ANSI/NEMA CC 1

ELECTRIC POWER CONNECTION FOR SUBSTATIONS

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Electric Power Connection for Substations

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NOTICE AND DISCLAIMER

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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:

Vice President, Technical Services
National Electrical Manufacturers Association
1300 North 17th Street
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:

Greg Nienaber, Chairman
Vince Baclawski, Secretary

Organization Represented:	**Name of Representative:**
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Galvan Industries, Inc.	Roger Montambo
Erico, Inc.	Steve Rohacz
Connector Castings Inc.	Ed Youngblood

Section 1
GENERAL

1.1 SCOPE

This standard covers uninsulated connectors and bus supports that are made of metal and intended for use with conductors or bus made of copper or aluminum alloy and found in substations. Connectors that are supplied in equipment are covered by the appropriate equipment standards and are excluded from this standard.

1.2 REFERENCES

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

American Society of Mechanical Engineers (ASME)
Three Park Avenue
New York, NY 10016-5990

B18.2.1-1996	*Standard for Square and Hex Bolts and Screws (Inch Series) Hex Cap Screw and Lag Screws*
B18.2.2-1987 (R1999)	*Square and Hex Nuts*
B18.22.1-1965 (2003)	*Standard for Plain Washers*
B18.21.1-1999	*Standard for Lock Washers*

Institute or Electrical and Electronics Engineers (IEEE)
445 Hoes Lane,
Piscataway, New Jersey

738-1993	*Standard for Calculating the Current-Temperature of Bare Overhead Conductors*
C2-2002	*National Electrical Safety Code*

International Electrotechnical Commission (IEC)
3, rue de Varembe
P.O. Box 131
1211 Geneva 20
Switzerland

60028 Ed. 2.0-1925	*International standard of resistance for copper*

National Electrical Manufacturers Association (NEMA)
1300 North 17th Street
Rosslyn, Virginia 22209

107-1987 (R1993) *Methods of Measurement 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.

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 that 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: An 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 electrical noise at nominal voltage.

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

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

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

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.

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 that joins a branch conductor to the main conductor at an angle of 90 degrees.

tang: A tang is that portion of a connector that 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.

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

"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.

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.

Section 2
REQUIREMENTS

2.1 CURRENT RATINGS FOR BARE COPPER CONDUCTORS AND TUBING

The 60-Hz current ratings of copper conductors having a conductivity of 98 percent IACS (International Annealed Copper Standard) and copper tubing conductors shall be in accordance with Tables 2-1 and 2-2.

Table 2-1
CURRENT (A) FOR BARE COPPER CABLE CONDUCTORS[1]

Size of Conductors		Current (A)[2]	
AWG or kcmil	**mm^2**	**Indoor**	**Outdoor**
Solid Conductor			
1/0	54	160	250
2/0	67	190	290
4/0	107	260	390
Stranded Conductor			
1/0	54	160	250
2/0	67	190	300
4/0	107	270	400
250	127	290	430
400	203	410	580
500	253	480	670
600	304	540	750
750	380	630	860
1000	507	770	1030
1500	760	1000	1310
2000	1013	1190	1530

NOTES—
1. Table 2-1 calculated according to ANSI/IEEE STD 738-1993
2. The minimum distance between conductors shall be 457 mm (18 in), unless the proximity effect should be taken into consideration.

Table 2-2
CURRENT (A) FOR BARE COPPER TUBING CONDUCTORS[1]

Standard Pipe Size			Current (A)[2]			
			Indoor		Outdoor	
Trade Size	O.D.		Schedule	Schedule	Schedule	Schedule
in.	In.	Mm	40	80	40	80
1/2	0.840	21.00	380	420	510	580
3/4	1.050	26.25	540	590	710	780
1	1.315	32.88	650	750	850	1010
1-1/4	1.660	41.50	870	975	1120	1250
1-1/2	1.900	47.50	1020	1150	1280	1450
2	2.375	59.38	1250	1500	1550	1850
2-1/2	2.875	71.88	1700	1975	2000	2400
3	3.500	87.50	2175	2475	2550	2950
3-1/2	4.000	100.00	2575	2875	3050	3400
4	4.500	112.50	2850	3100	3400	3800
5	5.563	125.03	3450	3850	4100	4600
6	6.625	165.63	4000	4500	4700	5200

NOTES—
1. The current ratings in this table are based upon NEMA Std 4-22-1943, Rev 7-13-1960.
2. The minimum distance between the tubing conductors shall be 457 mm (18 inches), unless the proximity effect should be taken into consideration.

2.1.1 Ampacity Rating Basis for Copper Conductors

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

2.1.1.2 Outdoor ratings are given for a wind velocity of 0.6 meters per second (2 ft per second), an ambient air temperature of 40°C, a conductor temperature of 70°C (30°C rise), and emissivity, e, equal to 0.35. Sun effect was not taken into consideration due to the wide variation depending upon the location. The designer should recalculate these values to take sun effect into consideration once the installation location is determined

2.1.1.3 If higher current ratings are desired, connector test currents per 3.1.1 should be adjusted accordingly

2.2 CURRENT RATINGS FOR ALUMINUM CONDUCTORS AND PIPE CONDUCTORS

The 60-Hz current ratings of aluminum conductors or aluminum pipe conductors shall be in accordance with Tables 2-3 and 2-4.

Table 2-3
CURRENT (A) FOR BARE ALUMINUM CABLE CONDUCTORS[1]

Size of Conductors		Current (A)[2, 3]	
AWG or kcmil	**mm^2**	**Indoor**	**Outdoor**
Solid Conductor			
1/0	54	120	190
2/0	67	140	220
4/0	107	210	300
Stranded Conductor			
1/0	54	130	200
2/0	67	150	230
4/0	107	200	320
250	127	240	350
400	203	340	480
500	253	400	550
600	304	450	620
750	380	530	720
1000	507	650	870
1500	760	850	1110
2000	1013	1030	1320

NOTES—
1. Table 2-3 calculated according to ANSI/IEEE STD 738-1993.
2. Current Ratings are based upon 57-61% conductivity IACS Cable.
3. The minimum distance between conductors shall be 457 mm (18 in), unless the proximity effect is be taken into consideration.

Table 2-4
CURRENT (A) FOR BARE ALUMINUM PIPE CONDUCTORS[1]

Standard Pipe Size			Current (A)[2, 3]			
			Indoor		Outdoor	
Trade Size	O.D.		Schedule	Schedule	Schedule	Schedule
in,	in.	mm	40	80	40	80
1/2	.840	21.00	315	360	400	455
3/4	1.050	26.25	400	455	495	565
1	1.315	32.88	535	605	650	740
1-1/4	1.660	41.50	680	780	810	930
1-1/2	1.900	47.50	790	910	930	1070
2	2.375	59.38	1000	1175	1155	1355
2-1/2	2.875	71.88	1365	1570	1550	1780
3	3.500	87.50	1670	1935	1895	2195
3-1/2	4.000	100.00	1945	2265	2170	2530
4	4.500	112.50	2230	2605	2460	2880
4-1/2	5.001	127.03	2515	2955	2750	3230
5	5.563	125.03	2845	3355	3080	3635
6	6.625	165.63	3500	4205	3735	4490

NOTES—

1. The current ratings in this table are based upon NEMA Std 8-16-1951, Rev. 7-13-1960.
2. Current Ratings are based upon 53% conductivity IACS. Pipe or Tubing available in other conductivity values will affect this table. See 2.2.3 below
3. The minimum distance between conductors shall be 457 mm (18 in), unless the proximity effect should be taken into consideration.

2.2.1 Ampacity Rating Basis for Aluminum Conductors

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

2.2.1.2 Outdoor ratings are given for a wind velocity of 0.6 meters per second (2 ft per second), an ambient air temperature of 40°C, a conductor temperature of 70°C (30°C rise), and emissivity, e, equal to 0.35. Sun effect was not taken into consideration due to the wide variation depending upon the location. The designer should recalculate these values to take sun effect into consideration once the installation location is determined.

2.2.1.3 If higher current ratings are desired, connector test currents per 3.1.1 should be adjusted accordingly.

2.2.2 Current Ratings for Different Aluminum Conductivity

For aluminum tubing with conductivities other than 53%, the current ratings should be adjusted in accordance with the following formula:

$$\boldsymbol{i_{(New\ Alloy)} = I_{(53\%)}(Conductivity\ of\ new\ alloy/0.53)^{1/2}}$$

$I_{(New\ Alloy)}$ – Current Rating of New Alloy
$I_{(53\%)}$ – Current Rating of 53% alloy from the table above

Example: To find the outdoor rating of 2 in., 6061-T6 Schedule 40 pipe.
$I_{(53\%)} = 1155$ A
Conductivity of 6061T6 pipe = 43%

$$I_{(6061)} = 1155\ A\ \ X\ (0.43 / 0.53)^{1/2} = 1040\ A$$

2.3 EHV AND UHV POWER CONNECTORS

The requirements for EHV and UHV power connectors shall be based on the minimum design phase spacing and distance from ground plane as shown in Table 2-5 (see 3.3, Corona and RIV tests). The visual corona and audible noise extinction voltage test shall be at least 10% 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.

Table 2-5
MINIMUM PHASE SPACINGS AND GROUND CLEARANCES

Nominal Operating Voltage	Phase Spacing		Distance from Ground Plane	
kV	m	ft	m	ft
230	3.4	11	4.6	15
345	4.9	16	7.6	25
500	7.6	25	9.1	30
765	13.7	45	13.7	45
1100*	16.8	55	16.8	55

*1100 kV spacing and height were based upon work performed for the Waltz Mill, Pa Test Station.

2.4 FREQUENCY

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

2.5 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. 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.

2.5.2 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.

2.6 PULLOUT STRENGTH (SEE 3.2.)

The pullout strength of the connector shall be as shown in Table 2-6.

Table 2-6
MINIMUM CONNECTOR PULLOUT STRENGTH

Wire or Cable Size		**Pullout Strength**	
AWG or kcmil	**mm^2**	**N**	**lbf**
6-1/0	13-54	1334	300
2/0-4/0	67-107	2224	500
250-500	127-253	4448	1000
above 500	**above** 253	8896	2000

2.7 CANTILEVER STRENGTH OF BUS SUPPORTS (SEE 3.4.)

When tested in accordance with 3.4, the minimum cantilever strength of bus supports shall be in accordance with Table 2-7.

Table 2-7
MINIMUM CANTILEVER STRENGTH OF BUS SUPPORTS

Bronze N (lbf)	**Aluminum N (lbf)**
2224 (500)	8896 (2000)

2.8 TORQUE STRENGTH OF BOLTED CONNECTORS

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

2.9 ALUMINUM WELDMENT COUPLERS

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

Section 3
TEST METHODS

3.1 TEMPERATURE RISE TESTS

3.1.1 Temperature Rise Tests

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% of the rated current in accordance with 3.1.3, with equilibrium temperatures obtained at each level. Equilibrium temperature is defined as a constant temperature (+/-2ºC) between three successive measurements taken five minutes apart. Measurements are made at the end of the first 30 minutes and at one-hour intervals thereafter until completion of the test. The rated current shall be in accordance with Table 2-1, 2-2, 2-3 or 2-4.

This test is not intended to qualify the connectors for service higher than the normal rating (2.0). If the user desires to operate the conductor and connectors at a higher temperature rating, the test currents shall be raised to a value agreed upon between the manufacturer and user.

3.1.2 Test Loop Preparation

In order to eliminate heat sinks or hot spots on the test loop, conductors of the correct size and type shall have a length from each opening of the connector to the point where the connection is made to the circuit of at least 8X the conductor diameter, but not less than 1.2m (4 ft).

3.1.3 Current Values to be Used in the Temperature Rise Tests

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

a) Terminal Connectors - The current shall be either the current rating of the equipment to which the connector is connected, or the current rating of the conductor for which the opening is designed, whichever is lower.

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

c) "T" Connectors - The test current shall be based on the conductor having the lowest current rating in the assembly.

3.1.4 Expansion Connector Measurements

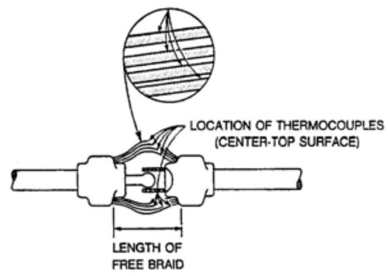


Figure 3-1
THERMOCOUPLE LOCATIONS

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

3.3 CORONA AND RIV TESTS

3.3.1 Test Setup

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.

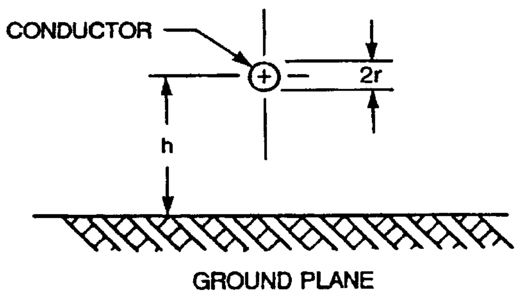
3.3.2 Tests Performed under Single-Phase Conditions

Tests shall be permitted to be performed under single-phase conditions, but results must be corrected to provide the connector rating at the center phase of a three-phase system. 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.

Where:

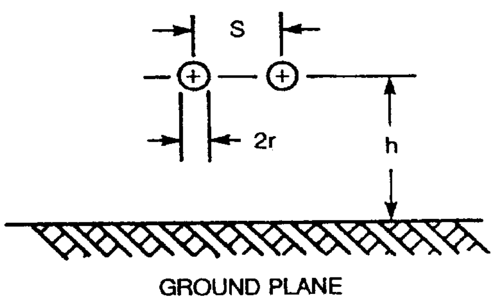
h =	distance from center of conductor to ground plane, centimeters.
r =	radius of the individual conductor, centimeters.
s =	conductor centerline spacing in the bundle, centimeters.
d =	phase-to-phase spacing of bundle centerlines, centimeters.
V_1 =	line-to-ground corona-extinction test voltage, kV.
V_2 =	line-to-ground corona-extinction operating voltage, kV.
E_a =	average voltage gradient at the surface of the conductor, kV/cm.
E_m =	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.
γ =	1 for 1-, 2- and 3- conductor bundles; γ =1.2 for 4-conductor bundles
ln =	natural logarithm.



$$E_a = \frac{V_1}{r \ln\left[\frac{2h}{r}\right]}$$

$$E_m = \frac{h}{h - r} E_a$$

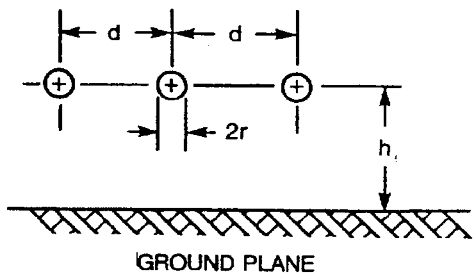
Figure 3-2
CONDUCTOR VOLTAGE GRADIENT
FOR SINGLE CONDUCTOR



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

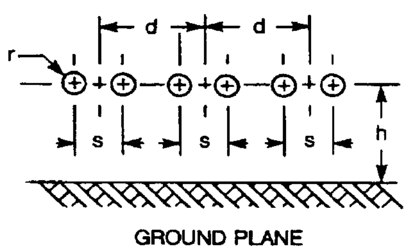
$$E_a = \frac{V_1}{n\, r \ln\left[\frac{2h}{r_e}\right]}$$

Figure 3-3
CONDUCTOR VOLTAGE GRADIENT FOR BUNDLED CONDUCTOR



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

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



$$V_2 = E_a\, r \ln \left[\frac{2hd}{r_e \quad 4h^2 + d^2} \right]$$

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

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

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 or image amplification equipment can be used to locate and observe the 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% above the test voltage 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 Publication No. 107-1987 (1993), *Methods of Measurement of Radio Influence Voltage (RIV) of High Voltage Apparatus* (see Annex A). RIV measurements may 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.

3.5 TORQUE STRENGTH TEST OF BOLTED CONNECTORS

The conductor(s) shall be assembled in the connector and the bolts tightened uniformly and alternately in 11.3 N-m (100 lb-in.)increments until 50% over the nominal torque value is achieved (see 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 20.8 mm per minute per meter (1/4 in. per minute per foot) of sample length

3.7 BENDING TEST OF WELDED COUPLERS

A load shall be applied at two points, at a distance of 76.2 mm (3 in.) from the weld and transverse to the conductor longitudinal axis.

The conductor shall be freely supported at each end.

Section 4
DESIGN AND MARKING REQUIREMENTS

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, ASME B18.2.1, and Square and Hex Nuts, ASME B18.2.2. Washers shall meet the requirements of the American National Standard for Plain Washers, ASME B18.22.1. Lock washers are optional and, if used, shall meet the requirements of the American National Standard for Lock Washers, ASME B18.21.1.

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, ASME B18.21.1, and Square and Hex Nuts, ASME B18.2.2. Flat washers shall meet the requirements of the American National Standard, ASME B18.22.1. Lock washers shall meet the requirements of the American National Standard, ASME B18.21.1.

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) Nominal 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 (kcmil) Reference is also made to the equivalent metric (mm^2) sizes for AWG or kcmil series conductors.
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) and EHPS (SCH 80). Special marking is required if the connector is limited to SPS (SCH 40) or EHPS (SCH 80) only.

4.4. THREAD DIMENSIONS FOR STUD TERMINAL CONNECTORS

The thread dimensions for internal threaded stud terminal connectors intended for use with electrical equipment shall be as shown in Table 4-1.

Table 4-1
STANDARD THREADS FOR STUD TERMINALS

Stud Diameter		Number of	Connector
in.	**mm***	**Threads per in.**	**Thread Class**
5/8	15.9	11	UNC-2B
-------3/4	19.0	16	UNF-2B
1	25.4	14	UNS-2A
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
3	76.2	12	UN-2B

* For reference only

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 power connectors shall be as shown in Annex B, Figure B-1 to B-6. Figures B-7 to B-9 show the typical spacing for multiple flat bar tangs.

Metric terminal pad spacing and sizes used in some countries other than the U.S. are given for information in Annex C.

4.6 CONDUCTOR CLAMPING BOLTS FOR CONNECTORS

4.6.1 General

Bronze alloy bolts shall be used on copper alloy connectors and aluminum alloy bolts shall be used on aluminum alloy conductors. Alternate alloy, including Steel or Stainless steel, materials shall be permitted to be used for bolts if performance requirements are met and no adverse material compatibility or galling of threads occurs and approved by the manufacturer.

4.6.2 Number and Diameter of Conductor Clamping Bolts

The number and diameter of clamping bolts for connectors are listed in Table 4-2.

4.6.2.1 U Bolts (See Figure 4-1)

Each U bolt shall count as two bolts.

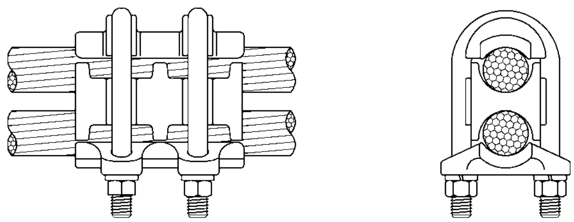


Figure 4-1
U- BOLT TYPE CONNECTOR

4.6.2.2 Shackles (See Figure 4-2)

Each bolt of a single casting, wrap-around conductor shackle design shall count as two bolts.

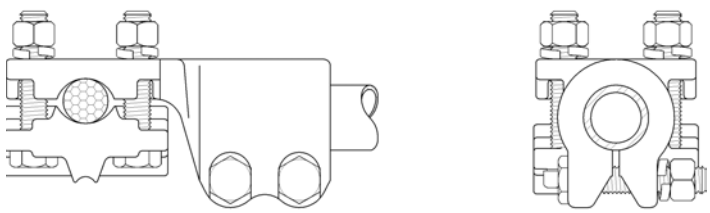


Figure 4-2
SHACKLE TYPE CONNECTOR

4.6.2.3 Different Sizes of Conductors

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

4.6.2.4 Exception 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.

Table 4-2
CONNECTOR CLAMPING BOLTS
U.S. STANDARD CONDUCTORS AND HARDWARE

Type of Conductor				For Copper Conductors						For Aluminum or ACSR Conductors			
				Bolts Per Conductor						Bolts per Conductor			
				Single Size Standard Duty		Single Size Heavy Duty		Range Taking		Range Taking*		Single Size	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Standard Pipe Size, in. (OD mm)	**Copper Cable, AWG or kcmil (mm^2)**	**Aluminum or ACSR Cable O.D. In. (mm)**	**Stud Dia. in. (mm)**	**No.**	**Dia. (in.)**	**No.**	**Dia. (in.)**	**No.**	**Dia. (in.)**	**No.**	**Dia. (in.)**	**No.**	**Dia. (in.)**
3/8 (16.53)	4 thru 2/0 (21.2) thru 67.4)	0.200 thru 0.399 (5.08 thru 10.13)	1/2 (12.7)	2	3/8	3	3/8	4	3/8	2	1/2	2	1/2
1/2 (21.00)	3/0 thru 500 (85.0 thru 253)	…	5/8 thru 1-1/8 (15.88 thru 28.58)	3	3/8	3	1/2	4	3/8	4	1/2	4	1/2
3/4 thru 1 26.25 thru 32.88)	550 thru 800 (279 thru 405)	…	…	3	3/8	4	1/2	4	1/2	4	1/2	4	1/2
1-1/4 thru 2-1/2 (41.50 thru 71.88)	900 thru 2000 (456 thru 1010)	0.400 thru 1.412 (10.16 thru 35.86)	1-1/4 thru 2-1/2 (31.75 thru 63.50)	3	1/2	4	1/2	4	1/2	4	1/2	4	1/2
3 thru 4 (87.50 thru 112.50)	2250 thru 3000 (1141 thru 1521)	1.413 thru 1.850 (35.89 thru 46.99)	2-3/4 thru 5 (69.85 thru 127.00)	3	5/8	4	5/8	4	5/8	4	5/8	4	5/8
4-1/2 thru 6 (127.03 thru 165.63)	…	…	…	…	…	…	…	…	…	…	…	6	5/8

NOTE—See Appendix B for terminal pad configurations.

Table 4-3
CONNECTOR CLAMPING BOLTS
ISO STANDARD CONDUCTORS AND HARDWARE

Type of Conductor				For Copper Conductors						For Aluminum or ACSR Conductors			
				Bolts Per Conductor						Bolts per Conductor			
				Single Size Standard Duty		Single Size Heavy Duty		Range Taking		Range Taking*		Single Size	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Standard Pipe Size, mm	Copper Cable, mm^2	Aluminum or ACSR Cable Outside Diameter, mm	Stud Dia. (mm)	No.	Dia. (mm)	No.	Dia. (mm)	No.	Dia. (mm)	No.	Dia. (mm)	No.	Dia. (mm)
	16 thru 50	5.0 thru 10.1	12.0	2	M10	3	M10	4	M10	2	M12	2	M12
	thru 240	…	30	3	M10	3	M12	4	M10	4	M12	4	M12
30	300 thru 400	…	…	3	M10	4	M12	4	M12	4	M12	4	M12
40 thru 60	600 thru 1000	10.2 thru 35.9	40 thru 60	3	M12	4	M12	4	M12	4	M12	4	M12
90 thru 120	1100 thru 1500	40.0 thru 47.0		3	M16	4	M16	4	M16	4	M16	4	M16
140 thru 170	…	…	…	…	…	…	…	…	…	…	…	6	M16

NOTE—See Annex C for terminal pad configurations.

Table 4-4
NOMINAL TORQUE VALUES

Diameter of Bolts			Torque		
in.	(mm)#	Material	N-m	lb-ft	lb_f-in.
1/4	(6.3)	SB	9	7	80
5/16	(7.9)	SB	20	15	180
3/8	(9.5)	SB	27	20	240
1/2	(12.7)	SB	54	40	480
5/8	(15.9)	SB	75	55	660
3/4	(19.1)	SB	118	87	1050
3/8	(9.5)	LA	19	14	168
1/2	(12.7)	LA	34	25	300
5/8	(15.9)	LA	54	40	480
3/4	(19.1)	LA	73	54	650

NOTES—
LA = Lubricated-Aluminum
SB = Silicon bronze or steel
See 4.5 for arrangement and sizes of bolts for terminal connectors.
For reference only.

4.6.3 Examples Illustrating the Use of Table 4-2

4.6.3.1 Example 1

A straight coupler connector or a 90-degree (1.57 radian) elbow connector is used to connect a conductor of 1-1/2-in. copper pipe to another conductor of 1-1/2-in. copper pipe. After locating the proper line for the 1-1/2-in. 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:

$$A \times B = C$$
$$3 \times 2 = 6$$

For standard duty terminal or stud connectors per 4.6.1.6

$$A \times B = C$$
$$4 \times 2 = 8$$

Where:

A = 1/2 in. diameter bolts per conductor
B = Number of conductors
C = Number of 1/2 in. diameter bolts per fitting

Table 4-5
EXAMPLE 1

Bolts per Conductor	Number of Conductors	Minimum Number of Bolts per Fitting	Comments
3	2	6	Minimum
4	2	8	see 4.6.1.4

Bolt Size is 1/2 in.

4.6.3.2 Example 2

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

After locating the proper line for the 3-inch pipe in the first column of the table, it can be seen that the connectors require four 5/8-in. diameter bolts per conductor (see columns 13 and 14 of Table 4-2).

After locating the proper line for the 0.743-in. outside diameter ACSR tap in the third column of the table, it can be seen that the connectors require four 1/2-inch diameter bolts per conductor (see columns 13 and 14 of Table 4-2).

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

4.6.3.3 Example 3

A copper stud connector having a 1-1/8-in.-12 thread is connected to a copper cable ranging in size from 400 to 800 kcmil (203 to 405 mm^2). 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 in.-diameter bolts per conductor for the 1-1/8 stud, range-taking column.
b) Four 1/2-in. diameter bolts per conductor for the cable (based on largest bolts required for the range, covers both 3/0 AWG thru 500 and 550 thru 300 kcmil 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 bolts per conductor or four 1/2-in. diameter bolts per conductor.

4.7 TENSILE STRENGTH OF BOLTS

Bronze alloy and steel (including Stainless Steel) bolts shall have a minimum tensile strength of 480 MPa (70,000 psi) and aluminum alloy bolts shall have a minimum tensile strength of 380 MPa (55,000 psi).

4.8 EXPANSION CONNECTORS

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

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

4.9 TERMINAL CONNECTORS

On Offset Pad connectors there shall be a minimum clearance of 3.18 mm (1/8-in.) between any part of the clamp or hardware and the contact surface of the pad. (See Figures 4-4 and 4-5.)

4.10 FLAT PLAIN WASHERS

The size of flat (plain) washers shall be in accordance with Table 4-6.

Table 4-6
FLAT WASHER/BOLT COMBINATIONS

Bolt Size		Washer Size					
		Inside Diameter				Outside Diameter	
		Min.		Max.		Max.	
In.	Mm	In.	Mm	In.	Mm	In.	mm
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 Annex B for arrangement and sizes of bolts for terminal connectors

4.11 DIMENSIONAL REQUIREMENTS FOR BUS SUPPORTS AND OFFSET PAD CONNECTORS

4.11.1 HEIGHT OF BUS SUPPORT CLAMPS (FITTINGS)

The distance from the centerline of the bus to the top of the insulator, as shown in Figure 4-3, shall be in accordance with Table 4-7.

Table 4-7
HEIGHT OF ALUMINUM AND COPPER BUS SUPPORT CLAMPS (FITTINGS)
(See Figure 4-3.)

Standard Pipe Size			Height of Conductor Centerline above the Insulator Top			
			Bolt Circle Diameter			
Trade Size	O.D.		3 in. (76.2mm)		5 and 7 in. (127.0 and 177.8 mm)	
in.	in.	mm	in.	mm	in.	mm
1/2	.840	21.00	1-3/4 ± 1/16	44.4 ± 1.6	2-1/8 ± 1/16	54.0 ± 1.6
3/4	1.050	26.25	2 ± 1/16	50.8 ± 1.6	2-1/4 ± 1/16	57.2 ± 1.6
1	1.315	32.88	2 ± 1/16	50.8 ± 1.6	2-1/4 ± 1/16	57.2 ± 1.6
1-1/4	1.660	41.50	2-1/4 ± 1/16	57.2 ± 1.6	2-3/8 ± 1/16	60.3± 1.6
1-1/2	1.900	47.50	2-1/2 ± 1/16	63.5 ± 1.6	2-1/2 ± 1/16	63.5 ± 1.6
2	2.375	59.38	2-3/4 ± 1/16	69.8 ± 1.6	2-3/4 ± 1/16	69.8 ± 1.6
2-1/2	2.875	71.88	3-1/8 ± 1/16	79.4 ± 1.6	3-1/8 ± 1/16	79.4 ± 1.6
3	3.500	87.50	3-5/8 ± 1/16	92.1 ± 1.6	3-5/8 ± 1/16	92.1 ± 1.6
3-1/2	4.000	100.00	4 ± 1/16	101.6 ± 1.6	4 ± 1/16	101.6 ± 1.6
4	4.500	112.50	4-1/2 ± 1/16	114.3 ± 1.6	4-1/2 ± 1/16	114.3 ± 1.6
5	5.563	125.03	5 ± 1/8	127.0 ± 3.2	5 ± 1/8	127.0 ± 3.2
6	6.625	165.63	5-1/2 ± 1/8	139.7 ± 3.2	5-1/2 ± 1/8	139.7 ± 3.2

NOTE—1/2 in SPS (12.7) applies to copper clamps only.

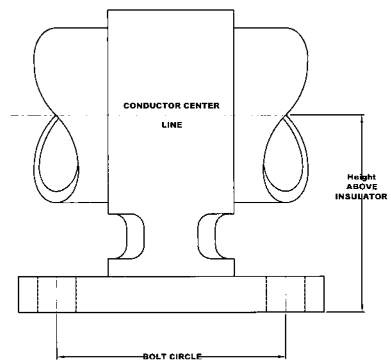


Figure 4-3
BUS SUPPORT CLAMP

4.11.2 OFFSET PAD TERMINAL CONNECTORS FOR TUBULAR BUS

The distance from the centerline of the bus to the pad contact, as shown in Figures 4-4 and 4-5 shall be in accordance with Table 4-8.

Table 4-8
HEIGHT OF OFFSET PAD TERMINAL CONNECTORS FOR TUBULAR BUS
(See Figures 4-4 and 45.)

Pipe Size			Height ± ½ in. (±13 mm)			
Trade Size	O.D.		Bolted Connectors		Welded Connectors	
in	in	mm	in	mm	in	mm
1/2	.840	21.00	1-3/8	35	15/16	24
3/4	1.050	26.25	1-3/8	35	1	25
1	1.315	32.88	1-3/8	35	1-1/8	29
1-1/4	1.660	41.50	1-1/2	38	1-1/4	32
1-1/2	1.900	47.50	1-5/8	41	1-1/2	38
2	2.375	59.38	1-3/4	44	1-3/4	44
2-1/2	2.875	71.88	2-1/8	54	2	54
3	3.500	87.50	2-3/8	60	2-3/8	60
3-1/2	4.000	100.00	2-5/8	67	2-5/8	67
4	4.500	112.50	3-1/8	79	2-7/8	73
5	5.563	125.03	3-3/4	95	3-3/8	86
6	6.625	165.63	4-3/8	111	4	102

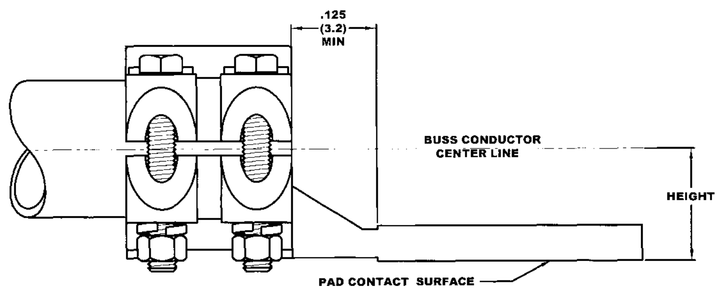


Figure 4-4
BOLTED OFFSET PAD TERMINAL CONNECTOR

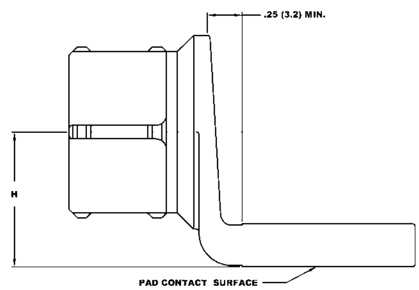


Figure 4-5
WELDED OFFSET PAD TERMINAL CONNECTOR

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 surface.

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 compatible solvent, if necessary.

Since it is the aluminum (anode) that 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 (i.e., the aluminum connector shall be sized to handle the full current rating of 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 wire-brushed and an appropriate joint compound applied 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 wire-brushed and an appropriate joint compound applied to the copper stud.

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

It is recommended that a welder qualified for the material perform the welding. Prior to welding, it is recommended that a test weld be made on a typical aluminum casting (see 2.9).

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 or silicone bronze hardware, spring-type (Belleville) washers should be used 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.

Annex A
NEMA Standards Publication No. 107-1987 (1993)

NEMA Standards Publication No. 107-1987 (R1993)

**METHODS OF MEASUREMENT OF RADIO INFLUENCE VOLTAGE (RI V)
OF HIGH VOLTAGE APPARATUS**

Reaffirmed with No Text Changes, December 1993

Published by:

**National Electrical Manufacturers Association
2101 L Street, N.W., Suite 300
Washington, D.C. 20037**

TABLE OF CONTENTS

FOREWORD

This standard supersedes and is an extensive revision of NEMA Standards Publication No. 107-1964 (R 1971, 1976, 1981), *Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus.*

Users of this NEMA Standards Publication are advised that radio influence voltage (RIV) measurements are not meant to be similar to corona measurements even though the source phenomena may be the same.

In the preparation of this Standards Publication, input of users and other interested par-ties has been sought and evaluated. Inquiries, comments, and proposed or recommended revisions should be submitted to the concerned NEMA subdivision by contacting the:

Manager, Engineering Department
National Electrical Manufacturers Association
2101 L Street, N.W.
Washington, D.C. 20037

Scope

This standard covers the methods of measurement of radio influence voltage in the frequency range of 0.015 to 30 megahertz that may be associated with high-voltage power apparatus used on transmission and distribution systems at line voltages of 0.6 kilovolts and above.

The decision as to whether this standard applies to a specific test sample may be deter-mined from the specifications or standards which apply to the equipment in question.

The radio influence voltage which is of principal concern in this standard is that voltage appearing at the terminals of test samples, or on conductors of power systems, which affects the coordination between power and communication circuits. Acceptable low level radio influence voltage measured on the terminals of power equipment may not affect the coordination between power systems and communication circuits, but, may be of concern in the life of the equipment's internal insulation.

Because of the large voltage range and, consequently, the large change in dimensions of high-voltage test equipment, it is not feasible to define a single standard high- voltage test circuit. The general form of the test circuit is defined, and nominal limits are placed on components of the circuit. In order that uniform and significant radio influence voltage measurements may be made, it is necessary that the test circuits be accurately calibrated as described in this standard. By means of this calibration, the effects of circuit elements and stray circuit constants of the test circuit are taken into consideration.

Section 1
REFERENCED STANDARDS AND DEFINITIONS

1.1 REFERENCED STANDARDS

The following publications are adopted, in whole or in part as indicated, by reference in this standards publication.

American National Standards Institute (ANSI)
1430 Broadway,
New York, NY 10018

ANSI C63.2-1980 American National Standard, *Specifications for Electromagnetic Noise and Field-Strength Instrumentation, 10kHz to 1 GHz*

ANSI C63.4-1981 American National Standard, *Method of Measurement of Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 10 kHz to 1 GHz*

ANSI C50.10-1977 American National Standard, *General Requirements for Synchronous Machines*

ANSI/IEEE 100-1984 IEEE Standard, *Dictionary of Electrical Terms*

1.2 DEFINITIONS

The following definitions apply specifically and only to the subject treated in this standard. For additional definitions see ANSI/IEEE 100-1984.

NEMA Standard 5-27-1987.

1.2.1 Radio Noise

1.2.1.1 BROAD-BAND RADIO NOISE

Radio noise having a spectrum which is broad compared with the nominal bandwidth of the radio-noise meter.

NEMA Standard 5-27-1987.

1.2.1.2 IMPULSIVE RADIO NOISE

Radio noise characterized by non-overlapping transient disturbances. This includes corona and other high-voltage discharges.

NEMA Standard 5-27-1987.

1.2.1.3 Radio Influence Voltage (RIV)

The voltage that appears on the conductors of electric equipment or circuits, as measured with a standard radio-noise meter used as a 2-terminal voltmeter in accordance with the methods described herein.

NEMA Standard 5-27-1987.

1.2.2 Tests

1.2.2.1 Circuit RIV Factor (P)

The ratio of the voltage at the terminals of the radio-noise meter (E_{cd}) to the signal generator voltage (E_{ab}). Thus, $E_{cd}/E_{ab} = P$.

NEMA Standard 5-27-1987.

1.2.2.2 Factory Tests

Tests that can be made in a factory or outdoor area, using a calibrated high-voltage test circuit, with the test sample energized at its rated test voltage so that operating conditions are simulated.

NEMA Standard 5-27-1987.

1.2.2.3 Field Tests

Tests which can be made (usually in an outdoor area) on energized power system equipment or lines, using a high-voltage coupling capacitor and the circuitry described herein.

NEMA Standard 5-27-1987.

1.2.2.4 Laboratory Tests

Tests that are made under controlled conditions of ambient radio noise, usually in a shielded enclosure, using a calibrated high-voltage test circuit and a filtered power supply, with the test sample energized so that operating conditions are simulated.

NEMA Standard 5-27-1987.

1.2.3 Test Sample

The equipment (unit, component assembly or system) which is to be tested to determine the RIV level. Test samples shall be permitted to include any power system equipment, such as insulators, bushings, transformers, switchgear, conductors, and so forth.

NEMA Standard 5-27-1987.

Section 2
GENERAL TEST CONDITIONS

2.1 TEST AREA

For laboratory, factory, or field tests, the test area shall be of a suitable size to maintain adequate clearances so that the electric field around the test sample is not distorted. See Figure 2-1.

NEMA Standard 5-27-1987.

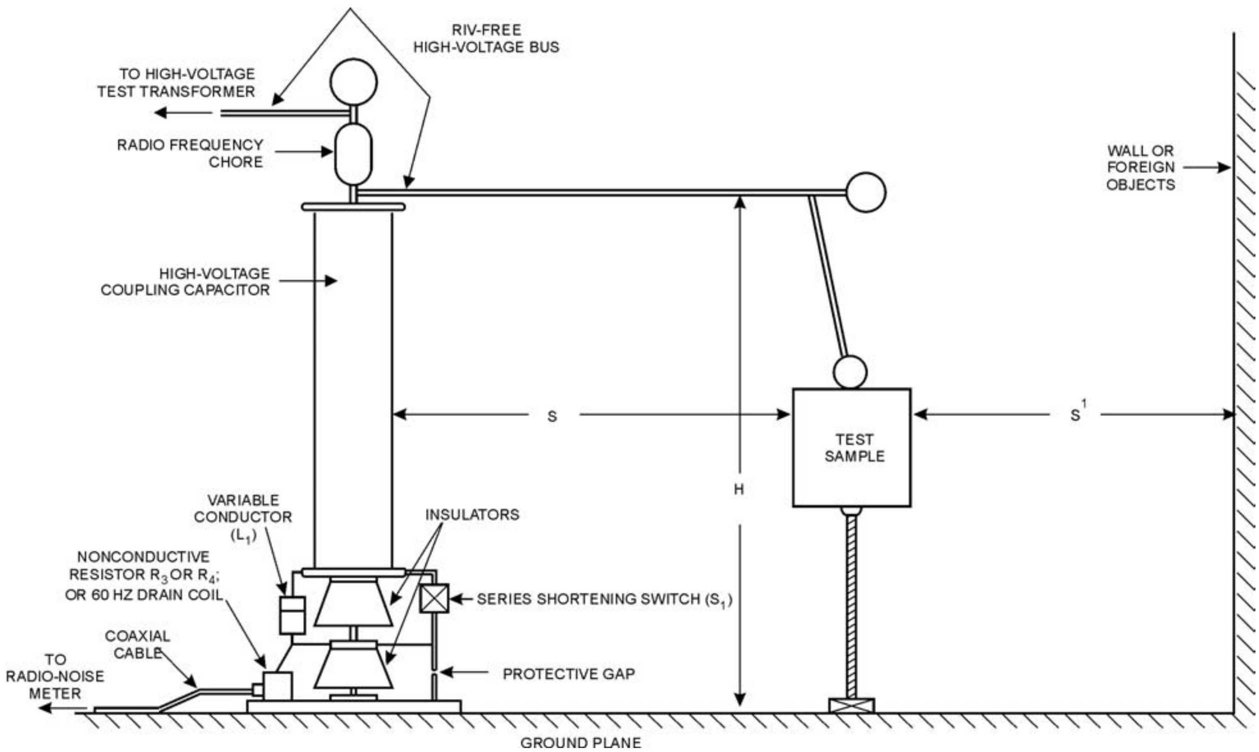


Figure 2.1
Setup of High-Voltage RIV Test Circuit

2.1.1 Ambient RIV

It is desirable that the ambient RIV level at each measurement frequency be measured for reference purposes at the required test voltage with the test sample disconnected. Where an allowable RIV limit is specified in the applicable specification or standard, it is usually desirable that the ambient RIV level be at least 6 decibels below (one-half) the specified limit.

Authorized Engineering Information 6-27-1987.

2.1.2 Calibration Accuracy

Evidence shall be given that the calibrations of the measuring instruments used are accurate for the temperature at which they are used. Further, the test sample, radio-noise meters, indicating devices and equipment shall be at the test location for a sufficient time prior to making calibrations and measurements to allow the temperature of the equipment to become stabilized with respect to the temperature of the testing location.

NEMA Standard 6-27-1987.

2.1.3 Humidity

Tests are conducted under atmospheric conditions prevailing at the time and place of the test, but it is recommended that tests be avoided when the vapor pressure exceeds 0.6 inch of mercury. Although there are no correction factors to cover the effect of humidity and barometric pressure currently, it is recommended that the barometric pressure and wet and dry-bulb thermometer readings be recorded so that, if suitable correction factors are determined in the future, they may be applied to previous measurements.

Authorized Engineering Information 5-27-1987.

2.1.4 Temperature

The ambient temperatures of the testing location should be within the range of 10°C to 40°C (50° F to 104° F).

Authorized Engineering Information 5-27-1987.

2.2 TEST SAMPLE SETUP

The arrangement of the components, interconnecting cable assemblies, and supporting structures of the test sample shall simulate actual installation and operation insofar as is practicable.

NEMA Standard 5-27-1987.

2.2.1 RIV Test Voltage

The test voltage shall be as stated in the individual equipment specification or standard.

NEMA Standard 5-27-1987.

2.2.2 Conditioning of Test Sample

The test sample shall be clean and dry, and energized for a sufficient period of time so that representative RIV conditions can be obtained on the specimen prior to making measurements.

NEMA Standard 5-27-1987.

2.2.3 Test Sample Grounding

The test sample shall be grounded in order to simulate installation conditions.

NEMA Standard 5-27-1987.

2.2.4 Test Sample Leads

The high-voltage leads which are used to connect the test samples to the high-voltage bus shall be free of RIV and corona at the test voltage.

NEMA Standard 5-27-1987.

2.3 INSTRUMENTATION AND MEASUREMENTS

Radio-noise instrumentation (meters) shall meet the requirements of ANSI C63.2.

NEMA Standard 5-27-1987.

2.3.1 RIV Impulses

When making measurements on RIV impulses with repetition rates so low that meter fluctuation makes reading of either the minimum or maximum pointer deflection doubtful, the slow-speed indicating output meter listed in ANSI C63.2 shall be used. The highest pointer deflection of the meter during a 15-second interval of observation shall be recorded as the RIV in order to minimize the differences between various operators in recorded results for noise sources with low repetition rates.

NEMA Standard 5-27-1987.

2.3.2 Radio-Noise Meter Calibration

Calibrations and adjustments shall be made as specified in the instruction manual for the radio-noise meter.

NEMA Standard 5-27-1987

2.3.3 Detector Function Selection

The detector function selector switch shall be set to the quasi-peak position on the radio-noise meter.

NEMA Standard 5-27-1987

2.3.4 Monitoring

When it is desired to identify the character of the RIV, measurements should be monitored using either a headset, loud-speaker, or oscilloscope. Precautions should be taken to determine whether these devices affect the radio-noise meter indications during measurements.

Authorized Engineering Information 5-27-1987.

2.3.5 Preferred Measurement Frequency

Radio interference studies have indicated that if radio influence voltages are generated by power system apparatus, readings can be obtained at 1 megahertz, the approximate midpoint of the AM broadcast band. Because of this, radio influence tests at the single frequency of 1 megahertz can be considered to produce representative test results, and tests on high-voltage power system apparatus may be carried out at this single frequency.

Authorized Engineering Information 5-27-1987.

2.3.6 Other Measurement Frequencies

For tests requiring measurements from 0.015 to 30 megahertz, the test frequencies given in Table 2-1 are recommended.

Authorized Engineering Information 5-27-1987.

Table 2-1
MEGAHERTZ

0.015	0.080	0.35	1.5	8.0
0.020	0.100	0.50	2.0	10.0
0.028	0.120	0.60	2.8	12.0
0.035	0.15	0.80	3.5	15.0
0.050	0.20	1.00	5.0	20.0
0.060	0.28	1.20	6.0	25.0
				30.0

2.3.7 Not Listed Frequencies

Other frequencies which are not listed for measurement in Table 2-1 can be scanned while monitoring with a headset or speaker. If any indicated peaks occur during scanning, measurements should be taken at each frequency where such a peak occurs. If an unwanted radio signal is encountered at any of the listed frequencies, another frequency on either side of the signal should be substituted.

Authorized Engineering Information 5-27-1987.

2.4 ACCEPTABLE RIV TEST LEVEL

The RIV level of a test sample shall be considered acceptable as long as the measured RIV level, which includes both the test area ambient and test sample RIV, is below the limit specified in the applicable test sample specification standard.

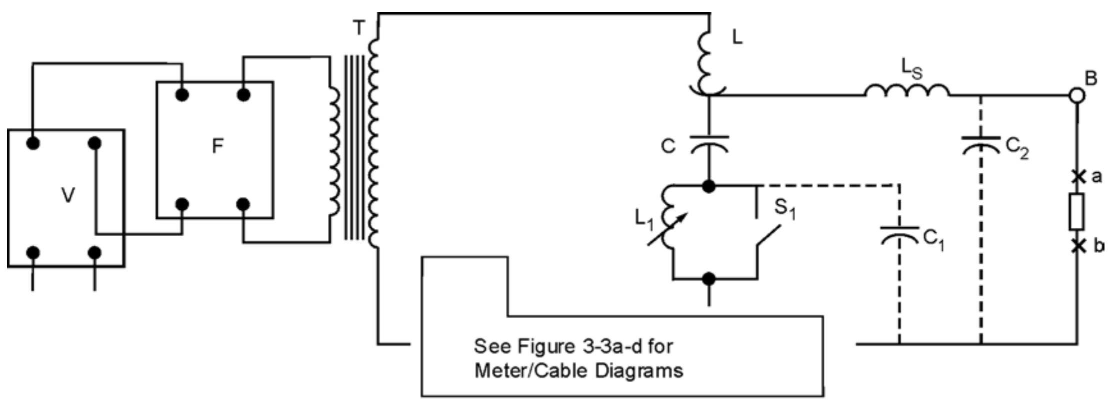
NEMA Standard 5-27-1987.

Section 3
LABORATORY AND FACTORY RIV TESTS—0.015 TO 30 MEGAHERTZ

3.1 TEST CIRCUIT

For laboratory and factory RIV tests, the circuit shown in Figure 3-1 shall be used. Because of the wide frequency range to be covered by this test circuit and the variable attenuation factors which will occur due to stray circuit constants (see C, and C_2, stray capacitances, and the series inductance, L_a), the circuit shall be calibrated for each frequency at which RIV measurements are made. Below 1.0 megahertz where the reactance of the high-voltage coupling capacitor, C, is generally high, a variable inductor (circuit element L_1) which is capable of producing series resonance in the high-voltage measuring circuit at the test frequency shall be introduced.

NEMA Standard 5-27-1987.



Item	*Description*	*See Paragraph(s)*
B	High-voltage bus	5.10
L_S	Bus inductance	5.10
C	High-voltage coupling capacitor	5.7.1, 5.7.2
C_1 and C_2	Stray capacitance of test circuit	5.10
F	Power line filter	5.3
L	Radio-frequency choke	5.6
L_1	Variable inductor	5.8
S_1	Series shorting switch	5.9
T	High-voltage test transformer	5.5
V	Variable voltage source	5.4
Point ab	Position of test sample or calibrating signal generator	3.2.1., 1.2.2.1

Figure 3-1
Circuit for the Measurement of Radio-Influence Voltge of High-Voltage Aparatus, 0.015 to 30 MegaHertz

3.2 TEST CIRCUIT CALIBRATION

3.2.1 High Voltage Apparatus

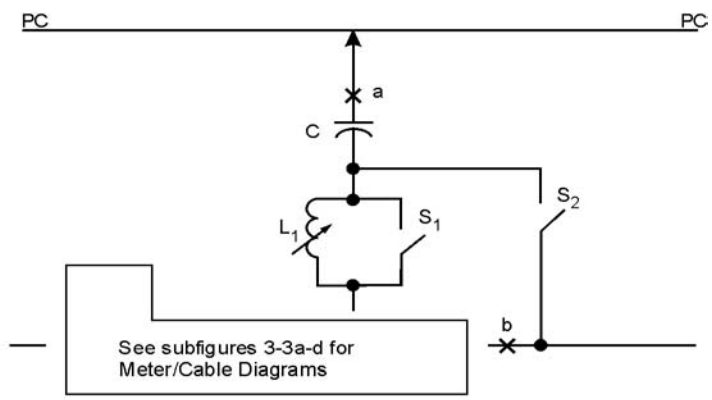
The Figure 3-1 circuit shall be calibrated by applying at points "a" and "b," with the test specimen not connected; the unmodulated sine wave output of a signal generator tuned to the desired test frequency. The output of this signal generator shall be set to a level at least ten times the ambient noise level which is measured by the radio-noise meter when tuned to the output of the signal generator. If tests are to be made at or above 1.0 megahertz, switch S_1 shall be closed. For tests below 1.0 megahertz, switch S_1 shall be open and variable inductance L_1, varied until a maximum signal is obtained on the radio-noise meter. The inductance of L_1 shall be held constant while the voltages E_{ab} (signal generator voltage at point ab) and E_{cd} (voltage at the radio-noise meter terminals, point cd) are measured.

NEMA Standard 5-27-1987.

3.2.2 Energized Power System

The Figure 3-2 circuit shall be calibrated by applying at points “a” and “b,” with point “a” not connected to the power conductor “PC,” the unmodulated sine wave output of a signal generator tuned to the desired test frequency. The signal generator output and other calibration provisions shall be the same as outlined in 3.2.1.

NEMA Standard 5-27-1987.



Item	Description	See Paragraph(s)
C	High-voltage coupling capacitor	5.7.1, 5.7.2
L_1	Variable inductor	5.8
PC	Power system conductor	5.7.11
S_1	Series shorting switch	5.9
S_2	Capacitor grounding switch	
Point ab	Position of calibrating signal, switch S_2 open, point “a” not connected to PC	3.2.2, 1.2.2.1

Figure 3-2
Circuit for the Measurement of Radio-Influence Voltage from an Energized Power System

3.2.3 Voltage Measurement

Calibrating voltages may be measured by either a high-frequency electronic voltmeter and oscilloscope or the radio-noise meter "M" when used as a 2-terminal voltmeter.

Authorized Engineering Information 5-27-1987.

3.2.4 Voltage Measurement Variables

Both calibrating voltages (E_{ab} and E_{cd}) shall be measured by the same instrument so that error is minimized. The coaxial cable, CA, of the length to be used for RIV measurements shall be in the circuit when the test circuit calibration is made.

NEMA Standard 5-27-1987.

3.2.5 Circuit RIV Factor (P)

The circuit RIV factor (P) should be held above 0.25 at midband at approximately 1 megahertz. The circuit RIV Factor (P) for other test frequencies between 0.03 and 5 megahertz should preferably be held greater than 0.2.

Authorized Engineering Information 5-27-1987.

3.2.6 RIV Factor Curve

Since this factor (P) will vary with frequency, a curve of the RIV factor can be obtained for the test circuit. The calibration curve so obtained may not be valid if the circuit components or the circuit configuration is changed.

Authorized Engineering Information 5-27-1987,

3.3 RIV METER READINGS

In carrying out radio influence voltage tests with the sample positioned at point ab, RIV meter readings shall be made in the manner described in 2.3. The reading so obtained shall then be divided by the circuit RIV factor (P), at the specific test frequency, to obtain the RIV level of the equipment under test.

NEMA Standard 5-27-1987.

Section 4
FIELD MEASUREMENTS OF RIV-0.015 TO 30

4.1 MEASURING CIRCUIT

For the measurements of RIV from the conductors and apparatus of an energized power system, the measuring circuit shown in Figure 3-2 may be used. Extreme care should be taken to insure that the application of this measuring circuit to the power system does not interfere with the normal operation of the circuit and that proper grounding of the low-voltage measuring circuit is carried out so that the equipment and the operators are not endangered.

Authorized Engineering Information 5-27-1987.

4.2 FIELD MEASUREMENT CIRCUIT CALIBRATION

The measuring circuit may be calibrated in accordance with 3.1 before the high-voltage coupling capacitor is connected to the power system. In carrying out this field calibration, precautions should be taken to insure that radio influence fields and conducted influence voltages (RIF and RIV) from the power system do not affect the calibration.

Authorized Engineering Information 5-27-1987.

Section 5
HIGH-VOLTAGE TEST-CIRCUIT COMPONENTS

5.1 GENERAL

The following components refer to items which are associated with the high-voltage RIV test circuits indicated schematically in Figures 3-1, 3-2, and 3-3, and illustrated in Figure 2-1.

Authorized Engineering Information 5-27-1987.

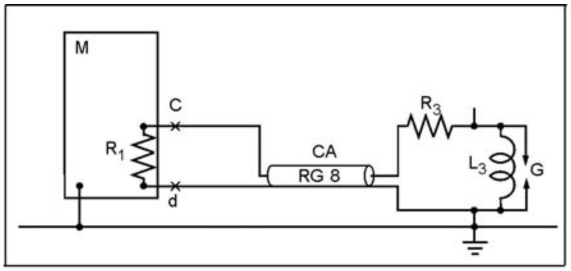


Figure 3-3a 50 Ohm Coax Cable, 50 Ohm Impedance RIV Meter

R_1 = 50 Ohm Internal Meter Impedance
R_3 = 100 Ohm Non-Inductive Resistor
L_3 = 60 Hz Drain Coil (Impedance at Test Frequency greater than 1500 Ohm)
CA = 50 Ohm Cable Impedance

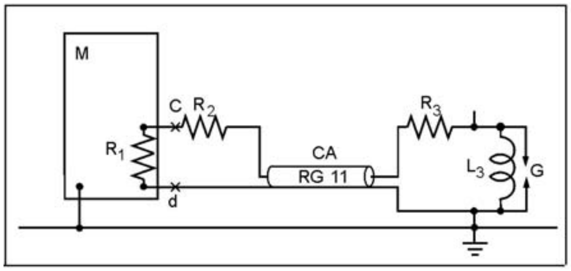


Figure 3-3b 75 Ohm Coax Cable, 50 Ohm Impedance RIV Meter

R_1 = 50 Ohm Internal Meter Impedance
R_2 = 25 Ohm Non-Inductive Resistor
R_3 = 75 Ohm Non-Inductive Resistor
L_3 = 60 Hz Drain Coil (Impedance at Test Frequency greater than 1500 Ohm)
CA = 75 Ohm Cable Impedance

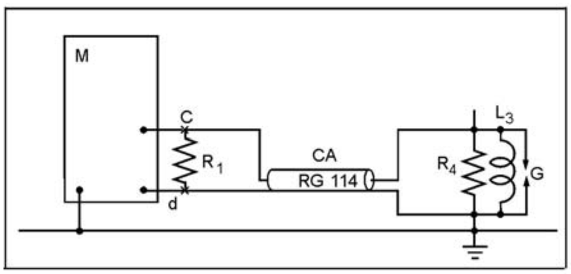


Figure 3-3c 185 Ohm Coax Cable, High Impedance RIV Meter

R_1 = 185 Ohm Non-Inductive Resistor
R_4 = 100 Ohm Non-Inductive Resistor
L_3 = 60 Hz Drain Coil (Impedance at Test Frequency greater than 1500 Ohm)
CA = 185 Ohm Cable
M = Meter Impedance Greater than 1 Megohm

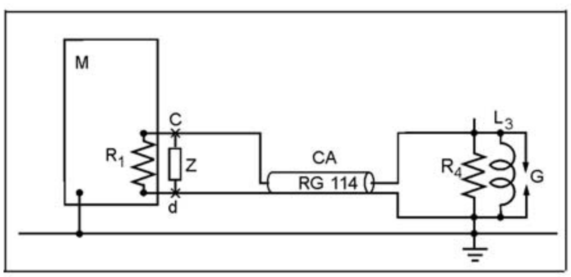


Figure 3-3d 185 Ohm Coax Cable, 50 Ohm Impedance RIV Meter

R_1 = 50 Ohm Internal Meter Impedance
R_4 = 50 Ohm Non-Inductive Resistor
Z = 185/50 Ohm Matching Impedance and/or Attenuate
L_3 = 60 Hz Drain Coil (Impedance at Test Frequency greater than 1500 Ohm)
CA = 185 Ohm Cable Impedance

Item	*Description*	*See Paragraph(s)*
CA	Coaxial cable	5.15
G	Protective gap	5.14
L_3	60 Hz drain coil	5.17
M	Radio-noise meter	2.3
R_1, R_2, R_3, R_4	Non-inductive resistors	5.12
Z	185/50 Ohm matching impedance and/or attenuator	5.13
Point ab	RIV measurement point or place at which E_{cd} is measured	3.2.4., 1.2.2.1

Figure 3-3
Circuit Diagrams for Use of 50, 75, and 185-Ohm Coaxial Cable in Conjunction with Figure 3-1 and 3-2

5.2 60-HERTZ VOLTAGE SOURCE

The power supply for the high-voltage test circuit shall have a kVA rating which is sufficient to supply a 60-Hertz sine wave voltage of acceptable commercial standard as defined in ANSI C50.10.

NEMA Standard 5-27-1987.

5.3 POWER LINE FILTER (F)

The power line filter, when employed, shall not distort the supply voltage. It shall suppress any RIV which may be on the power mains so that the conditions given in 2.1.1 will be met.

NEMA Standard 5·27-1987.

5.4 VARIABLE VOLTAGE (V)

A variable and undistorted voltage shall be supplied to the primary of the high-voltage test transformer.

NEMA Standard 5-27-1987.

5.5 HIGH-VOLTAGE TEST TRANSFORMER (T)

The high-voltage test transformer should be free of RIV within the voltage range at which tests are to be made.

Authorized Engineering Information 5-27-1987.

5.6 RADIO-FREQUENCY CHOKE (L)

A radio-frequency choke with an impedance of not less than 1500 ohms at the measurement frequency shall be installed at or near the top of the high-voltage coupling capacitor. This element shall limit the loss of conducted radio-freqency energy for the test sample and shall be free of RIV within the voltage range of the test circuit.

NEMA Standard 5-27-1987.

5.7 HIGH-VOLTAGE COUPLING CAPACITOR (C)

5.7.1 Radio Influence Voltage

The high-voltage coupling capacitor of the required voltage rating shall be free of RIV within the voltage range of the test circuit.

NEMA Standard 5-27-1987,

5.7.2 Coupling Capacitor

A coupling capacitor of small capacitance will draw a minimum current, but at the lower test frequencies it will appear as an excessively high reactive element and produce a low RIV factor (P) as described in Section 3. It is recommended that the capacitance be not less than 0.001 microfarad. The capacitance from the bottom end of the coupling capacitor to ground should be kept small so that this capacitance will not appreciably reduce the impedance of 150 ohms obtained from the metering system (Figure 3-3).

Authorized Engineering Information 5-27-1987.

5.8 VARIABLE INDUCTOR (L_1)

A variable inductor or inductors shall be used at the lower test frequencies (below 1 megahertz) to balance out the capacitive reactance of the high-voltage coupling capacitor, C.

NEMA Standard 5-27-1987.

5.9 SERIES SHORTING SWITCH (S_1)

A series shorting switch shall be applied across variable inductor L_1, when L_1 is used, to short out the inductor during RIV tests at 1.0 megahertz and above.

NEMA Standard 5-27-1987.

5.10 HIGH-VOLTAGE BUS (B)

A corona-free bus shall be connected from the high-voltage coupling capacitor to the test sample. This bus shall be supported by a minimum number of RIV-free insulators to minimize stray capacitance (C_2) to ground and shall be as short as possible to minimize series inductance (L_s).

NEMA Standard 5-27-1987.

5.11 CONDUCTOR DIAMETER

The smooth conductor diameter for a corona-free bus for voltages up to 400 kilovolts may be obtained by allowing at least 0.01 inch of bus diameter per kilovolt of test voltage. Above 400 kilovolts bundled conductors may be preferred to single conductors.

Authorized Engineering Information 5-27-1987.

5.12 NONINDUCTIVE RESISTORS (R_1, R_2, R_3, and R_4)

Resistors R_1, R_2, R_3, and R_4 shall be high frequency, noninductive elements (Figure 3-3 a-d).

NEMA Standard 5-27-1987.

5.13 185/50-OHM MATCHING IMPEDANCE AND/OR ATTENUATOR (Z)

A 185/50-ohm matching impedance and/or attenuator shall be between the coaxial metering cable and RIV meter whenever a 185-ohm cable is used with a low impedance RIV meter (See Figure 3-3 d).

Authorized Engineering Information 5-27-1987.

5.14 PROTECTIVE GAP (G)

A suitable protective gap (breakdown not to exceed 500 volts) shall be connected across circuit element L_3 (Figure 3-3 a-d).

NEMA Standard 5-27-1987.

5.15 COAXIAL CABLE (CA)

50-, 75-, and 185-ohm coaxial cables can be used providing the proper cable terminations at the sending and receiving ends are utilized. See Figure 3-3 a-d for the proper noninductive resistors or 185/50-ohm matching impedance and/or attenuator specifications. The coaxial cable designation may be either RG-8, RG-11, or RG-114.

Authorized Engineering Information 5-27-1987.

5.16 COAXIAL CABLE LENGTH

Because of cable attenuation, it is recommended that the cable length be kept as short as possible in order to meet the circuit RIV factor (P) recommendations.

Authorized Engineering Information 5-27-1987.

5.17 DRAIN COIL (L_3)

A 60-Hz drain coil with an impedance of not less than 1500 ohms at the measurement frequency, shall be in-stalled in the metering circuit across gap (G). For safety reasons, this unit shall be substantial in size, and all electrical connections shall be made mechanically and electrically secure.

NEMA Standard 5-27-1987.

Annex B
BOLT HOLES FOR TERMINAL CONNECTORS

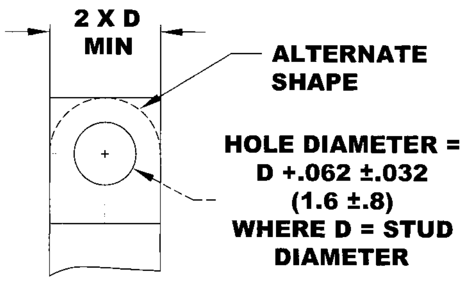


Figure B-1
1-HOLE TERMINAL PAD

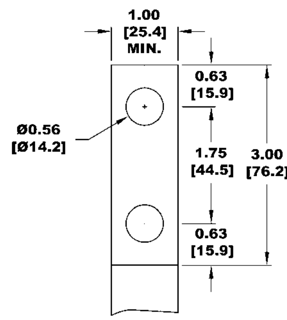


Figure B-2
2-HOLE NEMA PAD

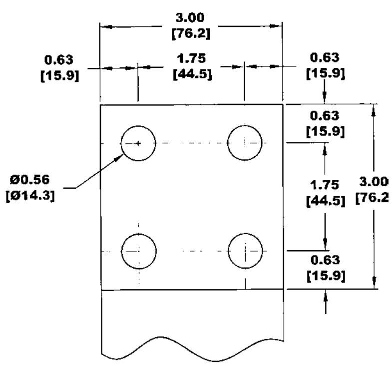


Figure B-3
4-HOLE NEMA PAD
(2 X 2 BOLT HOLE PATTERN)

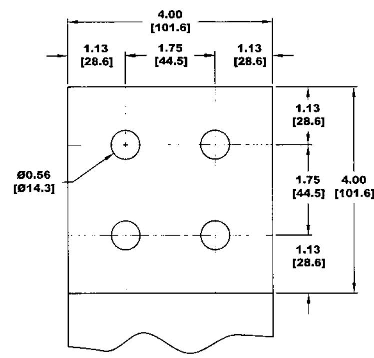


Figure B-4
4-HOLE WIDE NEMA PAD
(2 X 2 BOLT HOLE PATTERN)

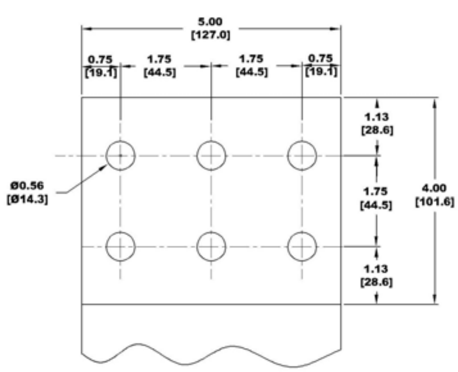


Figure B-5
6-HOLE NEMA PAD
(2 X 3 BOLT HOLE PATTERN)

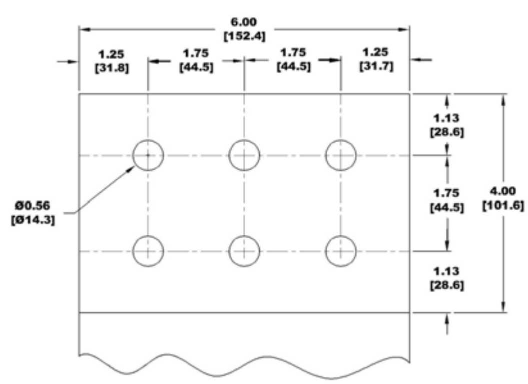


Figure B-6
6-HOLE WIDE NEMA PAD
(2 X 3 BOLT HOLE PATTERN)

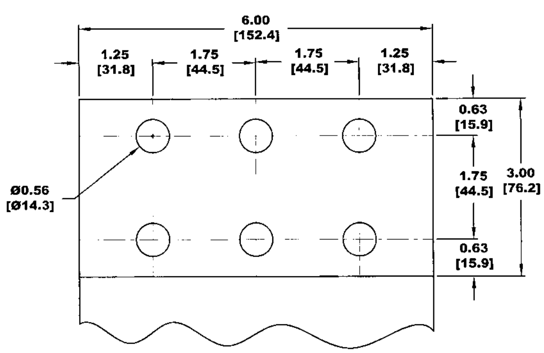


Figure B-7
2 X 3 BOLT HOLE PATTERN
FOR MULTIPLE FLAT BAR TANGS

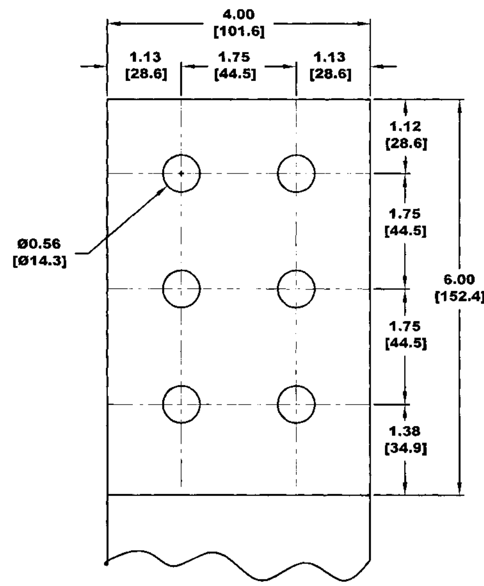


Figure B-8
3 X 2 BOLT HOLE PATTERN
FOR MULTIPLE BLAT BAR TANGS

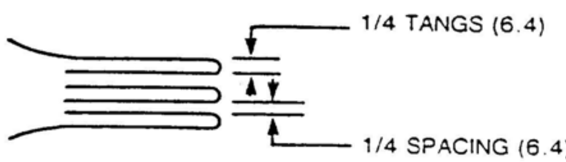


Figure B-9
TYPICAL SPACING FOR
MULTIPLE FLAT BAR TANGS

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

Annex C
BOLT HOLES FOR TERMINAL CONNECTORS USED IN OTHER COUNTRIES

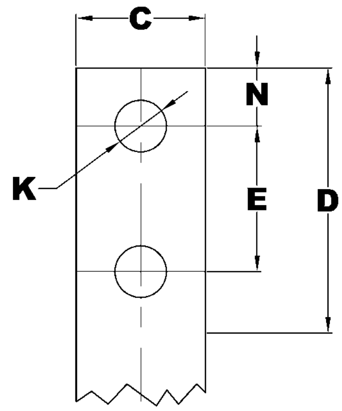


Figure C–1
BOLT HOLE PATTERN FOR TERMINAL CONNECTORS

Table C–1

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

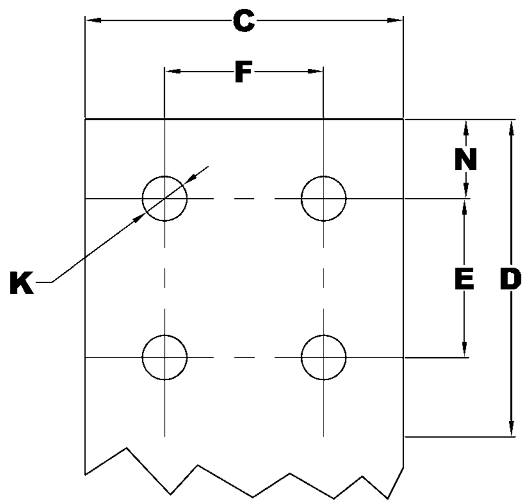


Figure C–2
2 X 2 BOLT HOLE PATTERN FOR TERMINAL CONNECTORS

Table C–2

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

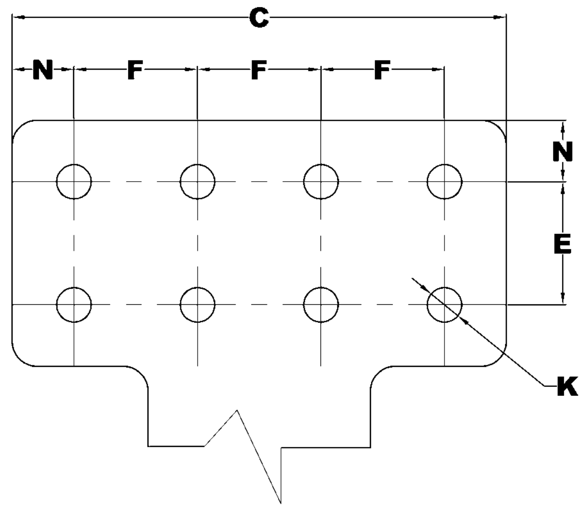


Figure C–3
2 X 4 BOLT HOLE PATTERN FOR TERMINAL CONNECTORS

Table C-3

COUNTRY	C		E	F	K	N
	mm		Mm	mm	mm	mm
GERMANY	200		50	50	14	25

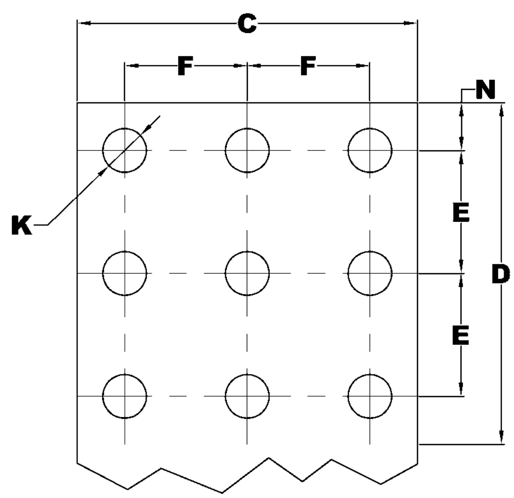


Figure C–4
3 X 3 BOLT HOLE PATTERN FOR TERMINAL CONNECTORS

Table C–4

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