the aluminum.

Some connectors are plated with other metals. The surfaces of these connectors should not be abraded since this may remove a portion of the plating. They may be cleaned with a solvent, if necessary.

Since it is the aluminum (anode) which corrodes in a copper-aluminum electrolytic cell, aluminum cable and tubing should not be used with unplated copper alloy connectors. The reverse however, (copper conductor and aluminum connector) is functionally acceptable provided the aluminum connector is "massive" in comparison to the copper conductor.

A prime precaution necessary in making any copper-to-aluminum joint concerns the relative positions of copper and aluminum conductors. Copper salts will attack aluminum, whereas aluminum salts will not attack copper. Thus, it is best to install, wherever possible, the aluminum conductors above the copper conductor. This will prevent the washing of copper salts over the aluminum.

In the case of an underhung copper switch pad, it is recommended that a copper bar extension first be bolted directly to the pad. This can be followed by directly bolting a massive aluminum connector properly scratch-brushed and compound-smeared, to the upper surface of the bar extension. This installation procedure avoids the positioning of the aluminum terminal beneath the copper switch pad.

Another common aluminum-to-copper connector is an aluminum conductor joined to a copper stud. Such a connection can be made satisfactorily by directly joining a massive aluminum connector, properly scratch-brushed and compound-smeared, to the copper stud.

Silver plated aluminum connectors should not be used on unplated aluminum bus.

It is recommended that welding be performed by a qualified welder of aluminum. Prior to welding, it is recommended that a test weld be made on a typical aluminum casting.

4.13 TONGUE MOUNTING FASTENERS

Where an aluminum connector is used for making a connection to a copper pad, tin-plated silicon-bronze or stainless steel bolts, nut and washers are suggested. Other suitable materials may also be used provided they meet the intent of the foregoing paragraph concerning galvanic corrosion. With steel hardware, consideration should be given to the use of spring-type washers to compensate for the different thermal coefficient of expansion between dissimilar metals and the flow of aluminum. Aluminum hardware is not recommended in a copper connection under corrosive conditions due to the effect of copper salts on the underside of the connection.

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Appendix A
BOLT HOLES FOR TERMINAL CONNECTORS

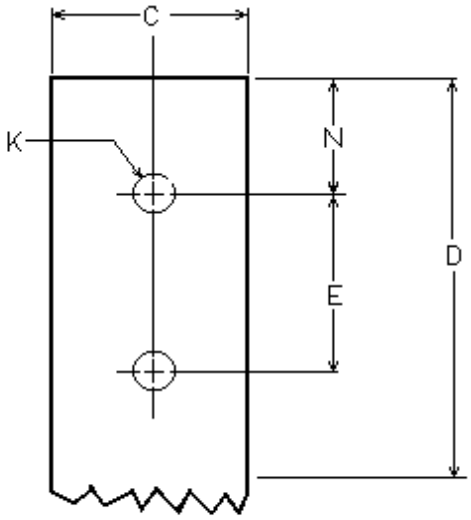


Figure A–1
BOLT HOLES FOR TERMINAL CONNECTORS

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Table A–2
DIMENSIONS IN MM.

COUNTRY	C	D	E	K	N
France	40	82	45	16	18

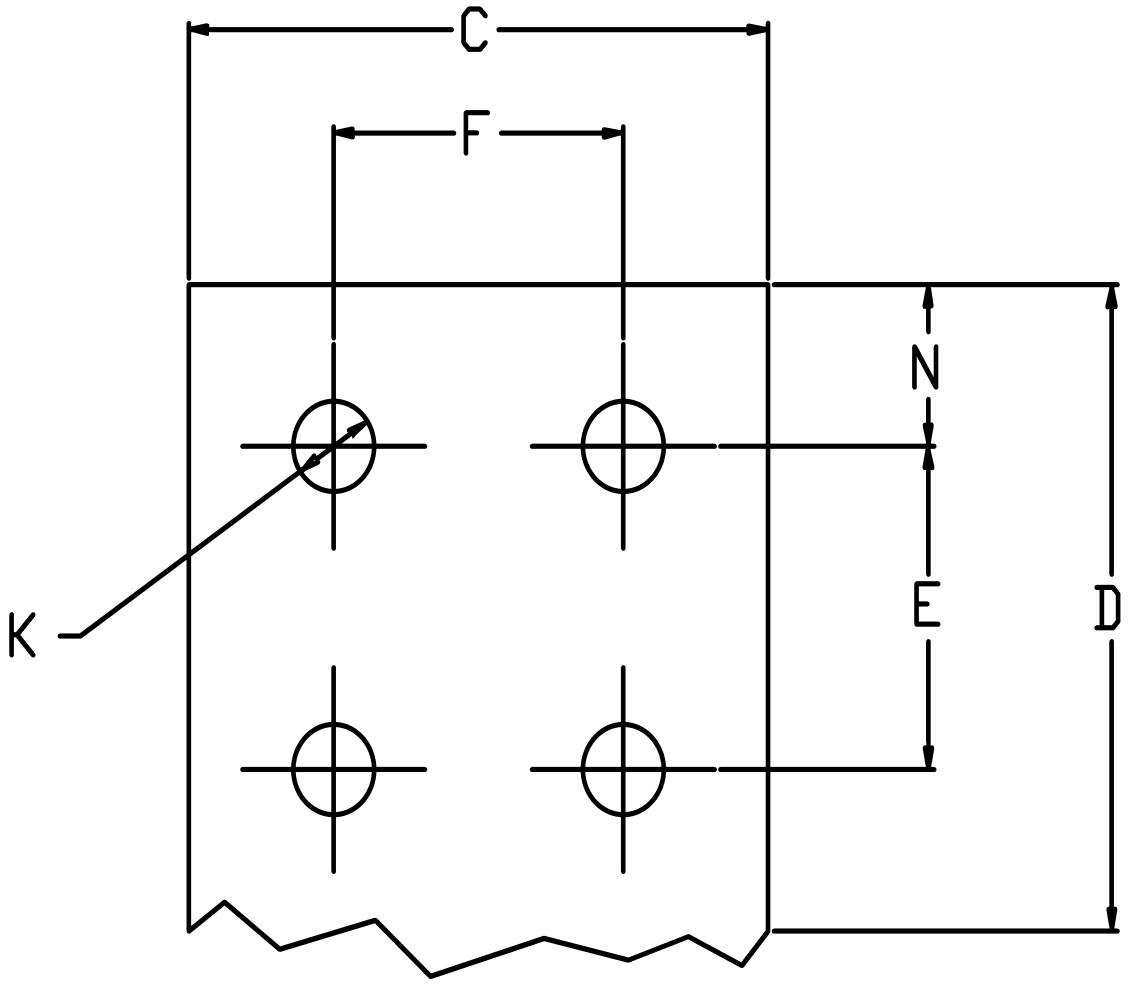


Figure A–2
BOLT HOLES FOR TERMINAL CONNECTORS,
DIMENSIONS IN MM

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Table A–3
DIMENSIONS IN MM

COUNTRY	C	D (min)	E	F	K	N
France	76	80	45	45	16	16
Germany	100	100	50	50	14	25
Sweden	76	76	40	40	14	18

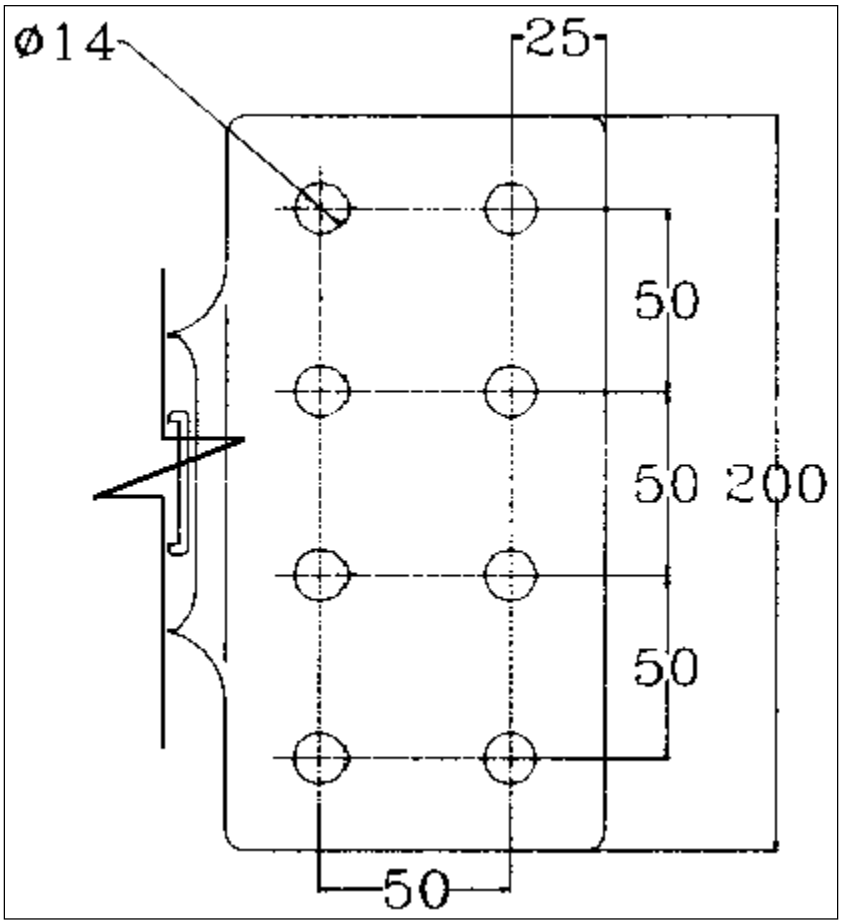


Figure A–3
GERMANY 8 HOLES BOLT FOR TERMINAL CONNECTORS,
HOLE DIMENSIONS IN MM

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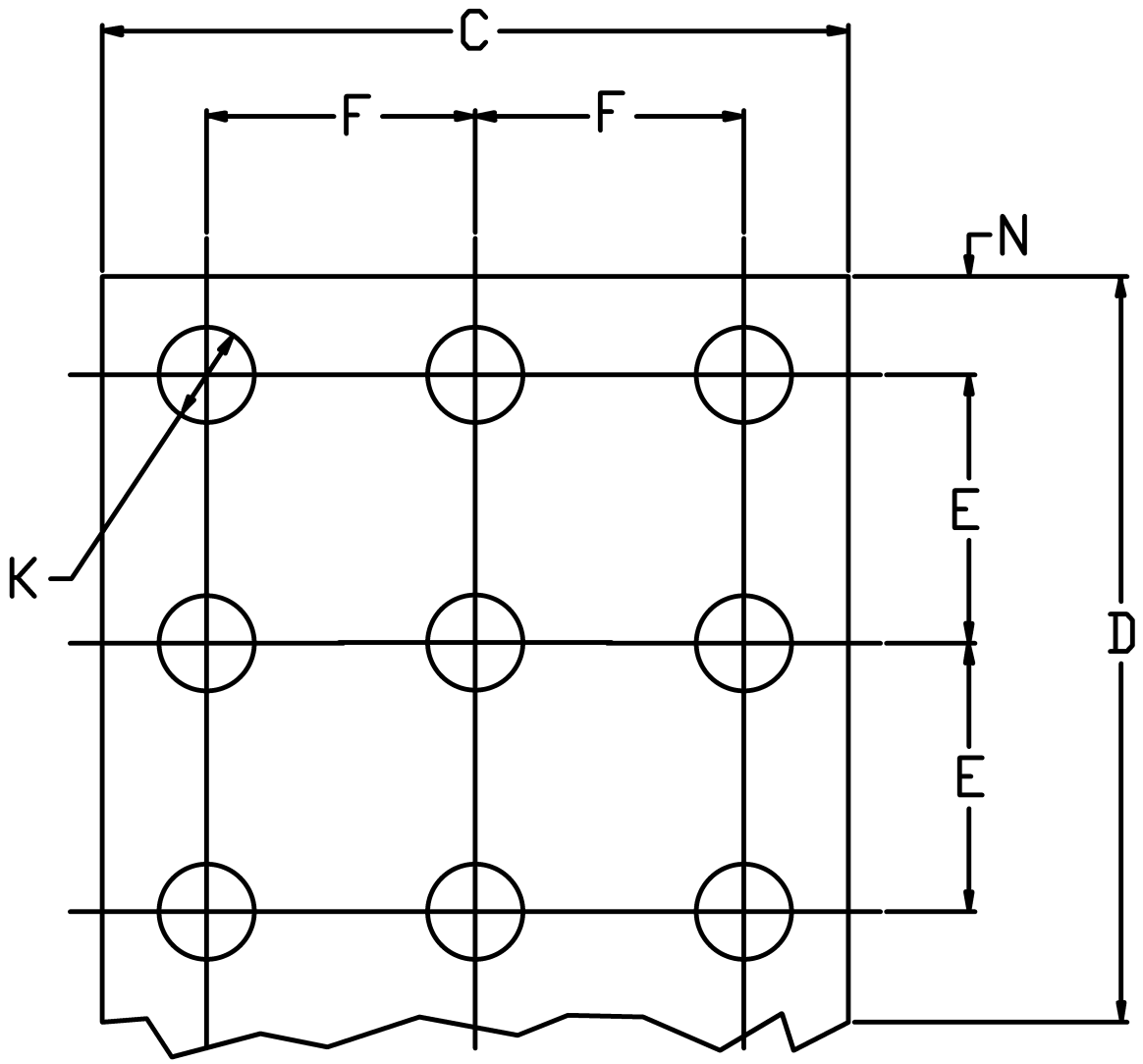


Figure A–4
BOLT HOLES FOR TERMINAL CONNECTORS

Table A–4
9 HOLE
DIMENSIONS IN MM

COUNTRY	C	D (min)	E	F	K	N
France	125	125	45	45	16	16
Sweden	120	120	40	40	14	20

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