NETA
Maintenance Testing Specifications
Part II

Metering Devices / Regulating Apparatus / Ground Systems / Ground-Fault Protection
Rotating Machinery / Motor Control / Adjustable Speed Drives / Direct Current Systems
Surge Arrestors / Capacitors & Reactors / Outdoor Bus Structures / Emergency Systems
Communication / Reclosers & Sectionalizers Fiber Optic Cables
Electric Vehicle Charging

NETA Format / Electric Equipment Maintenance Testing Requirements / Terminology / Theory

by

John A Camara, BS, MS, PE, TF

Nomenclature[1]

AC	Alternating Current	-
AFD	Adjustable Frequency Drive	-
ALF	Accuracy Limit Factor	-
ASD	Adjustable Speed Drive	-
ATS	Acceptance Testing Specifications	-
ANSI	American National Standards Institute	-
ASTM	American Society for Testing and Materials (International)	-
DAC	Damped Alternating Current	-
DAR	Dielectric Absorption Ratio	-
DC	Direct Current	-
ECS	Electrical Commissioning Specifications	-
FS	Security Factor	%
HMI	Human Machine Interface	-
ICRP	International Commission on Radiological Protection	-
IEC	International Electrotechnical Commission	-
IEEE	Institute of Electrical and Electronics Engineers	-
ISEA	International Safety Equipment Association	-
ISO	International Organization for Standardization	-
MAC	Magnetron Atmospheric Condition	-
MCC	Motor Control Center	-
MTS	Maintenance Testing Specifications	-
NEC	National Electrical Code	-
NECA	National Electrical Contractors Association	-
NETA	InterNational Electrical Testing Association	-
NIST	National Institute of Standards and Technology	-
NFPA	National Fire Protection Association	-
NIOSH	National Institute for Occupation Safety and Health	-
OEM	Original Equipment Manufacturer	-
OSHA	Occupational & Safety Health Administration	29CFR1910/1926
PI	Polarization Index	-

[1] Not all the nomenclature, symbols, or subscripts may be used in this course—but they are related and may be found when reviewing the references listed for further information. Further, all the nomenclature, symbols, or subscripts will be found in of many electrical courses (on SunCam, PDH Academy, and also in many texts). For guidance on nomenclature, symbols, and electrical graphics: IEEE 280-2021. IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering. New York: IEEE; and IEEE 315-1975. Graphic Symbols for Electrical and Electronics Diagrams. New York: IEEE, approved 1975, reaffirmed 1993.

RF	Rating Factor	-
RTD	Resistance Temperature Detector	-
TDR	Time Domain Reflectometer	-
UL	Underwriters Laboratories, Inc.	-
UPS	Uninterruptible Power Supply	-
VFD	Variable Frequency Drive	-
VLF	Very Low Frequency	-
VSD	Variable Speed Drive	-

Symbols

*	Optional Testing	-
C	Capacitance	F
Δ, δ	change (deviation)(delta)	-
ε	Deviation	%
E, *E*	Energy	J
I	Current	A
K	Remanence Factor	-
L	Inductance	H
R	Resistance	Ω
T	Temperature	ºC
V	Voltage, Potential	V

Subscripts

c	corrected	-
C	Capacitance	-
H	high	-
i	current	-
k	Knee Point	-
L	low	-
m	meter	-
n	nominal (rated)	-
p	primary	-
r	remanence	-
R	Resistance	-
s	secondary	-
t	turns	-

TABLE OF CONTENTS

Nomenclature....2
Symbols....3
Subscripts....3
List of Figures....6
List of Tables....6
COURSE INTRODUCTION....7
HISTORY AND CODE OVERVIEW....7
1. General Scope....9
2. Applicable References....9
3. Qualifications of Testing Organization and Personnel....10
4. Division of Responsibility....10
5. GENERAL....10
5.1 Safety and Precautions....10
5.2 Suitability of Test Equipment....10
5.3 Test Equipment Calibration....10
5.4 Test Report....11
5.5 Test Decal....11
6. POWER SYSTEM STUDIES....11
6.1 Short-Circuit Studies....11
6.2 Coordination Studies....11
6.3 Incident Energy Analysis....12
6.4 Load Flow Studies....12
6.5 Stability Studies....12
6.6 Harmonic Analysis Studies....12
7 INSPECTION AND TEST PROCEDURES....13
7.11.1 Metering Devices, Electromechanical and Solid-State....14
7.11.2 Metering Devices, Microprocessor-Based....14
7.12.1.1 Regulating Apparatus, Voltage, Step Voltage Regulators....14
7.12.1.2 Regulating Apparatus, Voltage, Induction Regulators....16
7.12.2 Regulating Apparatus, Current....16
7.12.3 Regulating Apparatus, Load Tap Changer....16
7.13 Grounding Systems....17
7.14 Ground Fault Protection Systems, Low Voltage....17
7.15.1 Rotating Machinery, AC Induction Motors and Generators....19
7.15.2 Rotating Machinery, Synchronous Motors and Generators....21
7.15.3 Rotating Machinery, DC Motors and Generators....22
7.16.1.1 Motor Control, Motor Starters, Low-Voltage....23
7.16.1.2 Motor Control, Motor Starters, Medium Voltage....24
7.16.2.1 Motor Control, Motor Control Centers, Low-Voltage....24
7.16.2.2 Motor Control, Motor Control Centers, Medium Voltage....24
7.17 Adjustable Speed Drive Systems....24
7.18.1.1 Direct-Current Systems, Batteries, Flooded Lead-Acid....27
7.18.1.2 Direct-Current Systems, Batteries, Vented Nickel-Cadmium....28

7.18.1.3 Direct-Current Systems, Batteries, Valve-Regulated Lead-Acid 29
7.18.2 Direct-Current Systems, Chargers 29
7.18.3 Direct-Current Systems, Rectifiers 30
7.19.1 Surge Arresters, Low-Voltage 30
7.19.2 Surge Arresters, Medium- and High-Voltage 31
7.20.1 Capacitors and Reactors, Capacitors 31
7.20.3 Capacitors and Reactors, Capacitor Control Devices 32
7.20.3.1 Capacitors and Reactors, Reactors (Shunt and Current-Limiting) Dry Type 32
7.20.3.2 Capacitor and Reactors, Reactors (Shunt and Current-Limiting) Liquid Filled 32
7.20.4 Resistors 33
7.21 Outdoor Bus Structures 33
7.22.1 Emergency Systems, Engine Generator 34
7.22.2 Emergency Systems, Uninterruptible Power Systems 35
7.22.3 Emergency Systems, Automatic Transfer Switches 36
7.23 Communications 36
7.24.1 Automatic Circuit Reclosers and Line Sectionalizers, Oil/Vacuum 36
7.24.2 Automatic Circuit Reclosers and Line Sectionalizers, Oil 36
7.25 Fiber-Optic Cables 37
7.26 Electric Vehicle Charging Systems 39
Conclusion/Summary of Part II 39
8 SYSTEM FUNCTION TESTS AND COMMISSIONING 40
9 THERMOGRAPHIC SURVEY 40
10 ELECTROMAGNETIC FIELD TESTING 40
11 ONLINE PARTIAL DISCHARGE SURVEY 40
TABLES 40
APPENDICES 40
NETA REFERENCE TABLES 41
REFERENCES 47
Appendix A: Equivalent Units Of Derived And Common SI Units 48
Appendix B: Fundamental Constants 49
Appendix C: Mathematical Constants 50
Appendix D: The Greek Alphabet 50

List of Figures

FIGURE 1: VARIABLE FREQUENCY DRIVE PROCESS 24
FIGURE 2: TRIP CURVE SHAPES 25
FIGURE 3: TRIP CURVE EXAMPLE 26
FIGURE 4: TDR WITH OPEN TERMINATION 37
FIGURE 5: TDR WITH SHORT-CIRCUIT TERMINATION 38
FIGURE 6: TDR IDEAL TERMINATION 38

List of Tables

TABLE 1: CAPACITOR DISCHARGE TIMES 31
TABLE 2: NETA 100.1 INSULATION RESISTANCE 41
TABLE 3: NETA 100.2 SWITCHGEAR WITHSTAND TEST VOLTAGES 41
TABLE 4: NETA 100.5 INSULATION RESISTANCE 42
TABLE 5: NETA 100.7 MOLDED CASE CB 300% TRIP TEST 42
TABLE 6: NETA 100.8 INSTANTANEOUS TRIP TOLERANCES 43
TABLE 7: NETA 100.9 DIELECTRIC TEST 43
TABLE 8: NETA 100.11 ROTATING MACHINERY INSULATION RESISTANCE 43
TABLE 9: NETA 100.12.1 TORQUE VALUES FOR ELECTRICAL CONNECTIONS 44
TABLE 10: NETA 100.17 DIELECTRIC WITHSTAND METAL BUSWAY 44
TABLE 11: NETA 100.18 THERMOGRAPHIC SURVEY 45
TABLE 12: NETA 100.19 DIELECTRIC WITHSTAND TEST VOLTAGES 45
TABLE 13: NETA 100.20.1 CONTROL VOLTAGE RANGES 46

COURSE INTRODUCTION

The information is primarily from Ref [A] as published by NETA, the National Electrical Testing Association now known as the InterNational Electrical Testing Association. Supporting information is in from Ref [B].[2] A source for electrical information and phenomena in general is Ref [C]. Technical definitions are in Ref [D]. The standards for electrical diagram and symbols are in Ref [E] and Ref [F]. The "standard" for electrical analysis is in Ref [G]. Appendices are provided with useful information for the electrical engineer.

HISTORY AND CODE OVERVIEW

NETA was founded in 1972 to establish uniform requirements for testing procedures for electrical equipment and associated apparatus. NETA is an accredited standards developer by the American National Standards Institute (ANSI). NETA standards differ from others in that in matters of testing, the relevant test and requirements derive from other standards: IEEE, IEC, NECA, NEMA, and UL. The focus is on acceptance testing; that is, ensuring the equipment are ready to be energized and will perform satisfactorily. The Maintenance Testing Specifications (MTS) goes through a four year review process.[3]

The Code consists of thirteen different and separate sections as follows.

- Section 1: General Scope
- Section 2: Applicable References
-
- Section 3: Qualification of Testing Organization and Personnel
- Section 4: Division of Responsibility
-
- Section 5: General[4]
-
- Section 6: Power System Studies

---

[2] This is a Handbook for NFPA 70 that contains the Code proper. Although not required, I highly recommend using NFPA's "Handbooks" as the contain a wealth of interpretation and examples that will save and Engineer a great deal of research time.

[3] While the standard will update periodically, the information herein is useful as general guidance and for understanding. Anytime a specific piece of equipment is to be tested, one should consult the latest standard.

[4] Safety / Precautions / Test Equipment / Test Reports

- **Section 7: Inspection and Test Procedures**
- Section 8: System Functioning Tests and Commissioning
-
- Section 9: Thermographic Survey
- Section 10: Electromagnetic Field Testing
- Section 11: Online Partial Discharge Survey
-
- **Reference Tables**
- Appendices

The breaks shown in the bullet list are to resolve the MTS into relevant areas. The Scope and References are just that. Sections 3 and 4 generally applies to the testing organization. Section 5 contains safety precautions, use of proper testing equipment, and the requirements for documentation. Section 6 covers the numerous studies for a new electrical installation.

Section 7 is the core of the specifications, listing the maintenance testing requirements for specific equipment. Section 7 is formatted in four main bodies of information:

A. Visual and Mechanical Inspection
B. Electrical Tests
C. Test Values—Visual and Mechanical
D. Test Values—Electrical

For the Visual and Mechanical Inspections in "A" the results values (specifications) will be located in "C" and will refer back to the paragraph in "A".[5] For the Electrical Tests in "B" the results values (specifications) will be located in "D" and *the paragraph/section numbering in "D" will match that in "B"*.[6]

Manufacturer's Instruction Manuals should be considered the primary source of information for testing and maintenance, though in this course sometimes only the NETA values are specified. Following that would be the many applicable standards—which are incorporated into the NETA

[5] They do this because not all the Visual and Mechanical Inspections will have a "specification" or "value", for example an inspection for cleanliness may not have an associated value.
[6] This is done because nearly all the electrical tests have a "specification" range or minimum/maximum "value" that must be met. This format makes it easier to locate required results for given tests.

MTS. Should neither the manufacturer nor the standard contain guidance, NETA uses the particular industry consensus as a guide. In this course the tables are listed in their own section, rather than throughout the course, since they are referenced multiple times in Section 7 for different equipment. Additionally, each table includes the NETA table number for ease of reference. Those equipments most often encountered (meaning those not utility oriented or seldom used) are more fully covered.

Section 8 contains information on the typical follow-on testing to make a site operational.[7]

Sections 9 through 11 provide information on specific surveys and tests.

The reference Tables provide industry acceptable results should manufacturer's data be lacking. Each table includes the NETA table number for ease of reference.

The Appendices are for information only and are not mandatory for compliance with the MTS. They do provide usable forms enabling documentation of the requirements.

1. General Scope

This specification field tests and inspections for maintenance testing. The testing is to ensure the equipment and systems are operational, within the tolerances of the manufacturers and applicable standards. Such work involves numerous hazards. Safety is the responsibility of the user. A review of regulatory limitations is warranted prior to testing.

2. Applicable References

The list provided is extensive. Of note, one should also review state and local codes and ordinances. Contact information for the various organizations is also provided.

[7] Detailed information for this topic includes NETA MTS (Maintenance Testing Specifications) and NETA ECS (Electrical Commissioning Specifications).

3. Qualifications of Testing Organization and Personnel

The testing organization should be a third party entity that uses qualified testing technicians. The technicians are certified by ANSI/NETA ETT, *Standard for Certification of Electrical Testing Technicians*. Crew leaders should be Level 3 or higher.

4. Division of Responsibility

This section covers the Owner's and the Testing Organization's responsibilities.

5. GENERAL

5.1 Safety and Precautions

All parties must be aware of industry-standard safety procedures. Guidance may be found in the Code of Federal Regulations (CFR) at OSHA 29CFR1910 and 29CFR1926.[8] Another useful reference is NFPA 70E, *Standard for Electrical Safety in the Workplace*.

A Safety Lead is identified prior to the commencement of work. A safety briefing precedes all work.

5.2 Suitability of Test Equipment

All test equipment shall be in good mechanical and electrical condition. It shall be accurate enough for the proposed testing.

5.3 Test Equipment Calibration

Test equipment shall be in calibration and the accuracy of such tests shall be directly traceable to the National Institute of Standards and Technology (NIST). All test equipment shall be calibrated within 12 months of the date of the test.

[8] The CFR is normally given by Title—CFR—Part.Subpart. The Title [1, 2, 3…50] itself may divided into Chapters [I, II, III, IV…]. Subchapters [A, B, C….] though the chapters and subchapters are normally not shown in the shortened abbreviation since the Title and Part will be adequate for locating the information.

5.4 Test Report

This section list all the information required to be on a test form.

5.5 Test Decal

A test decal is placed on the equipment following performance of a test. The decals are color coded with white indicating the equipment is acceptable, yellow indicating a minor deficiency (that does NOT affect fault detection and operation, and red indicating a deficiency affecting performance and indicating the equipment is not suitable for service.

6. POWER SYSTEM STUDIES

6.1 Short-Circuit Studies

These studies determine the short-circuit current available at each piece of equipment. The studies are guided by IEEE 3002.3 The goal being to determine the short-circuit available during a fault and evaluate the protection adequacy.[9] The output of such studies then provide the input for the coordination studies.

6.2 Coordination Studies

These studies determine whether the protective scheme is adequate for the fault current expected.[10] The first types of coordination mentioned is *selective coordination*, which provides for the full range of short-circuit currents at the point of application for each overcurrent protective device. The second type mentioned is *compromised coordination*, which permits ranges of non-coordination of overcurrent protective devices. Such studies are important for both new facilities and those undergoing additions.

---

[9] The principles of such analysis can be found in Chap. 26 of Ref [C] and the PE Continuing Education course titled "Electrical Fault Analysis". The information mentioned will be very helpful as a method for hand-calculations, which can be used to verify/anticipate the detailed and complex software outputs from SKM, ETAP, and others.

[10] The Navy rule of thumb was that the breaker closest to the fault should trip first and the one furthest from the fault trips last. The author saw one instant where this wasn't the case. A computer was plugged into a power strip and the entire building went dark. The reason: the building was re-purposed, the loads greatly increased, and the coordination study was not redone.

The studies are guided by IEEE 399 and IEEE 242. The settings shall comply with NFPA 70, the National Electrical Code.

6.3 Incident Energy Analysis

These studies determine the arc-flash energy levels and flash-protection boundary distances based on the short-circuit and coordination studies. The arc current flowing is determined by NFPA 70E[11], IEEE 1584, OSHA 1910.269, or other applicable standards.

6.4 Load Flow Studies

These studies determine the power, both active (real) and reactive, voltage current and power factor throughout the system. The studies are guided by IEEE 3002.3. Voltages outside the ranges recommended by NEMA C84.1 are clearly noted.[12]

6.5 Stability Studies

These studies determine the ability for the electrical systems' synchronous machines to stay in step with one another following a disturbance.

The studies are guided by IEEE 399.[13]

6.6 Harmonic Analysis Studies

These studies determine the impact of nonlinear loads and their harmonic contributions to the voltages and currents throughout the electrical system.

The studies are guided by IEEE 3002.8. Tabulations of rms peak values are included. The harmonics outside IEEE 519 are clearly noted. Transformer capabilities are analyzed per IEEE C57.110 with exceptions/overloads clearly noted.

[11] A continuing education course on NFPA 70E is available.
[12] ANSI/NEMA C84.1 is the standard used by utilities for the production of power.
[13] When a synchronous machines lags too far behind the applied frequency, it can “slip a pole” which results in large current flows that may damage or destroy said machines.

7 INSPECTION AND TEST PROCEDURES

Recall, in NETA MTS the following structure (below) is used. The focus in this course will be on the Electrical Tests and their specification results—Test Values Electrical, which are tied together by their number scheme (B#1 in Test correlates with D#1 in Values). Those values must be within the guidance in order to comprise a satisfactory result. It is these values that a PE is likely to focus, review for completeness, and certify to the appropriate party that the electrical equipment is installed and tested correctly. An understanding of the electrical tests is the focus.[14] That is, an understanding of why a test is accomplished, how it measures the desired trait, and the applicable limiting values are emphasized. Further, where NETA Tables are specified, one should remember that should they exist, manufacturer's instructions and limits take precedence.

A. Visual and Mechanical Inspection
B. Electrical Tests
C. Test Values—Visual and Mechanical
D. Test Values—Electrical

While NETA MTS covers multiple types of transformers, breakers, switches, et cetera, this course will cover the details of one type and mention they the others exists. Should the engineer required the details of the other types, NETA MTS should be consulted directly. Nevertheless, the knowledge gained here will be helpful in such research.

Optional tests are marked with an asterisk (*). Tests are considered optional is a) other tests provide similar information, b) how does the cost compare to those providing similar information, and c) how commonplace is the procedure? Is the technology new and potentially unproven?

[14] A NETA certified electrical technician will of course conduct all the tests, which will also be reviewed.

7.11.1 Metering Devices, Electromechanical and Solid-State

Electrical Tests

Verify / Check / Perform / Measure: Meter Accuracy / Calibrate / Instrument Multipliers

Test Values—Electrical

Meter Accuracy per manufacturer's data.

Calibration within manufacturer's tolerances.

Instrument Multipliers per design specifications.

7.11.2 Metering Devices, Microprocessor-Based

Electrical Tests

Verify / Check / Perform / Measure: Analog checks / Confirm Settings / Confirm Measurements consistent with system loads

Test Values—Electrical

Analog Checks of voltage and current *within manufacturer's tolerances.*

Confirm Settings of auxiliary input/output features *per manufacturer's data.*

Confirm Measurements after energization are *consistent with design loads.*

7.12.1.1 Regulating Apparatus, Voltage, Step Voltage Regulators

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation Resistance checks / Power-Factor or Dissipation Factor (Tan Delta) per manufacturer's data / Special Tests / *Gas

Blanket checks / Turns-Ratio test / Tap Changer Control Device / Tap Changer Compartment / Liquid Tests Main Tank / Liquid Test Tap Changer

Test Values—Electrical

Bolted Connection Resistance does not have a specified limit, per se.[15] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[16] Or, one could use a thermographic survey per Section 9.

Insulation Resistance values (phase-to-phase and phase to ground) for the primary and secondary windings shall not *be less than NETA Table 100.5*. Calculate the polarization index (PI). The *index shall NOT be less than 1.0.*

Power-Factor / Dissipation-Factor testing is also called tan delta (tanΔ or tanδ) or a tangent delta or dielectric dissipation factor testing.[17] It measures the condition of an insulation system by measuring the amount of energy lost to heat relative to the total amount of energy in the system. The test measures the impedance of the insulation, expecting primarily capacitive results. Details in Section 7.10.1. (The test is also performed on bushings.)

Winding Resistance, if taken, *should be no more than 2% from factory test values or between adjacent phases*.

Special Tests as recommended by the manufacturer *shall meet manufacturer's published requirements*.

Gas Blanket check in the tap-changer compartment *for the presence of oxygen.*

[15] Per se is used because point to point grounding systems are limited to a maximum of 0.5 Ω, which can be used for guidance. And, some of the values for bolted connections are in the micro-ohm region where 50% difference from the lowest value is miniscule. So, engineering judgment is called for here.
[16] Numerous torque tables exists varying with the size, material, and thread used.
[17] Technically, a power-factor test uses the cosine of the angle, whose value should be close to zero for a good result. The tan delta test uses a different angle measuring the resistive and reactive currents directly. The angle is called the Loss Angle or Dissipation Factor.

A **Turns Ratio** test run to ensure the nameplate turns ratio and tap-ratios are correct. The turns-*ratio shall not vary by more than 0.5% from the calculated ratio.*

Voltage Range Limiter *shall operate within manufacturer's recommendations.*

Regulator Control Device *shall operate as required and be within the accuracy for bandwidth, time delay, voltage, and line-drop compensation*.

Liquid Tests for dissolved gasses are *evaluated per IEEE C57.104 and ASTM D 3612.*

Main Tank (and tap changer tank) liquid tests shall be in accordance with NETA Table 100.4. Multiple tables exist. Consult NETA MTS for details.

Tap Changer Compartment insulating liquid per Table 100.4.

Dissolved Gas Analysis to be compared to previous results

7.12.1.2 Regulating Apparatus, Voltage, Induction Regulators

Tests are similar to 7.12.1.1.

7.12.2 Regulating Apparatus, Current

Reserved

7.12.3 Regulating Apparatus, Load Tap Changer

Tests are similar to 7.12.1.1 with the addition of a magnetron atmospheric condition (MAC) test and vacuum bottle integrity tests—both of which are optional.[18]

[18] The MAC test is interesting. Many sources online explain the theory.

7.13 Grounding Systems

All ground systems are to be in compliance with the National Electrical Code® (NEC®) Article 250.[19]

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Grounding Electrode to Ground Resistance / Point to Point Resistance /

Test Values—Electrical

Bolted Connection Resistance does not have a specified limit, per se.[20] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[21] Or, one could use a thermographic survey per Section 9.

Grounding Electrode to Ground Resistance *shall be no greater than 5 Ω for large commercial or industrial systems and 1 Ω or less for generating stations unless otherwise specified by the owner.*[22]

Point to Point Resistance *shall not exceed 0.5 Ω.*

7.14 Ground Fault Protection Systems, Low Voltage

In ground fault protection systems, the way connections are made is vital. In this instance, the Visual and Mechanical checks in the MTS should be verified carefully.

---

[19] See the NEC Overview course.
[20] Per se is used because point to point grounding systems are limited to a maximum of 0.5 Ω, which can be used for guidance. And, some of the values for bolted connections are in the micro-ohm region where 50% difference from the lowest value is miniscule. So, engineering judgment is called for here.
[21] Numerous torque tables exists varying with the size, material, and thread used.
[22] One will find numerous specifications for this value. Ensure you check the contract or references listed by the owner.

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Neutral to Ground Insulation Resistance / *Control Wiring Insulation / Ground Fault Protection Pickup / Polarity / Ground Fault Time Delay ≥150% of Pickup Value / Control Voltage / Blocking Capability

Test Values—Electrical

Bolted Connection Resistance does not have a specified limit, per se.[23] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[24] Or, one could use a thermographic survey per Section 9.

Neutral to Ground Insulation Resistance *shall be a minimum of 1 MΩ.*

Insulation resistance checks on control winding at 500 V for 300 V cable and 1000 V for 600 V cable for a total of one minute. *Resistance shall NOT be less than 2 MΩ.*.

Ground Fault Protection Pickup *>90% of device pickup AND less than 1200 A or 125% of the pickup setting, whichever is smaller.*

Polarity. *The ground fault device shall operate when current is in the direction of the polarity marks of the two current transformers and NOT operate when current is opposite of the polarity marks.*

Ground Fault Time Delay *≥150% of Pickup Value*

Control Voltage *and it shall operate at 55% of nominal AC voltage or 80% of DC voltage*.

[23] Per se is used because point to point grounding systems are limited to a maximum of 0.5 Ω, which can be used for guidance. And, some of the values for bolted connections are in the micro-ohm region where 50% difference from the lowest value is miniscule. So, engineering judgment is called for here.
[24] Numerous torque tables exists varying with the size, material, and thread used.

Blocking Capability. *Zone blocking shall be per manufacturer's published data and design specifications.*

7.15.1 Rotating Machinery, AC Induction Motors and Generators

Here again many visual and mechanical checks are important and likely done during product acceptance or installation. Examples include air-gap checks, machine alignment, bearing checks, shaft runout, lubrication checks, and RTD checks.

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation checks per IEEE Standard 43 for >200 HP for 10 minutes and calculate PI, for ≤200 HP for 1 minute and calculate DAR for 60/30 second periods / Withstand test for >2300 V machines using IEEE 95 for DC and NEMA MG1 for AC tests / Phase to Phase Stator Resistance / * Power Factor/Dissipation tests / *Power Factor or Dissipation Factor Tip-Up tests / *Surge Comparison tests / *Insulation on Bearings / Surge Protection per 7.19 and 7.20 / Surge Protection / Motor Starter per 7.16 / RTD check / Space Heater / *Vibration test / *Bearing temperatures / *Current Signature / *Partial Discharge

Test Values—Electrical

Bolted Connection Resistance does not have a specified limit, per se.[25] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[26] Or, one could use a thermographic survey per Section 9.

Insulation Checks *shall be per NETA Table 100.11. The polarization index (PI) ≥2.0. The dielectric absorption ratio (DAR) ≥1.*

[25] Per se is used because point to point grounding systems are limited to a maximum of 0.5 Ω, which can be used for guidance. And, some of the values for bolted connections are in the micro-ohm region where 50% difference from the lowest value is miniscule. So, engineering judgment is called for here.
[26] Numerous torque tables exists varying with the size, material, and thread used.

Withstand Test. To pass there shall be *no evidence or distress or insulation failure at the completion of the test*.

Stator Resistance *shall be investigated if values deviate by more than 5%.*

Power-Factor / Dissipation-Factor testing is also called tan delta (tanΔ or tanδ) or a tangent delta or dielectric dissipation factor testing.[27] It measures the condition of an insulation system by measuring the amount of energy lost to heat relative to the total amount of energy in the system. The test measures the impedance of the insulation, expecting primarily capacitive results. Details in Section 7.10.1.

Power Factor or Dissipation Factor Tip-Up *shall indicate no significant increase in power factor.*[28]

Surge Comparison Test. To pass there shall be *no evidence or distress or insulation failure at the completion of the test*. The tests results of the phases shall be neatly "nested" (i.e., similar). A lack of waveform nesting would indicate an issue.

Bearing Insulation *results per manufacturer's data and similar to other machines.*

Surge Protection per 7.19 and 7.20.

Motor Starter per 7.16.

RTD *check per design and manufacturer's data.*

Heaters, if used, shall be operational.[29]

[27] Technically, a power-factor test uses the cosine of the angle, whose value should be close to zero for a good result. The tan delta test uses a different angle measuring the resistive and reactive currents directly. The angle is called the Loss Angle or Dissipation Factor.
[28] As cables age the PF will increase with increasing voltage.
[29] Heaters minimize moisture buildup in machines that are shutdown.

Vibration Test on uncoupled and unloaded machine *per manufacturer's data. If no data use NETA Table 100.10. If values are greater than 100.10 perform a complete vibration analysis.*[30]

Bearing Temperatures. *Ensure temperatures are as expected.*

Current Signature analysis is conducted to ensure the structural integrity of the motor. This checks the rotor, air gap, and bearings. See NETA MTS for details.

Partial Discharge is used as a baseline for future comparison for the health of the stator.

7.15.2 Rotating Machinery, Synchronous Motors and Generators

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation checks per IEEE Standard 43 for >200 HP for 10 minutes and calculate PI, for ≤200 HP for 1 minute and calculate DAR for 60/30 second periods / Withstand test for >2300 V machines using IEEE 95 for DC and NEMA MG1 for AC tests / Phase to Phase Stator Resistance / * Power Factor/Dissipation tests / *Power Factor or Dissipation Factor Tip-Up tests / *Surge Comparison tests / Insulation on Bearings / Surge Protection per 7.19 and 7.20 / Motor Starter per 7.16 / RTD check / Space Heater / *Vibration test / Insultation Tests: Main Rotating Field, Exciter Field, Exciter Armature per IEEE Standard 43 / *AC Voltage Drop on Rotating Field Poles / *High Potential Test on Excitation System per IEEE 421.3 / *Back to Back Resistance Tests on Field Diodes and Gating Tests of SCRs / *Electrical Characteristics / *Exciter check / *Power Factor Relay check / *Bearing Temperatures under Load / Current Signature / *Partial Discharge

Test Values—Electrical

Tests are similar to the induction motor/generator tests with the addition of a number of items to setup the generator for operation, i.e., adjust it for proper voltage and relay protections.

[30] See NETA MTS for details. The table comes from NEMA MG 1-2016, Section 7.8.1, Table 7-1. Vibration analysis can provide a wealth of information and should be conducted by a trained technician.

7.15.3 Rotating Machinery, DC Motors and Generators

Here again many visual and mechanical checks are important and likely done during product acceptance or installation.

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation checks per IEEE Standard 43 for >200 HP for 10 minutes and calculate PI, for ≤200 HP for 1 minute and calculate DAR for 60/30 second periods / High-Potential test per NEMA MG1 Section 3.01 / *AC Voltage Drop test on all field poles / Surge Comparison test on field and armature windings / Polarity Check on series and shunt windings / Armature and Field Current / *Vibration Test while under load / Protective Devices per 7.16

Test Values—Electrical

Bolted Connection Resistance does not have a specified limit, per se.[31] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[32] Or, one could use a thermographic survey per Section 9.

Insulation Checks *shall be per NETA Table 100.11.*

High-Potential test. To pass there shall be *no evidence or distress or insulation failure at the completion of the test*.

AC Voltage Drop *pole-to-pole shall not exceed 10% variance from the average value (average value = test voltage / # of coils).*

Surge Comparison test *running current and field current or voltage shall be comparable to nameplate data.*

---

[31] Per se is used because point to point grounding systems are limited to a maximum of 0.5 Ω, which can be used for guidance. And, some of the values for bolted connections are in the micro-ohm region where 50% difference from the lowest value is miniscule. So, engineering judgment is called for here.
[32] Numerous torque tables exists varying with the size, material, and thread used.

Vibration Test on uncoupled and unloaded machine *per manufacturer's data. If no data use NETA Table 100.10. If values are greater than 100.10 perform a complete vibration analysis.*[33]

7.16.1.1 Motor Control, Motor Starters, Low-Voltage

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation checks / *Insulation Resistance on Control Wiring / Motor Protection Devices check per 7.9 / Circuit Breakers check per 7.6.1.1 / Operational tests

Test Values—Electrical

Bolted Connection Resistance does not have a specified limit, per se.[34] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[35] Or, one could use a thermographic survey per Section 9.

Insulation Checks *shall be per NETA Table 100.1. Values less than the table shall be investigated*.

Insulation resistance checks on control winding at 500 V for 300 V cable and 1000 V for 600 V cable for a total of one minute. *Resistance shall NOT be less than 2 MΩ.*.

Motor Protection Devices checks *per 7.9.*

Circuit Breakers checks *per 7.6.1.1.*

Operational tests *per system design requirements.*

---

[33] See NETA MTS for details. The table comes from NEMA MG 1-2016, Section 7.8.1, Table 7-1. Vibration analysis can provide a wealth of information and should be conducted by a trained technician.
[34] Per se is used because point to point grounding systems are limited to a maximum of 0.5 Ω, which can be used for guidance. And, some of the values for bolted connections are in the micro-ohm region where 50% difference from the lowest value is miniscule. So, engineering judgment is called for here.
[35] Numerous torque tables exists varying with the size, material, and thread used.

7.16.1.2 Motor Control, Motor Starters, Medium Voltage

Tests are similar to low-voltage starters. Notable exceptions are the MAC test, dielectric withstand, blowout coil, transformer tests, and protection devices.

7.16.2.1 Motor Control, Motor Control Centers, Low-Voltage

Motor Control Centers (MCCs) provide for a single location for grouping electrical motor control, automation, power distribution, and protection. The requirements for MCCs are listed in various other locations of the MTS: 7.1, 7.5.1.2, 7.6, 7.6.1.2.

7.16.2.2 Motor Control, Motor Control Centers, Medium Voltage

Required Tests are covered in other sections. See MTS for details.

7.17 Adjustable Speed Drive Systems

Adjustable Speed Drives (ASDs) are also known as Variable Frequency Drives (VFDs).[36]

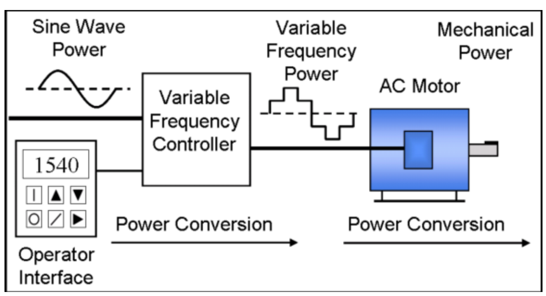

Figure 1: Variable Frequency Drive Process
[Source: *https://en.wikipedia.org/wiki/Variable-frequency_drive*]

ASDs allow for precise speed control, efficient operation, soft-starts, and improved torque control.

---

[36] An excellent description of their operation is found at *https://library.e.abb.com/public /d3c711ec2acddb18c125788f002cf5da/ABB_Technical_guide_No_4_REVC.pdf* .

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Motor Overload Relay / Input Circuit Breaker per Section 7.6 / *Control Wiring Checks / Relay Calibration per Section 7.9 / Continuity Bonding Tests per Section 7.13 / Operational Tests

Test Values—Electrical

Bolted Connection Resistance does not have a specified limit, per se.[37] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[38] Or, one could use a thermographic survey per Section 9.

Motor Overload Relay *tested at 300% of rating per manufacturer's published curve data.* (See an example in the figure below. The curves are numbered and selectable. The bold line is at 300%.)(A simplified curve the author uses for clarification is show directly below.)

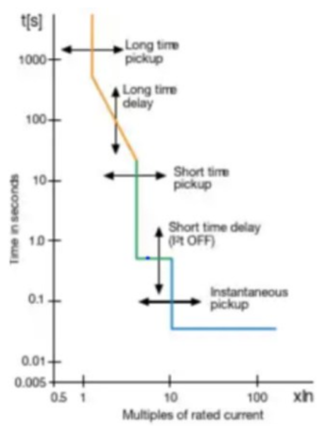

Figure 2: Trip Curve Shapes

Circuit Breaker Test *per 7.6.*

[37] Per se is used because point to point grounding systems are limited to a maximum of 0.5 Ω, which can be used for guidance. And, some of the values for bolted connections are in the micro-ohm region where 50% difference from the lowest value is miniscule. So, engineering judgment is called for here.
[38] Numerous torque tables exists varying with the size, material, and thread used.

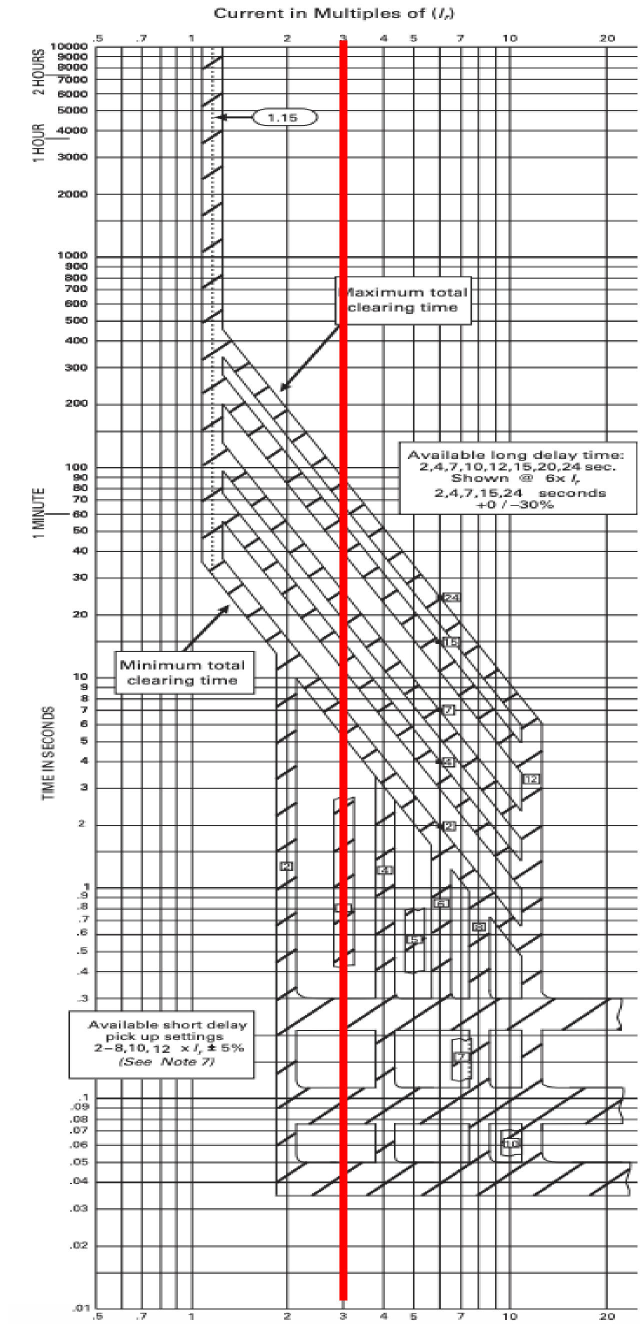

Figure 3: Trip Curve Example

[Source: *https://www.eaton.com/content/dam/eaton/products/electrical-circuit-protection/molded-case-circuit-breakers/series-c-molded-case-circuit-breakers/f-frame-time-current-curves-tc01200002e.pdf*]

Insulation Resistance of Control Winding *compared to previous but not less than 2 MΩ.*.

Relay Calibration Tests *per 7.9.*

Continuity of Bonding *per 7.13.*

Operational Tests *as per design. Control devices per system requirements.*

7.18.1.1 Direct-Current Systems, Batteries, Flooded Lead-Acid[39]

Visual and Mechanical Tests are important, and unique, here. Proper location of the battery; ventilation; eyewash equipment; electrolyte level; flame arresters; containment installation; and others.

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Charger Float & Equalizer Voltage / Charger Functions / Total Battery and Individual Cell Voltage / Intercell Connection Resistance / Internal Ohmic Measurement / *Load Test per IEEE 450 / Battery Voltage

Test Values—Electrical

Bolted Connection Resistance does not have a specified limit, per se.[40] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest*

[39] The IEC 62133 standard sets out requirements and tests for the safety and performance of lithium ion batteries used in *portable* electronic devices, including cell phones, laptops, tablets, and other devices. The standard covers various aspects of battery safety, including electrical, mechanical, and chemical safety. For stationary applications, which generally involves larger batteries use IEEE 1679.1-2017 *IEEE* Guide *for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications*. Lithium-ion batteries are new enough in large commercial applications, and have unique testing requirements, that they have yet to be incorporated into NETA MTS. Having said that, they are in use in airplanes and the international space station.

[40] Per se is used because point to point grounding systems are limited to a maximum of 0.5 Ω, which can be used for guidance. And, some of the values for bolted connections are in the micro-ohm region where 50% difference from the lowest value is miniscule. So, engineering judgment is called for here.

value. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[41] Or, one could use a thermographic survey per Section 9.

Charger Float & Equalizer Voltage *per manufacturer's data.*

Charger Functions and Alarms *per manufacturer's data.*

Individual Cell Voltage *shall be within 0.05 V of each other*. [Charger Energized / Battery of a Float]

Intercell Connection Resistance *shall be investigated for those that deviate more than 50% from the lowest value.*

Intercell Ohmic Measurement values shall not vary by more than 25% between identical cells in a fully charged state.

Load Test *per IEEE 450*.[42]

Battery Voltage *positive to ground and negative to ground shall be equal in magnitude*.

7.18.1.2 Direct-Current Systems, Batteries, Vented Nickel-Cadmium

The tests done here are nearly identical to those of 17.18.1.1 except the load test is accomplished per IEEE 1106.

[41] Numerous torque tables exists varying with the size, material, and thread used.
[42] Capacity tests generally involve discharge at a certain rate until some specified minimum cell voltage is met. This lets one know the capacity (in time) and prevents a cell reversal condition.

7.18.1.3 Direct-Current Systems, Batteries, Valve-Regulated Lead-Acid[43]

The tests done here are nearly identical to those of 17.18.1.1 except the load test is accomplished per IEEE 1188.

7.18.2 Direct-Current Systems, Chargers

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Float Voltage & Equalize Voltage / *High-Voltage Shutdown / Load Sharing / Meter Calibration / Alarms / Input Voltage & Current / AC Ripple Current and Voltage / *Full Load Testing

Test Values—Electrical

Bolted Connection Resistance What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[44] Or, one could use a thermographic survey per Section 9.

Float Voltage & Equalize Voltage *per manufacturer's data.*

High-Voltage Shutdown *per manufacturer's data.*

Load Sharing between parallel chargers *per system design.*

Meter Calibration *per Section 7.11.*

Alarm Operation *per manufacturer's data and system design.*

[43] VRLA stands for Valve-Regulated Lead-Acid and is the designation for low-maintenance lead-acid rechargeable batteries. Because of their construction, VRLA batteries do not require regular addition of water to the cells. VRLA batteries are commonly further classified as an Absorbent Glass Mat battery or Gel battery.

[44] Numerous torque tables exists varying with the size, material, and thread used.

Input Voltage & Current *per manufacturer's data.*

AC Ripple Current and Voltage *per manufacturer's data.*[45]

Full Load Testing. *Charger shall be capable of full load conditions.*

7.18.3 Direct-Current Systems, Rectifiers

Reserved

7.19.1 Surge Arresters, Low-Voltage

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation Resistance per NETA Table 100.1 / Grounding Connections per Section 7.13

Test Values—Electrical

Bolted Connection Resistance What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[46] Or, one could use a thermographic survey per Section 9.

Insulation Checks *shall be per NETA Table 100.1. Values less than the table shall be investigated*.

Grounding Connections *per Section 7.13 and less than 0.5 Ω.*

[45] Excessive ripple can result in premature battery degradation, reduced lifespan, and potential damage due to excessive heating and internal stress.

[46] Numerous torque tables exists varying with the size, material, and thread used.

7.19.2 Surge Arresters, Medium- and High-Voltage

Tests are similar to 7.19.1 with the optional addition of a watts-loss test whose values should be compared to similar units and manufacturer's data.[47]

7.20.1 Capacitors and Reactors, Capacitors

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation Resistance for one minute per NETA Table 100.1 / Capacitance on Terminal Connections / Resistance of Discharge Resistors

Test Values—Electrical

Bolted Connection Resistance What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[48] Or, one could use a thermographic survey per Section 9.

Insulation Checks *shall be per NETA Table 100.1. Values less than the table shall be investigated*.

Capacitance of Terminal Connections *shall be per manufacturer's data.*

Resistance of Discharge Resistors *per manufacturer's data. Also, per NFPA 70, Art. 460, the residual voltage shall be reduced to 50 V in the time intervals shown in the table below.*

Table 1: Capacitor Discharge Times

Rated Voltage	Discharge Time
≤600 V	1 minute
>600 V	5 minutes

[47] A surge arrester watt loss test measures the power loss of a surge arrester at a specified voltage to evaluate its insulation integrity.
[48] Numerous torque tables exists varying with the size, material, and thread used.

7.20.3 Capacitors and Reactors, Capacitor Control Devices

Reserved

7.20.3.1 Capacitors and Reactors, Reactors (Shunt and Current-Limiting) Dry Type[49]

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation Resistance per NETA Table 100.1 / Winding Resistance / *Dielectric Withstand / *Online Partial Discharge Survey

Test Values—Electrical

Bolted Connection Resistance What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[50] Or, one could use a thermographic survey per Section 9.

Insulation Checks *shall be per NETA Table 100.1. Values less than the table shall be investigated*.

Winding Resistance *shall be within 1% of factory results.*

Dielectric Withstand shall be conducted and not more than 75% of factory testing for one minute for AC testing. And, DC testing shall not exceed 100% of factory testing for one minute. To pass there shall be *no evidence or distress or insulation failure at the completion of the test*.

7.20.3.2 Capacitor and Reactors, Reactors (Shunt and Current-Limiting) Liquid Filled

Tests are similar to those for the dry type in 7.20.3.1 with the addition of a power-factor or dissipation factor test and various liquid tests and measurement per ASTM.

---

[49] Having been trained in the nuclear Navy, the term “reactor” meant something different to this author. The term “inductor” is applicable here.
[50] Numerous torque tables exists varying with the size, material, and thread used.

7.20.4 Resistors

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Resistance to Ground, Calculate Polarization Index / Power Factor or Dissipation Factor Test / Resistance / Current Transformer per 7.10.1

Test Values—Electrical

Bolted Connection Resistance What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[51] Or, one could use a thermographic survey per Section 9.

Insulation Resistance *per NETA Table 100.1*.

Power-Factor or Dissipation Factor *per manufacturer's data, previous results, or test equipment manufacturer's data. Representative Values in Table 100.3. For Bushings, values should be within 10% of nameplate.*

Resistance *should be within 2% of Factory Acceptance Testing.*[52]

Current Transformer *testing per 7.10.16.*

7.21 Outdoor Bus Structures

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Insulation Resistance on equipment rated less than 46 kV per NETA Table 100.1 / *Dielectric Withstand per NETA Table 100.1 / *Power-Factor or Dissipation Factor

[51] Numerous torque tables exists varying with the size, material, and thread used.
[52] Both this test and the next are listed in Electrical Test but not Test Values. It will likely be corrected in next edition.

Test Values—Electrical

Bolted Connection Resistance What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[53] Or, one could use a thermographic survey per Section 9.

Insulation Resistance *per NETA Table 100.1*.

Power-Factor or Dissipation Factor *per manufacturer's data, previous results, or test equipment manufacturer's data. Representative Values in Table 100.3. For Bushings, values should be within 10% of nameplate.*

Winding Resistance *should be within 2% of Factory Acceptance Tests, if not consult the Manufacturer.*

Dielectric Withstand shall be *no evidence or distress or insulation failure at the completion of the test*.

7.22.1 Emergency Systems, Engine Generator

Electrical Tests

Verify / Check / Perform / Measure: Insulation checks per IEEE Standard 43 for >200 HP for 10 minutes and calculate PI, for ≤200 HP for 1 minute and calculate DAR for 60/30 second periods / Protective Relays / Engine Shutdown Checks / *Vibration test on each main bearing cap / Performance test per NFPA 110[54] / Correct Functioning of Generator & Regulator

[53] Numerous torque tables exists varying with the size, material, and thread used.
[54] NFPA 110 is the *Standard for Emergency and Standby Power Systems*.

Test Values—Electrical

Insulation Checks *shall be per IEEE 43 and NETA Table 100.11. The DAR or PI shall not be less than 1.*

Protective Relay *per Section 7.9.*

Engine Shutdown *per manufacturer's data.*

Vibration *per manufacturer's data.*

Performance Test *per manufacturer's data and NFPA 110.*

Generator & Regulator *per manufacturer's data and system design.*

7.22.2 Emergency Systems, Uninterruptible Power Systems

Many UPS systems exists from simple to complex. The tests in this section are "possible tests" with the primary guidance coming from the manufacturer's commissioning tests.

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connection Resistance / Static Transfer / Oscillator / *Undervoltage Trip on Input Breaker / *Alarms / Synchronizing Indicators / UPS Breakers per Section 7.6 / UPS Automatic Transfer Switches per Section 7.22.3 / UPS Battery per Section 7.18 / UPS for Rotating Machinery per Section 7.15

Test Values—Electrical

Bolted Connection Resistance What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12.*[55] Or, one could use a thermographic survey per Section 9.

[55] Numerous torque tables exists varying with the size, material, and thread used.

Static Transfer *per manufacturer's data.*

Oscillator free running frequency *per manufacturer's data.*

DC Undervoltage *shall trip inverter input breaker.*

Alarms *per system design.*

Synchronizing Indicators *per design.*

Remaining checks per the indicated NETA MTS sections.

7.22.3 Emergency Systems, Automatic Transfer Switches

Tests are very similar to those in 7.22.3 with a focus on paralleling checks.

7.23 Communications

Reserved

7.24.1 Automatic Circuit Reclosers and Line Sectionalizers, Oil/Vacuum

Tests are similar to others previously mentioned for circuit breakers including liquid testing per ASTM. See NETA MTS for details on these specialized pieces of gear.

7.24.2 Automatic Circuit Reclosers and Line Sectionalizers, Oil

Tests similar to 7.24.1. See MTS for Details.

7.25 Fiber-Optic Cables

Electrical Tests

Verify / Check / Perform / *Measure: Cable Inspections / *Connector & Splice Integrity / *Cable Attenuation Loss / *Connector & Splice Attenuation Loss / Transmit & Receive Power Measurement[56]

Test Values—Electrical

Cable Inspections the optical time domain reflectometer signal is analyzed for backscatter using the power/distance graph. *Abnormalities are investigated/corrected.* (Examples of TDR responses are in the figures below.)

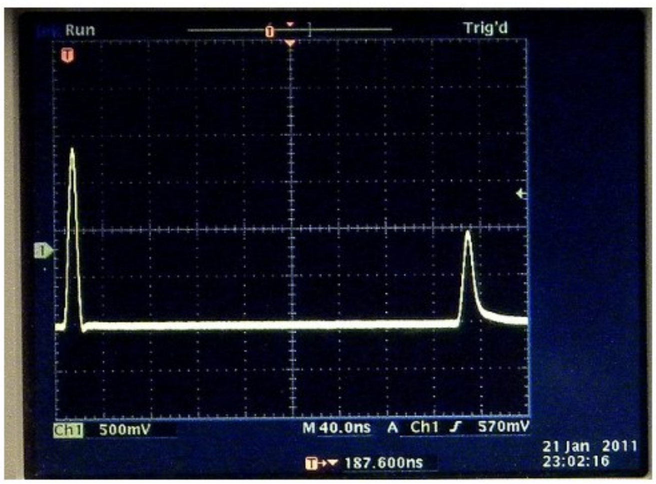

Figure 4: TDR with Open Termination
[Source: *https://en.wikipedia.org/wiki/Time-domain_reflectometer*]

[56] This is the only test from the ATS that is still required. All others are optional.

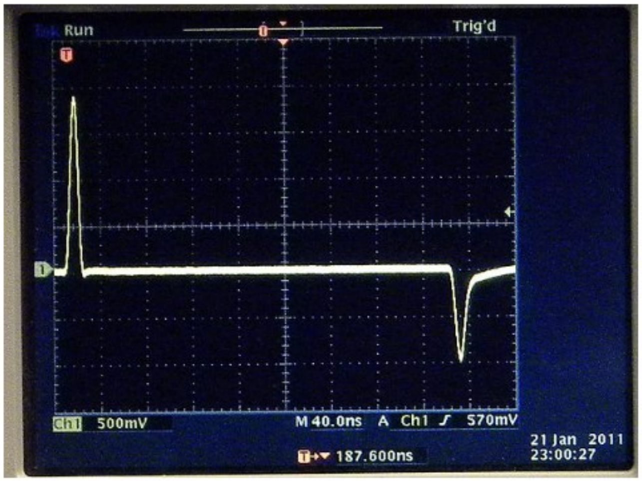

Figure 5: TDR with Short-Circuit Termination
[Source: *https://en.wikipedia.org/wiki/Time-domain_reflectometer*]

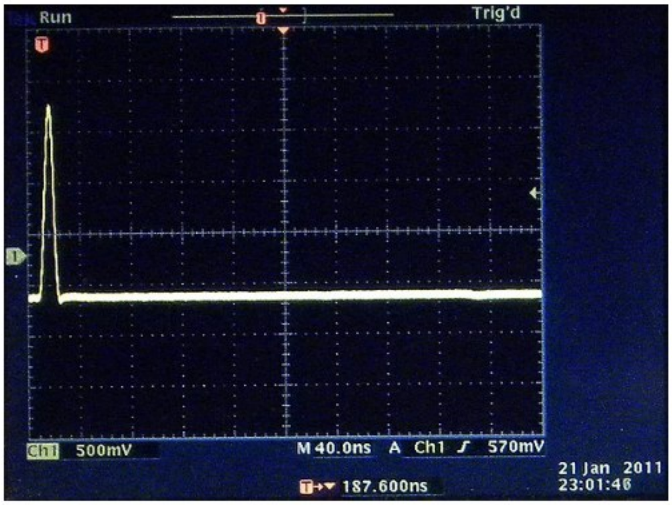

Figure 6: TDR Ideal Termination
[Source: *https://en.wikipedia.org/wiki/Time-domain_reflectometer*]

Connector & Splice Integrity. The optical time domain reflectometer signal is analyzed. *Abnormalities are investigated/corrected.* The attenuation allowed is design dependent.

Cable Attenuation Loss shall be expressed in dB/km. *Losses shall be per manufacturer's recommendations.*

Connector & Splice Attenuation Loss shall be expressed in dB/km. *Losses shall be per manufacturer's recommendations.*

Transmit & Receive Power Measurement *shall be compared to manufacturer's published data.*

7.26 Electric Vehicle Charging Systems

Electrical Tests[57]

Verify / Check / Perform / Measure: Bolted Connection Resistance / System Function

Test Values—Electrical

Bolted Connection Resistance What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, one can *verify the torque applied to the bolts using NETA Table 100.12*.[58] Or, one could use a thermographic survey per Section 9.

System Function tests *per manufacturer's published data.*

Conclusion/Summary of Part II

The components covered in Part I are those more often encountered during testing of electrical distribution systems already in place. Part II covers generally larger distribution system equipment and those associated with utility power. The distinction is the author's, not NETA.

[57] Many updates to the Visual/Mechanical Inspection Test. See the MTS for details.
[58] Numerous torque tables exists varying with the size, material, and thread used.

8 SYSTEM FUNCTION TESTS AND COMMISSIONING

These type of tests prove the overall functioning of the sensing, processing, and action devices. These are covered in a different standard: ANSI/NETA ECS *Standard for Electrical Commissioning Specifications for Electrical Power Equipment & Systems.*

9 THERMOGRAPHIC SURVEY

This survey checks for temperature differences between similar equipment or between the equipment and ambient temperature. The results are evaluated using NETA MTS Table 100.18 in the Tables Section. This test is normally done at full loading.

10 ELECTROMAGNETIC FIELD TESTING

This testing takes baseline reading of magnetic flux density, vector direction, and temporal variations over an area. this test is conducted per IEEE 644.

11 ONLINE PARTIAL DISCHARGE SURVEY

This survey checks for degradation of insulation using auditable indications or concentrations of ozone. The sensor used depends on the equipment to be checked.

TABLES

Tables are used in multiple equipment specifications in Section 7. All tables are sourced from ANSI/NETA *Standard for Maintenance Testing Specifications for Electric Power Equipment and Systems*, 2023 Edition as allowed by said edition. *Manufacturer's instructions always take precedence—if available*. Without such instructions, one should use the NETA Tables.

APPENDICES

NETA MTS App. A covers definitions. Appendix B is reserved. Appendix C is about NETA itself. Appendix D contains a form for comments. And, finally, App. E contains a form for proposals to the specifications.

NETA REFERENCE TABLES

Table 2: NETA 100.1 Insulation Resistance

TABLE 100.1
Insulation Resistance Test Values
Electrical Apparatus and Systems Other Than Rotating Machinery

Nominal Rating of Equipment (Volts)	Minimum DC Test Voltage	Recommended Minimum Insulation Resistance (Megohms)
250	500	25
600	1,000	100
1,000	1,000	100
2,500	1,000	500
5,000	2,500	1,500
8,000	2,500	2,500
15,000	2,500	5,000
25,000	5,000	10,000
34,500	5,000	100,000
46,000 and above	5,000	100,000

Table 3: NETA 100.2 Switchgear Withstand Test Voltages

TABLE 100.2
Switchgear Withstand Test Voltages

Type of Switchgear	Rated Maximum Voltage (kV) (rms)	Maximum Test Voltage kV	
		AC	DC
Low-Voltage Power Circuit Breaker Switchgear	.254/.508/.635	1.6	2.3
	.730/1.058	2.2	3.1
Metal-Clad Switchgear	4.76	14	20
	8.25	27	37.5
	15	27	37.5
	27	45	†
	38	60	†
Station-Type Cubicle Switchgear	15.5	37	†
	38	60	†
	72.5	120	†
Metal Enclosed Interrupter Switchgear	With stress cone type terminations (With IEEE 386 type terminations)	With stress cone type terminations (With IEEE 386 type terminations)	
	4.76 (4.76)	14 (14)	20
	8.25 (8.25)	27 (25)	37
	15.0 (14.4)	27 (25)	37
	27.0 (26.3)	45 (30)	†
	38.0 (36.6)	60 (37)	†

Table 4: NETA 100.5 Insulation Resistance

TABLE 100.5
Transformer Insulation Resistance Acceptance Testing

Transformer Coil Rating Type (Volts)	Minimum DC Test Voltage	Recommended Minimum Insulation Resistance (Megohms)	
		Liquid Filled	Dry
0 - 600	1,000	100	500
601 – 5,000	2,500	1,000	5,000
Greater than 5,000	5,000	5,000	25,000

Table 5: NETA 100.7 Molded Case CB 300% Trip Test

TABLE 100.7
Inverse Time Trip Test at 300% of Rated Continuous Current of Circuit Breakers Molded-Case Circuit Breakers

Range of Rated Continuous Current (Amperes)	Maximum Trip Time in Seconds For Each Maximum Frame Rating[a]	
	≤ 250 V	251-600 V
0-30	50	70
31-50	80	100
51-100	140	160
101-150	200	250
151-225	230	275
226-400	300	350
401-600	----	450
601-800	----	500
801-1,000	----	600
1,001-1,200	----	700
1,201-1,600	----	775
1,601-2,000	----	800
2,001-2,500	----	850
2,501-5,000	----	900
6,000	----	1,000

Table 6: NETA 100.8 Instantaneous Trip Tolerances

TABLE 100.8
Instantaneous Trip Tolerances for Field Testing of Circuit Breakers

		Tolerances of Manufacturer's Published Trip Range	
Breaker Type	**Tolerance of Settings**	**High Side**	**Low Side**
Electronic Trip Units[1]	+30% -30%	----	----
Adjustable[1]	+40% -40%	----	----
Nonadjustable[2]	----	+25%	-25%

Table 7: NETA 100.9 Dielectric Test

TABLE 100.9
Instrument Transformer Dielectric Tests Field Acceptance

Nominal System Voltage (kV)	BIL (kV)	Periodic Dielectric Withstand Test Field Test Voltage (kV)	
		AC	**DC***
0.60	10	3.0	4
1.20	30	7.5	10

Table 8: NETA 100.11 Rotating Machinery Insulation Resistance

TABLE 100.11
Insulation Resistance Test Values Rotating Machinery for One Minute at 40° C

Winding Rated Voltage[a] (V)	DC Test Voltage	Recommended Minimum Insulation Resistance (Megohms): Windings Before 1970, Field Windings, Others Not listed in Table 100.11[b]	Recommended Minimum Insulation Resistance (Megohms): AC Windings Built After 1970, (form-wound coils)	Recommended Minimum Insulation Resistance (Megohms): DC Armature, Random-Wound Stator Coils, Form-Wound Coils below 1 kV
< 1,000	500	kV + 1	100	5
1,000 – 2,500	500 – 1,000	kV + 1	100	-
2,501 – 5,000	1,000 – 2,500	kV + 1	100	-
5,001 – 12,000	2,500 – 5,000	kV + 1	100	-
> 12,000	5,000 – 10,000	kV + 1	100	-

Table 9: NETA 100.12.1 Torque Values for Electrical Connections

TABLE 100.12.1
Bolt-Torque Values for Electrical Connections
US Standard Fasteners[1]
Heat-Treated Steel – Cadmium or Zinc Plated[2]

Grade	SAE 1&2	SAE 5	SAE 7	SAE 8
Head Marking				
Minimum Tensile (Strength) (lbf/in^2)	64K	105K	133K	150K
Bolt Diameter (Inches)	**Torque (Pound-Feet)**			
1/4	4	6	8	8
5/16	7	11	15	18
3/8	12	20	27	30
7/16	19	32	44	48
1/2	30	48	68	74

Table 10: NETA 100.17 Dielectric Withstand Metal Busway

TABLE 100.17
Dielectric Withstand Test Voltages
Metal-Enclosed Bus

Type of Bus	Rated kV	Maximum Test Voltage, kV	
		AC	DC
Isolated Phase for Generator Leads	24.5 29.5 34.5	37.0 45.0 60.0	52.0 ---- ----
Isolated Phase for Other than Generator Leads	15.5 27.0 38.0	37.0 45.0 60.0	---- ---- ----
Nonsegregated Phase	1.058 4.76 8.25 15.0 15.5 27.0 38.0	2.25 14.2 27.0 27.0 37.5 45.0 60.0	---- ---- ---- ---- ---- ---- ----
Segregated Phase	15.5 27.0 38.0	37.0 45.0 60.0	---- ---- ----
DC Bus Duct	0.3/.325 0.8 1.2 1.6 3.2	1.6 2.7 36.0 4.0 6.6	---- ---- ---- ---- ----

Table 11: NETA 100.18 Thermographic Survey

Thermographic Survey
Suggested Actions Based on Temperature Rise

Temperature difference (ΔT) based on comparisons between similar components under similar loading.	Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures.	Recommended Action
1ºC - 3ºC	1ºC - 10ºC	Possible deficiency; warrants investigation
4ºC - 15ºC	11ºC - 20ºC	Indicates probable deficiency; repair as time permits
-- -- --	21ºC - 40ºC	Monitor until corrective measures can be accomplished
>15ºC	>40ºC	Major discrepancy; repair immediately

Temperature specifications vary depending on the exact type of equipment. Even in the same class of equipment (i.e., cables) there are various temperature ratings. Heating is generally related to the square of the current; therefore, the load current will have a major impact on ΔT. In the absence of consensus standards for ΔT, the values in this table will provide reasonable guidelines.

An alternative method of evaluation is the standards-based temperature rating system as discussed in Chapter 8.9.2, Conducting an IR Thermographic Inspection, *Electrical Power Systems Maintenance and Testing*, by Paul Gill, PE, 1998.

It is a necessary and valid requirement that the person performing the electrical inspection be thoroughly trained and experienced concerning the apparatus and systems being evaluated as well as knowledgeable of thermographic methodology.

Table 12: NETA 100.19 Dielectric Withstand Test Voltages

TABLE 100.19
Dielectric Withstand Test Voltages for Electrical Apparatus Other than Inductive Equipment

Nominal System (Line) Voltage[1] (kV)	Insulation Class	AC Factory Test (kV)	Maximum Field Applied AC Test (kV)	Maximum Field Applied DC Test (kV)
1.2	1.2	10	6.0	8.5
2.4	2.5	15	9.0	12.7
4.8	5.0	19	11.4	16.1
8.3	8.7	26	15.6	22.1
14.4	15.0	34	20.4	28.8
18.0	18.0	40	24.0	33.9
25.0	25.0	50	30.0	42.4
34.5	35.0	70	42.0	59.4
46.0	46.0	95	57.0	80.6
69.0	69.0	140	84.0	118.8

Table 13: NETA 100.20.1 Control Voltage Ranges

TABLE 100.20.1
Rated Control Voltages and Their Ranges for Circuit Breakers

(11) Rated Control Voltage	Direct Current Voltage Ranges (1)(2)(3)(5) Volts, DC (8)(9) — Closing and Auxiliary Functions: Indoor Circuit Breakers	Direct Current Voltage Ranges (1)(2)(3)(5) Volts, DC (8)(9) — Closing and Auxiliary Functions: Outdoor Circuit Breakers	Opening Functions All Types	Rated Control Voltage (60Hz)	Alternating Current Voltage Ranges (1)(2)(3)(4)(8) Closing, Tripping, and Auxiliary Functions
				Single Phase	Single Phase
24 (6)	----	----	14-28	120	104-127 (7)
48(6)	38-56	36-56	28-56	240	208-254 (7)
125	100-140	90-140	70-140		
250	200-280	180-280	140-280	Polyphase	Polyphase
----	----	----	----	208Y/120	180Y/104-220Y/127
----	----	----	----	240	208-254

REFERENCES

A. ANSI/NETA MTS. Standard for Maintenance Testing Specifications for Electrical Power Equipment & Systems. Portage, MI: NETA, 2023.

B. Earley, Mark, ed. *NFPA 70, National Electrical Code Handbook*. Quincy, Massachusetts: NFPA, 2020.

NOTE

Electrical refers to something related to electricity while "electric" refers to a device or machine that runs on electricity. Nevertheless, the NEC is sometimes referred to as the National Electric Code.

C. Camara, John A. *PE Power Reference Manual*. Belmont, CA: PPI (Kaplan), 2021.

D. Parker, Sybil P., editor in chief. *McGraw-Hill Dictionary of Scientific and Technical Terms,* 5th ed. New York, McGraw-Hill, 1994.

E. IEEE 315-1975. Graphic Symbols for Electrical and Electronics Diagrams. New York: IEEE, approved 1975, reaffirmed 1993.

F. IEEE 280-2021. IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering. New York: IEEE.

G. Grainger, John J., and William Stevenson, Jr. *Power System Analysis*. New York, McGraw Hill, 1994.

Appendix A: Equivalent Units Of Derived And Common SI Units

Symbol	Equivalent Units			
A	C/s	W/V	V/Ω	$J/(s \cdot V)$
C	$A \cdot s$	J/V	$(N \cdot m)/V$	$V \cdot F$
F	C/V	C^2/J	s/Ω	$(A \cdot s)/V$
F/m	$C/(V \cdot m)$	$C^2/(J \cdot m)$	$C^2/(N \cdot m^2)$	$s/(\Omega \cdot m)$
H	W/A	$(V \cdot s)/A$	$\Omega \cdot s$	$(T \cdot m^2)/A$
Hz	1/s	s^{-1}	cycles/s	$\text{radians}/(2\pi \cdot s)$
J	$N \cdot m$	$V \cdot C$	$W \cdot s$	$(kg \cdot m^2)/s^2$
m^2/s^2	J/kg	$(N \cdot m)/kg$	$(V \cdot C)/kg$	$(C \cdot m^2)/(A \cdot s^3)$
N	J/m	$(V \cdot C)/m$	$(W \cdot C)/(A \cdot m)$	$(kg \cdot m)/s^2$
N/A^2	$Wb/(N \cdot m^2)$	$(V \cdot s)/(N \cdot m^2)$	T/N	$1/(A \cdot m)$
Pa	N/m^2	J/m^3	$(W \cdot s)/m^3$	$kg/(m \cdot s^2)$
Ω	V/A	W/A^2	V^2/W	$(kg \cdot m^2)/(A^2 \cdot s^3)$
S	A/V	1/Ω	A^2/W	$(A^2 \cdot s^3)/(kg \cdot m^2)$
T	Wb/m^2	$N/(A \cdot m)$	$(N \cdot s)/(C \cdot m)$	$kg/(A \cdot s^2)$
V	J/C	W/A	C/F	$(kg \cdot m^2)/(A \cdot s^3)$
V/m	N/C	$W/(A \cdot m)$	$J/(A \cdot m \cdot s)$	$(kg \cdot m)/(A \cdot s^3)$
W	J/s	$V \cdot A$	V^2/Ω	$(kg \cdot m^2)/s^3$
Wb	$V \cdot s$	$H \cdot A$	T/m^2	$(kg \cdot m^2)/(A \cdot s^2)$

Appendix B: Fundamental Constants

Table Note 1

Quantity	Symbols	US Customary	SI Units
Avogadro's number	N_A, L		6.022×10^{23} mol^{-1}
Bohr magneton	μ_B		9.2732×10^{-24} J/T
Boltzmann constant	κ	5.65×10^{-24} ft-lbf / R	1.3805×10^{-23} J/T
electron volt: $\left(\frac{e}{C}\right)$ J	eV		1.602×10^{-19} J
Faraday constant, $N_A e$	F		96485 C/mol
fine structure constant, inverse α^{-1}	α α^{-1}		7.297×10^{-3} (≈1/137) 137.035
gravitational constant	g_c	32.174 lbm-ft/lbf-sec^2	
Newtonian gravitational constant	G	3.44×10^{-8} ft^4 / lbf-sec^4	6.672×10^{-11} N·m^2 / kg^2
nuclear magneton	μ_N		5.050×10^{-27} J/T
permeability of a vacuum	μ_0		1.2566×10^{-6} N/A^2 (H/m)
permittivity of a vacuum, electric constant $1/\mu_0 c^2$	ε_0		8.854×10^{-12} C^2 / N·m^2 (F/m)
Planck's constant	h		6.6256×10^{-34} J·s
Planck's constant: h/2π			1.0546×10^{-34} J·s
Rydberg constant	R_∞		1.097×10^{7} m^{-1}
specific gas constant, air	R	53.3 ft-lbf/lbm- R	287 J/kg·K
Stefan-Boltzmann constant		1.71×10^{-9} BTU/ft^2-hr-°R^4	5.670×10^{-8} W/m^2·K^4
triple point, water		32.02 F, 0.0888 psia	0.01109 C, 0.6123 kPa
universal gas constant	R*	1545 ft-lbf/lbmol- R 1.986 BTU/lbmol- R	8314 J/kmol·K

Table Notes
1. Units come from a variety of sources, but primarily from the Handbook of Chemistry and Physics, The Standard Handbook for Aeronautical and Astronautical Engineers, and the Electrical Engineering Reference Manual for the PE Exam. See also the NIST website at https://pml.nist.gov/cuu/Constants/. The unit in Volume of "lbmol" is an actual unit, not a misspelling.

Appendix C: Mathematical Constants

Quantity	Symbol	Value
Archimedes' constant (pi)	π	3.1415926536
base of natural logs	*e*	2.7182818285
Euler's constant	*C* or τ	0.5772156649

Appendix D: The Greek Alphabet

Α	α	alpha	Ν	υ	nu
Β	β	beta	Ξ	ξ	xi
Γ	γ	gamma	Ο	ο	omicron
Δ	δ	delta	Π	π	pi
Ε	ε	epsilon	Ρ	ρ	rho
Ζ	ζ	zeta	Σ	σ	sigma
Η	η	eta	Τ	τ	tau
Θ	θ	theta	ϒ	υ	upsilon
Ι	ι	iota	Φ	ϕ	phi
Κ	κ	kappa	Χ	χ	chi
Λ	λ	lambda	Ψ	ψ	psi
Μ	μ	mu	Ω	ω	omega