NETA
Maintenance Testing Specifications
Part I

Switchgear / Transformers / Cables / Busways / Switches / Circuit Breakers / Protective Relays / Instrument Transformers

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

by

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Nomenclature[1]

AC	Alternating Current	-
ALF	Accuracy Limit Factor	-
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	%
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	-
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	-
RF	Rating Factor	-
TDR	Time Domain Reflectometer	-
UL	Underwriters Laboratories, Inc.	-
VLF	Very Low Frequency	-

[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.

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	-

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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 maintenance 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 eleven 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 Function Test
-
- Section 9: Thermographic Survey
- Section 10: Electromagnetic Field Testing
- Section 11: Online Partial Discharge Survey for Switchgear
-
- **Reference Tables**
- Appendices [Informational Documents]

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.

[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" [also known as a "target" on NETA forms] that must be met. This format makes it easier to locate required results for given tests.

Following that would be the many applicable standards—which are incorporated into the NETA 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 to assess the suitability for continued service. The testing is to ensure the equipment and systems are operational, within the tolerances of the manufacturers and applicable standards, and are suitable for continued service. Such work involves numerous hazards. Safety is the responsibility of the user. A review of regulatory limitations is warranted prior to testing. Much of the testing is similar to NETA ATS, though some items are optional for "maintenance" with some value expanded/relaxed for items with service time.

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.

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[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 3002.2. 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.

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[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 using these standards: 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.

7.1 Switchgear and Switchboard Assemblies

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Insulation resistance checks (phase-to-phase and phase to ground) for one minute per NETA Table 100.1/ *Dielectric withstand per NETA Table 100.2 for one minute / *Insulation resistance checks on control wiring for one minute / Transformer Tests per Section 7.10 / Grounding tests are in Section 13 / Accuracy of metering devices is in Section 11 / Control Power Transformers / …[15]

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[16] 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.[17] Or, one could use a thermographic survey per Section 9.

Insulation resistance values (phase-to-phase and phase to ground) using the voltages in NETA Table 100.1. As always, good practice is to look up requirements each time they are needed. But, since many exist and often few are used, one should memorize those one requires most often. A suggestion is circled in green in the NETA Table. Most common voltages are <600 V; therefore, one could commit to memory that transformers in this range need a *1000 V test for one minute with a minimum result of 100 MΩ*.[18]

Dielectric withstand is applied per NETA Table 100.2 phase to ground with the phases not being tested grounded. To pass there shall be *no evidence or distress or insulation failure at the completion of the test*.

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[15] Several other tests are listed with the criteria that items be in accordance with "design, drawings, specifications" and "perform as designed.". As this is always the case, such items will not be mentioned. And, those test mentioned but covered elsewhere will be explained in detail in the appropriate section.

[16] 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.

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

[18] Obviously, this guidance must be adjusted to the engineer's most common tasks.

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.*

Control Power Transformers insulation resistance per NETA Table 100.1. *Turns ratio shall NOT deviate by more than 0.5%.*

Heaters should be operational.

Online Partial-Discharge Survey should be within manufacturer's published data, in the absence of such data, use Table 100.23.

All tests required for switchgear are mentioned in this section of NETA MTS but are covered in detail elsewhere; therefore, they will be covered in their appropriate section.[19]

7.2.1.1 Transformers, Dry-Type, Air-Cooled, Low-Voltage, Small

This category is for a) power transformers rated for ≤600 V and b) single-phase transformers rated for ≤167 kVA or three-phase rated ≤500 kVA.

Electrical Tests

Verify / Check / Perform / Measure: Bolted Connections / Insulation Resistance / *Turns Ratio

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.

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[19] This will be the policy throughout this course. This avoids repetition.

[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.

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*. As always, good practice is to look up requirements each time they are needed. But, since many exist and often few are used, one should memorize those one requires most often. A suggestion is circled in green in the NETA Table. Most common voltages are <600 V and most transformers are of the dry type; therefore, one could commit to memory that transformers in this range need a 1000 V test for one minute with a minimum result of 500 MΩ.[22]

A **Turns Ratio** test run to ensure the nameplate turns ratio is correct. The turns-*ratio shall not vary by more than 0.5% from the calculated ratio or that of the adjacent coils*.

7.2.1.2 Transformers, Dry-Type, Air-Cooled, Large

This category is for a) power transformers rated for >600 V and b) single-phase transformers rated for >167 kVA or three-phase rated >500 kVA.

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance or torque or thermographic survey / Insulation resistance checks at 1000 V for one minute per NETA Table 100.5 / Power-Factor or Dissipation Factor (Tan Delta) per manufacturer's data / *Power-Factor or Dissipation Factor *tip-up* test on windings >2.5 kV / Turns-Ratio tests / Excitation tests / *Winding resistance (at no more than 10% rated current) / Core insulation resistance at 500 V (if core is insulated and core ground strap can be removed) / *Applied voltage test phase-to-phase and phase-to-ground per IEEE C57.12.91 Sec. 10.2 & 10.9 / Verify secondary voltage phase-to-phase and phase-to-ground after energization and prior to loading / Surge arrestor test per Sec. 7.19 / *Partial discharge survey on windings >1000 V per Sec. 11

[22] Obviously, this guidance must be adjusted to the engineer's most common tasks.

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.

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*. As always, good practice is to look up requirements each time they are needed. But, since many exist and often few are used, one should memorize those one requires most often. A suggestion is circled in green in the NETA Table. Most common voltages are <600 V and most transformers are of the dry type; therefore, one could commit to memory that transformers in this range need a 1000 V test for one minute with a minimum result of 500 MΩ.[25]

The dielectric absorption ratio (DAR) and polarization index (PI) shall NOT be less than 1.0. The dielectric absorption ratio (DAR) is a measurement of the absorption current in insulating materials, such as those found in plants and equipment. *It's calculated by dividing the megohms measured at 60 seconds by the megohms measured at 30 seconds*. The tests are similar with the PI test measuring values at one minute and ten minutes. *The ratio of the ten minute value to the one minute value is the PI.*

Power-Factor / Dissipation-Factor testing is also called tan delta (tanΔ or tanδ) or a tangent delta or dielectric dissipation factor testing.[26] 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.

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[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.
[25] Obviously, this guidance must be adjusted to the engineer's most common tasks.
[26] 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.

The following value are typical for insulation power factor testing. The term C_{HL} is the power factor from the High side winding to the Low side winding. (The C stands for capacitance given that a good insulator is mostly capacitive.) *C_{HL} on power transformers should be ≤ 2%. For distribution transformers C_{HL} should be ≤ 5%.*[27]

Power-Factor or Dissipation Factor *Tip-Up* test on windings >2.5 kV. *A tip-up exceeding 1% shall be investigated.* Limits, which depend upon insulation are in the figure "Tan Delta Values for Insulation Types" in Section 7.10.1.

PF tip-up testing can be useful to verify the quality of the winding manufacturing process, insulation material performance, consolidation of conductors, uniformity of groundwall taping and state of resin curing. The in-service PF tip-up test can potentially identify groundwall insulation aging since the capacitance between the copper conductor and the core is generally reduced as delamination and/or air pockets become present in the insulation between the coils and the core.[28]

The test is accomplished by measuring the percent power factor from its value at a high voltage to its value at a low value. A power factor that increases as the voltage increases indicates the presence of voids or ionization in the insulation. *This measurement can be used as a baseline for tracking trends over time*.[29] See the figure below.

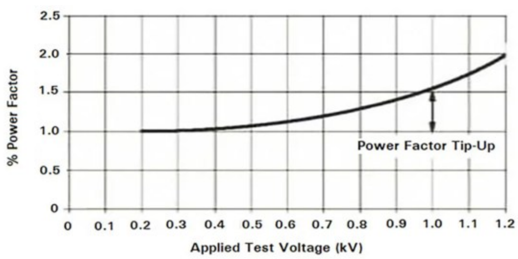

Figure 1: PF Tip-Up Testing

[27] The values given are the percentage power factor. A 100% power factor has a value of 1.00. Recall PF = P_{kW}/S_{VA}. For maximum efficiency one want value near 1.00. For insulation values, one wants values near 0.00.
[28] The source for this information is https://easa.com/training/private-webinars/getting-the-most-from-power-factor-tip-up-testing. Tip-up is essentially a partial discharge test.
[29] Background information may be found in IEEE 286-2000. Although for rotating machinery, the principles for testing a transformer are the same.

A **Turns Ratio** test run to ensure the nameplate turns ratio is correct. The turns-*ratio shall not vary by more than 0.5% from the calculated ratio or that of the adjacent coils.*

Excitation Test current should show a pattern for a three-legged core transformer of *two similar current* readings *and one lower current reading*. This should be expected from a three-phase system. See the Excitation Test figure below.

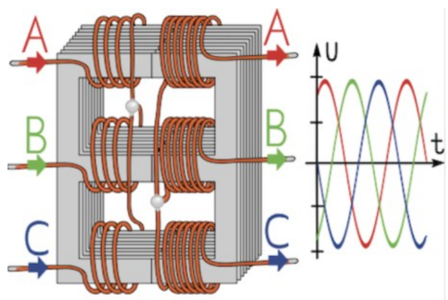

Figure 2: Excitation Test Three-Legged Core
[Source: *https://tameson.com/pages/transformer-three-phase*]

Winding Resistance, if taken, *should be no more than 1% of previous results*. The results should be temperature corrected.

Core Insulation Resistance shall *be not less than 1 MΩ.*

Applied Voltage Test phase-to-phase and phase-to-ground per IEEE C57.12.91 Sec. 10.2 & 10.9 is also known as **Dielectric Withstand Test**. For AC tests, it is done at 75% of the factory test voltage for one minute. For DC tests, it is done at 100% of factory test voltage for one minute. *If no evidence of distress or insulation failure is observed, the specimen passes*.

Verify Secondary Voltage phase-to-phase and phase-to-ground after energization and prior to loading. *The voltages shall be in agreement with the nameplate data.*

Surge Arrestor Tests and are described in Section 7.19.

Partial Discharge Surveys are conducted per manufacturer's data. Lacking such data, *use NETA Table 100.23*.[30]

[30] This table is actually multiple tables based on the nature and strength of the signal. Consult NETA MTS directly.

7.2.2 Transformers, Liquid Filled

Tests are similar to other transformers with the addition of multiple optional requirements as well as many related to the cooling liquid itself.

7.3.1 Cables, Low-Voltage, Low-Energy

This section is reserved for now with no requirements listed.

7.3.2 Cables, Low-Voltage, 1000-Volt Maximum

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance or torque or thermographic survey / Insulation resistance checks on each conductor using 500 V for 300-volt rated cable and 1000-volts for 600-volt rated cable / *Uniform Resistance of parallel conductors

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 resistance checks with *satisfactory results per the manufacturer or NETA Table 100.1*.

Parallel Conductors should be *investigated if deviations in resistance occur.*

7.3.3 Shielded Cables, Medium- and High-Voltage

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance or torque or thermographic survey / Insulation Resistance checks using NETA Table 100.1 / Shield Continuity Test / *Jacket Integrity Test / Cable Withstand tests, VLF, Power Frequency, Damped Alternating Current (DAC) / Diagnostic checks: Tan Delta, VLF, DAC, DC Insulation Resistance, Partial Discharge (online or offline)

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[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.

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[33] 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.[34] Or, one could use a thermographic survey per Section 9.

Insulation resistance checks with *satisfactory results per the manufacturer.*

Shield Continuity should be checked with *resistance values <10 Ω per 1000 ft, otherwise investigate*.

Cable Withstand tests vary, but regardless of the test, *if no evidence of distress or insulation failure is observed, the specimen passes.*

Diagnostic checks vary, one needs to consult manufacturer's literature or the applicable standards for *acceptable values*.[35] For evaluation of tan-delta tests, see Table 100.6.7 or IEEE 400.2.

Partial Discharge Tests should show no evidence of partial discharge for online testing. For offline testing there should be no evidence of partial discharge at the PD limit per the manufacturer or IEEE 400.3.

7.4 Metal-Enclosed Busways, Low- and Medium-Voltage

There are three basic types of metal-enclosed bus assemblies: nonsegregated-phase, segregated-phase, and isolated-phase.

A metal-enclosed busway is a prefabricated electrical distribution system that consists of insulated conductors (bus bars) within a metallic housing. The housing protects the bus bars and usually provides an equipment grounding path. Busways are often used in commercial and industrial applications because they are less expensive and easier to install than cable and conduit.

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[33] 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.
[34] Numerous torque tables exists varying with the size, material, and thread used.
[35] The more common of these tests are covered later in the course where most often encountered.

Busway is an excellent alternative to cable and conduit in commercial and industrial applications because it's not as complex to configure and is less expensive to install and easier to replace, especially in applications where load locations are likely to change.[36] See an example in the Sandwich Style Busway figure below.

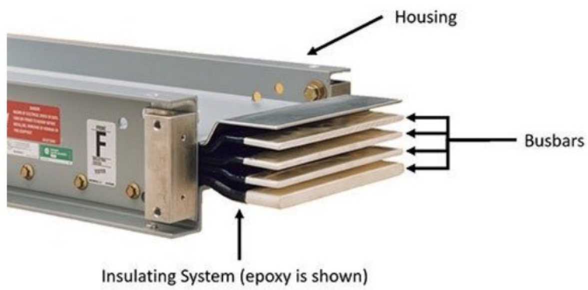

Figure 3: Sandwich Style Busway
[Source: https://www.eaton.com/ca/en-gb/products/low-voltage-power-distribution-control-systems/busway /busway--fundamentals-of-low-and-medium-voltage busway]

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance or torque or thermographic survey / Insulation **Resistance** checks for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / Dielectric Withstand for one minute using NETA Table 100.17 / *Contact Resistance at each connection point / *Online Partial-Discharge per Section 11

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.

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[36] Source of information: https://www.eaton.com/ca/en-gb/products/low-voltage-power-distribution-control-systems/busway/busway--fundamentals-of-low-and-medium-voltage busway

[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.

Insulation resistance checks *are measured per manufacturer's data or NETA Table 100.1 using a 1000 ft run as the basis for table entry. Those less than this modified value shall be investigated.*

Equation 1: Busway Resistance per 1000 Feet

$$R_{1000\,ft} = R_{\text{measured}} \times \frac{L_{\text{busway run, ft}}}{1000\text{ ft}}$$

Dielectric Withstand tests vary, but regardless of the test, *if no evidence of distress or insulation failure is observed, the specimen passes.* If manufacturer has no recommendation use Table 100.17. Where no DC Test value is shown, use the AC value. *Test voltage is applied for one minute.*

Contact Resistance on assembled sections. *Compare values with adjacent phases*.

Partial-Discharge Survey is covered in Section 11. Surveys are conducted per manufacturer's data. Lacking such data, *use NETA Table 100.23*.[39]

7.5.1.1 Switches, Air, Low-Voltage

Switches are isolating mechanisms whereas circuit breakers can provide circuit protection. Switches *in general* are used for light loads whereas circuit breakers are for heavy loads (high current). Disconnect switches are used for isolation for electrical safety (e.g., maintenance) and are designed to be operated multiple times. Air switches operate in air or use air to operate. Those that operate in oil covered separately. Tests for each type vary.
Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Contact resistance on switchblade and fuseholder / Insulation Resistance checks on each pole for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / Fuse resistance / Space Heater Operation/ Ground fault tests per Section 7.14 / Protective devices tests per Section 7.9

[39] This table is actually multiple tables based on the nature and strength of the signal. Consult NETA MTS directly.

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 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.

Contact resistance should *not exceed the high range in manufacturer's data*. If not available, values of micro-ohm or dc milli-volt drop values from similar *switches or poles that deviate more than 50% from the* ***lowest*** *value shall be investigated.*

Insulation resistance per *NETA Table 100.1 with values less than this investigated.*

Fuse resistance *values that deviate more than 15% from each other shall be investigated.*

Heaters *should be operational.*

Ground fault tests are covered in Section 7.14.

Protective devices tests are covered in Section 7.9.

7.5.1.2 Switches, Air, Medium-Voltage, Metal-Enclosed

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Contact resistance on switchblade and fuseholder / Insulation Resistance checks on each pole for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / Dielectric withstand voltage per NETA Table 100.2 / Fuse resistance / Space Heater Operation / Dielectric withstand per NETA Table 100.2 / *Partial Discharge Survey per Section 11

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

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[42] 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.[43] Or, one could use a thermographic survey per Section 9.

Contact resistance should *not exceed the high range in manufacturer's data*. If not available, values of micro-ohm or dc milli-volt drop values from similar *switches or poles that deviate more than 50% from the* ***lowest*** *value shall be investigated.*

Insulation resistance per *NETA Table 100.1 with values less than this investigated.*

Dielectric withstand is applied per NETA Table 100.9 on the primary winding with the secondary ground. The CT shall *no evidence or distress or insulation failure at the completion of the test*.

Fuse resistance *values that deviate more than 15% from each other shall be investigated.*

Heaters *should be operational.*

Partial Discharge Survey is covered in Section 11.

7.5.1.3 Switches, Air, Medium- and High-Voltage, Open

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Contact resistance on switchblade and fuseholder / Insulation Resistance checks on each pole for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / *Insulation resistance on control wiring / Dielectric withstand voltage per NETA Table 100.2 / Fuse resistance / Dielectric withstand per NETA Table 100.19

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[42] 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.
[43] Numerous torque tables exists varying with the size, material, and thread used.

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[44] 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.[45] Or, one could use a thermographic survey per Section 9.

Contact resistance should *not exceed the high range in manufacturer's data*. If not available, values of micro-ohm or dc milli-volt drop values from similar *switches or poles that deviate more than 50% from the* lowest *value shall be investigated.*

Insulation resistance per *NETA Table 100.1 with values less than this 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 comparable to previous results but shall NOT be less than 2 MΩ.*.

Dielectric withstand is applied per NETA Table 100.9 on the primary winding with the secondary ground. The CT shall *no evidence or distress or insulation failure at the completion of the test*.

Fuse resistance *values that* deviate *more than 15% from each other shall be investigated.*

7.5.2 Switches, Oil, Medium-Voltage

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Contact-Pole Resistance / Insulation Resistance checks on each pole for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / *Insulation resistance on control wiring / *Dielectric withstand voltage per NETA Table 100.2 / *Insulating Liquid tests per ASTM / Fuse resistance

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

Test Values—Electrical

Test values are identical to 7.5.1 with the addition of **Insulating Liquid Tests** *per ASTM* (formerly, American Society of Testing and Materials, now, ASTM International).[46]

7.5.3 Switches, Vacuum, Medium-Voltage

Tests and Values are nearly identical with the addition of vacuum interrupter magnetron atmospheric condition (MAC) test. The MAC value shall be *no greater than* $1x10^{-2}$ *Pa* and *shall not deviate from adjacent poles by more than two orders of magnitude. Also, liquid tests are per NETA Table 100.4*.[47]

7.5.4 Switches, SF_6, Medium-Voltage

Sulfur hexafluoride is used because it offers excellent electrical insulation properties and high thermal stability. Check NETA MTS for specific requirements.

7.5.5 Switches, Cutout

The cut out (also called the service head) is a piece of electrical equipment that links the mains/service electricity cable and the internal wires in your property. It makes sure that electricity passes safely and efficiently into your property. It also houses the main fuse. *In general*, cutout switches are a combination of a fuse and a switch.

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Contact resistance across each cutout / Insulation Resistance checks on each pole for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / Dielectric withstand voltage per NETA Table 100.1 / Fuse resistance

[46] Several ASTM standards are involved. Check NETA ASTM directly.
[47] Multiple tables are involved depending on the insulating material. Consult NETA MTS directly.

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[48] 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.[49] Or, one could use a thermographic survey per Section 9.

Contact resistance should *not exceed the high range in manufacturer's data*. If not available, values of micro-ohm or dc milli-volt drop values from similar *switches or poles that deviate more than 50% from the* lowest *value shall be investigated.*

Insulation resistance per *NETA Table 100.1 with values less than this investigated.*

Dielectric withstand is applied per NETA Table 100.1. *If no evidence or distress or insulation failure at the completion of the test the specimen passes.*

Fuse resistance *values that* deviate *more than 15% from each other shall be investigated.*

7.6.1.1 Circuit Breakers, Air, Insulated-Case/Molded-Case

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Insulation Resistance checks on each pole for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / Contact/Pole Resistance test / *Insulation Resistance on control winding / Long-Time Pickup & Delay / Short-Time Pickup & Delay / Ground Fault Pickup & Delay / Instantaneous Pickup / *Trip Unit Functions / Minimum Pickup of shunt-trip and close coils / Auxiliary Features check / Charging Mechanism check

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[48] 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.
[49] Numerous torque tables exists varying with the size, material, and thread used.

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[50] 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 with values less than this investigated.*

Contact resistance should *not exceed the high range in manufacturer's data*. If not available, values of micro-ohm or dc milli-volt drop values from similar *switches or poles that deviate more than 50% from the* lowest *value 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.*.

Long-Time Pickup as specified. If not available, *times shall not exceed NETA Table 100.7*.

Short-Time Pickup *per manufacturer's published time tolerance*.

Ground-Fault Pickup *per manufacturer's published time tolerance*.

Instantaneous Pickup *per manufacturer's published time tolerance or NETA Table 100.8.*

Trip Unit Functions *per manufacturer's tolerances.*

Minimum Pickup of shunt and trip coils *per manufacturer's tolerances*, if available. Or, *use NETA Table 100.20.*[52]

Auxiliary Features. Breaker open, close, trip, trip-free, anti-pump and auxiliary features *function as designed.*

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[50] 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.

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

[52] Multiple tables exists each for a difference type of tripping unit.

Charging Mechanism *operates per manufacturer's data*.

7.6.1.2 Circuit Breakers, Low-Voltage Power

Tests are identical to those of 7.6.1.1

7.6.1.3 Circuit Breakers, Air, Medium-Voltage

Of note here, the visual and mechanical checks include a requirement to check "puffer operation". A puffer device is used in most medium voltage air breakers to help accelerate the arc into the arc chute. The puffer will have a tube positioned under the stationary contacts and uses the movement of the mechanism or contact arm to displace air from a chamber on the breaker into the arc path.

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Insulation Resistance checks on each pole for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / *Insulation Resistance on control winding per NETA Table 100.1 / Contact/Pole Resistance test / Test Position checks / *Minimum Pickup of shunt-trip and close coils per NETA Table 100.20 / *Power Factor or Dissipation-Factor tests on breaker and bushings / *Dielectric Withstand per NETA Table 100.19 / Blowout Coil resistance / Heater operation / *Test Instrument Transformers per 7.10

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[53] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*. Or, use NETA Table 100.12.[54] Or, use a thermographic survey per Section 9.
Insulation resistance per *NETA Table 100.1 with values less than this investigated.*

[53] 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.
[54] Numerous torque tables exists varying with the size, material, and thread used.

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.*

Contact/Pole resistance should *not exceed the high range in manufacturer's data*. If not available, values of micro-ohm or dc milli-volt drop values from similar *switches or poles that deviate more than 50% from the* lowest *value shall be investigated.*

Minimum Pickup voltage checks using voltages in NETA Table 100.20 (20.1 or 20.2).

Power-Factor / Dissipation-Factor testing is also called tan delta (tanΔ or tanδ) or a tangent delta or dielectric dissipation factor testing.[55] 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. The test is conducted over increasing voltages and varying frequencies. IEEE 400.2 contains guidance (see the Figure *Tan Delta Values for Insulation Types* below). The principles of the $tan\delta$ test are shown in the Figure *Tan Delta Principles*. The tangent of δ gives the relationship between I_R/I_C. The smaller the angle, the better the insulation. For an acceptance test, without a serious failure of the cable, the results establish a baseline for monitoring the health of the insulation over time. The *results should match manufacturer's or test equipment published data*.

Dielectric Withstand on each phase with breaker closed and the poles not under test grounded. Voltage per NETA Table 100.9. *If no evidence of distress or insulation failure is observed, the specimen passes*.

Blowout Coil *shall exhibit continuity*.[56]

7.6.2 Circuit Breakers, Oil, Medium- and High-Voltage

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[55] 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.

[56] A blowout coil is a safety device that suppresses electric arcs that occur when high currents are switched. Blowout coils use a magnetic field to push the arc away from the contact field, preventing it from causing serious hazards.

Test values are similar to earlier breakers with the addition of **Insulating Liquid Tests** *per ASTM* (formerly, American Society of Testing and Materials, now, ASTM International).[57] Also, these breakers have an optional *dynamic* contact/pole resistance test.

The contact resistance is dynamically measured via a close-open operation. The contact characteristic and the arc contact can be reliably determined via the measurement results. Also, signature obtained is a non –invasive diagnosis measurement which indicates the erosion of arcing and main contacts looseness, damage, misalignment and helps to measure length of arcing tip. *Guidance is in the manufacturer's data*.

7.6.3 Circuit Breakers, Vacuum, Medium-Voltage

Tests and Values are nearly identical with the addition of vacuum *interrupter magnetron atmospheric condition* (MAC) test. (*no greater than* $1x10^{-2}$ *Pa*) and *shall not deviate from adjacent poles by more than two orders of magnitude.*

7.6.4 Circuit Breakers, SF_6

Sulfur hexafluoride is used because it offers excellent electrical insulation properties and high thermal stability. Leak tests and measurement of the gas properties are added to standard tests. Check NETA MTS for specific requirements.

7.7 Circuit Switchers

A *circuit switcher* switches and protect transformers and, more generally, loads (reactors, lines, cables...), as an alternative to dead tank circuit-breakers[58], in general used in the place of circuit breakers for economic reasons. They contain SF_6 interrupters. They are most often operated by a utility. See the figure below.

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[57] Several ASTM standards are involved. Check NETA ASTM directly.

[58] In live tank circuit breakers, the enclosure that houses the contacts is energized, i.e., "live". Dead tank circuit breaker's contact enclosures are not energized and are connected to the ground grid. Live tank breakers are less expensive than dead tank breakers and require less space.

Figure 4: Circuit Switcher

Test are similar to other circuit breaking devices, in this case with the addition of checking SF_6 pressure and interrupter operation per manufacturer's published data. Check NETA MTS for details.

7.8 Network Protectors, 600-Volt Class

A network protector is a special self-contained air breaker or switching unit having a full complement of current, potential and control transformers, as well as relay functionality. The network protector enables the paralleling of two or more primary feeders on the same low voltage bus. They are available for transformer mounting in submersible or non-submersible housings, or suitable for mounting within a low voltage switchgear assembly. The protective relay automatically closes the protector if power flow is forwarded into the collector bus. It also trips the protector upon flow of reverse fault or magnetizing currents. Standards for network protectors are defined by IEEE C57.12.44.

Figure 5: Network Protector
[Source: *https://www.eaton.com/us/en-us/products/utility-grid-solutions/network-protector-solutions/network-protectors--fundamentals-of-network-protectors.html*]

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance / Insulation Resistance checks on each pole for one minute phase-to-phase and phase-to-ground using NETA Table 100.1 / Contact/Pole Resistance test / *Insulation Resistance on control winding per NETA Table 100.1 / *Current Transformer ratios per 7.10 / Fuse Resistance values / Minimum Pickup of voltage of motor control relay / *Motor Closing voltage / Trip Actuator pickup / Network Protector Relay calibrations / Network Protector Operation

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[59] 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.[60] Or, one could use a thermographic survey per Section 9.

Insulation resistance per *NETA Table 100.1 with values less than this investigated.*

Contact/Pole resistance should *not exceed the high range in manufacturer's data*. If not available, values of micro-ohm or dc milli-volt drop values from similar *switches or poles that deviate more than 50% from the lowest value shall be investigated.*

Control Wiring 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.*.

Current Transformer ratios *per 7.10.*

Fuse resistance *values that deviate more than 15% from each other shall be investigated.*

Minimum Pickup of motor control relay *in accordance with manufacturer's data but no more than 75% or rated control circuit voltage*.

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[59] 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.
[60] Numerous torque tables exists varying with the size, material, and thread used.

Motor Closing voltage should not exceed *more than 75% or rated control circuit voltage*.

Trip Actuator minimum pickup voltage should not exceed *more than 75% or rated control circuit voltage*.

Network Protector Relay *calibrations in accordance with 7.9.*

Network Protector operation *in accordance with system design requirements.*[61]

System Design paralleling checks. *Phasing, phase rotation, and synchronizing shall be in accordance with design requirements.*[62]

7.9.1 Protective Relays, Electromechanical and Solid-State

The relay tests, while they have a name, are known by numbers given in ANSI/IEEE C37.2-2022 *Electrical Power System Device Function Numbers, Acronyms, and Contact Designations*.

[61] One must check the appropriate coordination/protection study.
[62] Because of software automation, paralleling is not as well-known as it is for those that parallel manually (go Navy). Phasing is A, B, C with the rotation being A-B-C. The oncoming bus should be at slightly higher frequency so that it picks up load during synchronization (connection) of the two buses.

Table 1: IEEE Device Numbers[63]

ANSI/IEEE Standard Device Numbers

In North America protective relays are generally referred to by standard device numbers. Letters are sometimes added to specify the application (IEEE Standard C37.2-2008).

Device Numbers (the more commonly used ones are in bold)

1 - Master Element
2 - Time Delay Starting or Closing Relay
3 - Checking or Interlocking Relay
4 - Master Contactor
5 - Stopping Device
6 - Starting Circuit Breaker
7 – Rate of Change Relay
8 - Control Power Disconnecting Device
9 - Reversing Device
10 - Unit Sequence Switch
11 – Multifunction Device
12 - Overspeed Device
13 - Synchronous-speed Device
14 - Underspeed Device
15 - Speed or Frequency-Matching Device
16 – Data Communications Device
20 - Elect. operated valve (solenoid valve)
21 - Distance Relay
23 - Temperature Control Device
24 – Volts per Hertz Relay
25 - Synchronizing or Synchronism-Check Device
26 - Apparatus Thermal Device
27 - Undervoltage Relay
30 - Annunciator Relay
32 - Directional Power Relay
36 - Polarity or Polarizing Voltage Devices
37 - Undercurrent or Underpower Relay
38 - Bearing Protective Device
39 - Mechanical Condition Monitor
40 –Field (over/under excitation) Relay
41 - Field Circuit Breaker
42 - Running Circuit Breaker
43 - Manual Transfer or Selector Device
46 – Rev. phase or Phase-Bal. Current Relay
47 - Phase-Seq. or Phase-Bal. Voltage Relay
48 - Incomplete-Sequence Relay
49 - Machine or Transformer Thermal Relay
50 - Instantaneous Overcurrent
51 - AC Inverse Time Overcurrent Relay
52 - AC Circuit Breaker
53 – Field Excitation Relay
55 - Power Factor Relay
56 - Field Application Relay
59 - Overvoltage Relay
60 - Voltage or Current Balance Relay
62 - Time-Delay Stopping or Opening Relay
63 - Pressure Switch
64 - Ground Detector Relay
65 - Governor
66 – Notching or jogging device
67 - AC Directional Overcurrent Relay
68 - Blocking or "out of step" Relay
69 - Permissive Control Device
74 - Alarm Relay
75 - Position Changing Mechanism
76 - DC Overcurrent Relay
78 - Phase-Angle Measuring Relay
79 - AC-Reclosing Relay
81 - Frequency Relay
83 - Automatic Selective Control or Transfer Relay
84 - Operating Mechanism
85 – Pilot Communications, Carrier or Pilot-Wire Relay
86 - Lockout Relay
87 - Differential Protective Relay
89 - Line Switch
90 - Regulating Device
91 - Voltage Directional Relay
92 - Voltage and Power Directional Relay
94 - Tripping or Trip-Free Relay

Suffixes indicating zone of protection
B –Bus
G – Ground or generator
L—Line
N –Neutral
T – Transformer
U—Unit

Electrical Tests

Verify / Check / Perform / Measure: Insulation Resistance tests per manufacturer's data / Relay Tests

[63] As of this writing, 2022 is the latest version.

Test Values—Electrical

Some 25 different relays are listed by device number. All are tested per manufacturer's data. Of not, NETA says "when critical test points are specified, the relay shall be calibrated to these points even though other test points may be out of tolerance."

7.9.2 Protective Relays, Microprocessor-Based

Electrical Tests

Verify / Check / Perform / Measure: Insulation Resistance tests per manufacturer's data / Voltage-Current registration / *SCADA verification at remote terminals / *Relay Protection Elements / Control Elements

Test Values—Electrical

Some 25 different relays are listed by device number. All are tested per manufacturer's data. SCADA checks are per manufacturer's data. Check NETA MTS for details.

7.10.1 Instrument Transformers, Current Transformers

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance or torque or thermographic survey / Insulation resistance checks at 1000 V for one minute—for solid state units, follow the manufacturer's instructions / *Polarity Test per IEEE C57.13.1 / *Ratio Verification test per IEEE C57.13 / *Excitation test for relaying applications per IEEE C57.13.1[64] / *CT burdens per IEEE C57.13.1 / Insulation resistance with secondary grounded per NETA Table 100.5 / Dielectric withstand per NETA Table 100.9 / *Power-Factor or Dissipation Factor per manufacturer's data / Grounding Point per IEEE C57.13.3

Test Values—Electrical

[64] Relaying applications are protective in nature as opposed to metering applications that provide indications only.

Bolted connection resistance does not have a specified limit, per se.[65] 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.[66] 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*. As always, good practice is to look up requirements each time they are needed. But, since many exist and often few are used, one should memorize those one requires most often. A suggestion is circled in green in the NETA Table. Most common voltages are <600 V and most transformers are of the dry type; therefore, one could commit to memory that transformers in this range need a 1000 V test for one minute with a minimum result of 500 MΩ.[67]

A **Polarity Test** is accomplished to ensure the transformer is properly hooked up. *The polarity marking should match the transformer markings.* Think of the "dot convention". Current into H1 should flow out of X1 . In terms of polarity, when a positive polarity exists on the primary winding [H1] at the dot (as a load), a positive polarity exists on the dot in the secondary winding [X1] (as a source) What is described is subtractive polarity, which is common in instrument transformers.[68]

A **Ratio Verification** test run to ensure the nameplate turns ratio is correct. *The turns ratio should be within 10% of the nameplate value per IEEE C57.13.1.*

Excitation (saturation) **Test** results verify accuracy and vary by class of CT. Class C is low leakage. Class T is high leakage whose accuracy must be determined by testing. Class X is high accuracy most often used in protective relaying systems.[69]

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[65] 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.
[66] Numerous torque table exists varying with the size, material, and thread used.
[67] Obviously, this guidance must be adjusted to the engineer's most common tasks.
[68] See Ref [C] for an indepth discussions.
[69] Other classes exist. Class H is accurate with 5-20 times the secondary rated current—typically wound CTs. Class L is accurate at 20 time the rated secondary current at the maximum burden—typically donut, bar, or bushing types.

Per IEEE C57.13.1, *Class C turns ratio accuracy should be 3% at rated current, 10% at 20 times rated current.*

Class X accuracy is determined by evaluation of the knee-point voltage, which is the point on the magnetizing curve where the current starts to significantly increase with a small voltage change, and the magnetizing current—both of which are shown in standardized NETA testing (see Figure Excitation Test Terminology).

The knee-point and magnetizing current *should not show any substantial deviation of the excitation curve for the CT under test from curves of similar CT's or manufacturer's data shall be investigated.*[70] Specifically, *the knee point voltage should be above the rated secondary voltage*.

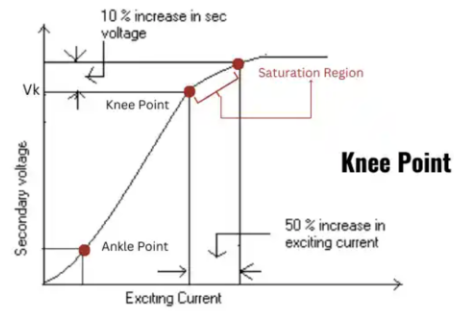

Figure 6: Excitation Test Terminology

Burden ratings also come into play. ANSI/IEEE standard burden ratings[71] B-0.1, B-0.2, B-0.5, B-1.0, B-2.0 and B-4.0. The burden rating indicates the CT maintains stated accuracy with up to 0.1 Ω, 0.2 Ω, 0.5 Ω…up to 4.0 Ω of impedance, respectively. So, *the measure impedance from the NETA test must be checked against the burden ratings to ensure compliance.* If the burden rating is exceeded, the accuracy will not be as stated.[72]

[70] Substantial difference is not defined. The basic premise is to ensure the linear region comprises the rating of the secondary (e.g., 5 V) and the knee, which indicates saturation and starts to make the data horizontal (as the magnetizing current increases the output does not vary or increases slightly), does NOT occur until after the rating (e.g., 5 V) is exceeded.
[71] Burden ratings are the mostly resistive secondary impedance allowed for which the CT will maintain accuracy.
[72] Class 0.2s and 0.5s are used in revenue metering with an accuracy of 0.2% error from 20% to 120% of rated current.

Examples of Metering and Relay accuracy and burden labeling are shown below. The first number of the accuracy class for both classes of CTs is the rated ratio accuracy in percent. Therefore a "0.3B0.1" metering class CT's ratio would be accurate within 0.3% as long as the CT burden rating was not exceeded.

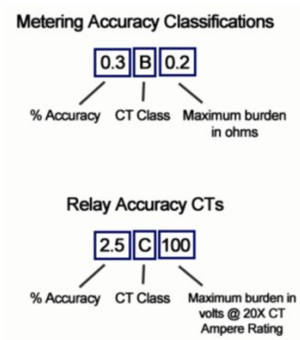

Figure 7: Relay and Metering Labeling Examples

[Source*: IEEE C57.13.1 via https://www.nktechnologies.com/wp-content/uploads/application-notes/Current_Transformer_White%20Paper_071415.pdf*]

Insulation resistance values (with secondary grounded) shall *not be less than NETA Table 100.5*.[73]

Dielectric withstand is applied per NETA Table 100.9 on the primary winding with the secondary ground. The CT shall *no evidence or distress or insulation failure at the completion of the test*.

Power-Factor / Dissipation-Factor testing is also called tan delta (tanΔ or tanδ) or a tangent delta or dielectric dissipation factor testing.[74] 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. The test is conducted over increasing voltages and varying frequencies. IEEE 400.2 contains guidance (see the Figure *Tan Delta Values for Insulation Types* below). The principles of the $tan\delta$ test are shown in the Figure *Tan Delta Principles*. The tangent of δ gives the relationship between I_R/I_C. The smaller the angle, the better the insulation. For an acceptance test, without a serious failure of the cable, the results establish a baseline for monitoring the health of the cable over time.

[73] This checks for any connection between the primary and secondary windings.

[74] 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.

The *results should match manufacturer's or test equipment published data*. Though an acceptable result depends on the type of insulation (see the Figure below), a *new cable value of 0.5 for tanδ* ***deviation from the measure norm for the type of insulation*** *is an acceptable value with a stability value (deviation) of less than 0.05 being acceptable. A stability value of >0.1 is acceptable for unknown insulation.*

Condition Assesment	No Action Required	Furtner Study Advised	Action Required	No Action Required	Furtner Study Advised	Action Required	No Action Required	Furtner Study Advised	Action Required
Insuation Type	PE Based Insulation (PE, XLPE, WTRX-LPE)			Unidentified Filled Insulation (EPR)			Mineral Filled Insulation (EPR)		
Stability for TD (Standard Deviation)	< 0.05	0.05 to 0.5	> 0.5	> 0.1	0.1 ro 1.3	> 1.3	< 0.1	0.1 ro 1	> 1
	And	Or		And	Or		And	Or	
Tip Up (TD1.5U0 – TD0.5U0)	< 5	5 to 80	> 80	< 5	5 to 100	> 100	< 4	4 to 120	> 120
	And	Or		And	Or		And	Or	
Mean TD @ U0	< 4	4 to 50	> 50	< 35	35 to 120	> 120	< 20	20 to 100	> 100

Figure 8: Tan Delta Measured Range of Values for Insulation Types
[Source*: IEEE 400.2 and https://hvinc.com/wp-content/uploads/2019/11*]
/HVI-TD-FAQ-WEB-2019.pdf]

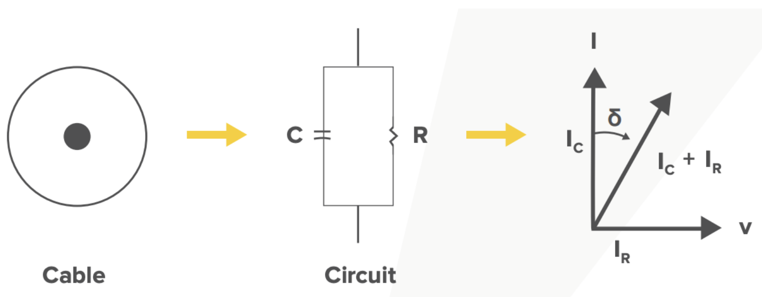

Figure 9: Tan Delta Principles
[Source*: https://hvinc.com/wp-content/uploads/2019/11/HVI-TD-FAQ-WEB-2019.pdf*]

Grounding Point per IEEE C57.13.3 and engineering drawings should be checked. *CT secondary circuits should have only one grounding point*.

Test Sheet Terminology varies with equipment and customers. Several terms that are likely useful to understand follow.

- ALF: Accuracy Limit Factor a parameter used to measure the ability of a current transformer (CT) to maintain accuracy under high fault current conditions. The ALF is expressed as a numerical value, such as 10, 20, or 30, and indicates the multiple of the rated primary current at which the CT remains unsaturated.

- ε_t: Turns Error Ratio deviation. In general, for IEEE, *the turns ratio should be 10% at rated burden and current.* The *turns-ratio deviation (accuracy) should be equal or less than the value of the CT Class Accuracy.*[75]
- ε_c: Corrected Error Ratio. This terms collects the turns-ratio inaccuracy and combines the angle inaccuracy ($\Delta\phi$) to give a total percentage inaccuracy.
- FS or FSi: Security Factor ("i" for current) represents a factor for the rated current at which accuracy is 10%.[76]
- I_{pn}: Rated Primary Current
- I_{sn}: Rated Secondary Current
- K_r: Remanence Coefficient/Factor—percentage of maximum flux that remains in the core of the CT if driven into saturation.[77] (See Fig. K_r below.) The remanence factor is used to calculate the transient dimensioning factor, which is used to determine if the transformer needs to be over dimensioned to prevent saturation during a protective relay measurement. Meaning, if *K_r is <100% the CT is of the proper "dimension"*.
- L_s: Inductance of Secondary Winding
- L_m: Inductance of the meter attached to the CT.
- Operating Burden: The total resistance of the secondary load, or the maximum load that can be applied to the CT's secondary. It's expressed in ohms (Ω) or volt-amperes (VA).[78]
- RF: The Rating Factor, which is the amount primary current may increase without exceeding the CT temperature rise limit.

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[75] For example, a Class 0.6 CT should not have the turns ratio deviate more and 0.6%. The error is also corrected for the phase angle deviation between the primary and secondary. The phase angle deviation is normally quite small and measure in "minutes". (Degrees, Minutes, Seconds)

[76] The number may be 10 or 20 times the rated current for modern CTs.

[77] This can occur during faults. The residual magnetism must be removed to preclude improper operation of protective relays.

[78] This is expressed in various ways depending upon the manufacturer. For example: 1.5 VA / 1.00 means a burden of 1.5 VA at 1.00 ohms. Sometimes this is written as 1.5 VA / 100 where the 100 is volts (usually at 20 times the rated current). One must divide by 100 to get the resistance value in ohms. The take-away: read the test equipment owner's manual.

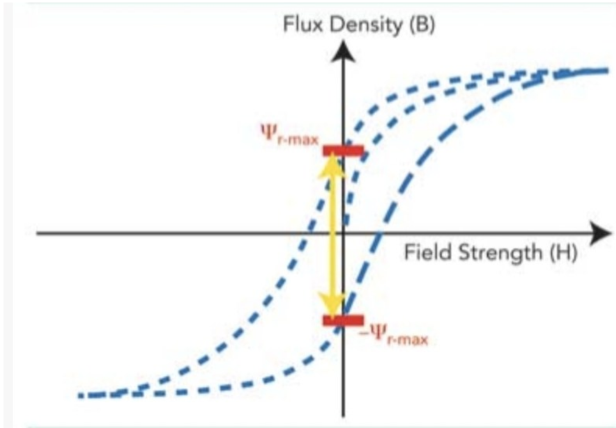

Figure 10: Concept of Remanence Factor K_r
[Source: *https://www.power-grid.com/news/a-revolution-in-current-transformer-testing/*]

7.10.2 Instrument Transformers, Voltage Transformers

Electrical Tests

Verify / Check / Perform / Measure: Bolted connection resistance or torque or thermographic survey / Insulation resistance checks at 1000 V for one minute with test voltages per NETA Table 100.5 / *Polarity Test per IEEE C57.13.1 / *Ratio Verification test per IEEE C57.13 / Excitation test for relaying applications per IEEE C57.13.1[79] / *Voltage Circuit burdens per IEEE C57.13.1 / Insulation resistance with secondary grounded per NETA Table 100.5 / *Dielectric withstand per NETA Table 100.9 / *Power-Factor or Dissipation Factor per manufacturer's data / Grounding Point per IEEE C57.13.3

Test Values—Electrical

Bolted connection resistance does not have a specified limit, per se.[80] What is required is that one should investigate values for similar connections that deviate more than *50% from the lowest value*.

[79] Relaying applications are protective in nature as opposed to metering applications that provide indications only.
[80] 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.

Or, one can verify the torque applied to the bolts using NETA Table 100.12.[81] 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*.

A **Polarity Test** is accomplished to ensure the transformer is properly hooked up. *The polarity marking should match the transformer markings.* Think of the “dot convention”. Current into H1 should flow out of X1 . In terms of polarity, when a positive polarity exists on the primary winding [H1] at the dot (as a load), a positive polarity exists on the dot in the secondary winding [X1] (as a source) What is described is subtractive polarity, which is common in instrument transformers.[82]

A **Ratio Verification** test run to ensure the nameplate turns ratio is correct. *The turns ratio should be ≤±0.1% and ±0.9 mrad (3 minutes) for the phase angle for revenue metering. For other applications, turns ratio should be ≤+1.2% and ±17.5 mrad (1 degree) for the phase angle*

Burden ratings *per instrument transformer ratings.* [See 7.10.1]

Dielectric withstand is applied per NETA Table 100.9 on the primary winding with the secondary ground. The CT shall *no evidence or distress or insulation failure at the completion of the test*.

Power-Factor / Dissipation-Factor testing is also called tan delta (tanΔ or tanδ) or a tangent delta or dielectric dissipation factor testing.[83] 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. [See 7.10.1]

Grounding Point per IEEE C57.13.3 and engineering drawings should be checked. C*ircuits should have only one grounding point*.

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[81] Numerous torque table exists varying with the size, material, and thread used.
[82] See Ref [C] for an indepth discussions.
[83] 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.

7.10.3 Instrument Transformers, Coupling-Capacitor Voltage Transformers

A coupling capacitor voltage transformer (CCVT) is a device that provides scaled-down voltage signals for metering, protection, and control devices in high voltage systems. CCVTs are a common type of instrument transformer in higher voltage transmission systems.

Testing is very similar to other transformers with the addition of measuring the capacitance and ensuring values are per manufacturer's data.

Conclusion/Summary of Part I

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. Also, the testing in the MTS is very similar to the ATS. The difference lies in some tests being unneeded and more being optional for maintenance.

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.

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*, 2021 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 100.12.1 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/in²)	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 9: 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 10: 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 11: 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 12: 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			Rated Control Voltage (60Hz)	Alternating Current Voltage Ranges (1)(2)(3)(4)(8) Closing, Tripping, and Auxiliary Functions
	Indoor Circuit Breakers	Outdoor Circuit Breakers	Opening Functions All Types	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.

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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	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	∝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	∝N		5.050×10^{-27} J/T
permeability of a vacuum	∝0		1.2566×10^{-6} N/A^2 (H/m)
permittivity of a vacuum, electric constant $1/\mu_0 c^2$	ε0		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	$R_{\times}$		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	o	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

