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AMERICAN NATIONAL STANDARD

American National Standard

ANSI C12.1-1995

CODE FOR ELECTRICITY METERING

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION
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ANSI® C12.1-1995

American National Standard
for Electric Meters

CODE FOR ELECTRICITY METERING

Secretariat
Accredited Standards Committee C12
National Electrical Manufacturers Association

Approved June 12, 1995
American National Standards Institute

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Foreword (This Foreword is not part of American National Standard C12.1-1995)

The existing standard C12.1 has been rewritten with the intent to bring it up to date in an industry that is changing dramatically, due in part to technology and economics. The standard has been significantly reorganized to encompass all metering devices excluding instrument transformers, providing a more logical flow. The review team has added tests to help insure new electronic equipment is capable of providing the dependability existing devices have shown.

Areas of the standard dealing with user testing were rewritten to allow more flexibility for individual users while maintaining current effectiveness. Proven reliability of today's equipment as well as the consistency of new metering equipment was used as the basis to redefine how, where, and when testing can be accomplished. The section dealing with standards and standardizing equipment has been revised to be more in line with current procedures while maintaining existing methods if applicable.

In addition, an effort was made to align this standard with international standards and make reference to these standards where possible. The existing standard was broadened to include tests and requirements for all metering, while leaving other standards to provide the details for their specific devices, to avoid duplication. Parts of the existing standard that were viewed as user practices, not standards, were removed or placed into the appendices as examples or for references.

The Secretariat of the Accredited Standards Committee on Electricity Metering, C12, is held by the National Electrical Manufacturers Association (NEMA) and the National Institute of Standards and Technology. At the time this standard was processed and approved, the C12 Committee had the following members:

R. S. Turgel, Chairman
C. F. Merther, Secretary

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AMERICAN NATIONAL STANDARD FOR CODE FOR ELECTRICITY METERING

1 Scope and references

1.1 Scope

This Code establishes acceptable performance criteria for new types of ac watthour meters, demand meters, demand registers, pulse devices, and auxiliary devices. It describes acceptable in-service performance levels for meters and devices used in revenue metering. It also includes information on related subjects, such as recommended measurement standards, installation requirements, test methods, and test schedules. This Code for Electricity Metering is designed as a reference for those concerned with the art of electricity metering, such as utilities, manufacturers, and regulatory bodies.

1.2 References

The following publications shall be used in conjunction with this standard. When they are superseded by an approved revision, the revision shall apply:

ANSI C39.1-1992, *American National Standard Requirements for Electrical Analog Indicating Instruments*

Chapter 13 in the *Handbook for Electricity Metering, 9th Edition, Washington, D.C.: Edison Electric Institute, 1992*

IEEE C57.13-1993, *Standard Requirements for Instrument Transformers*

ANSI/ASQC Z1.9-1993, *Sampling Procedures and Tables for Inspection by Variables for Percent Nonconforming.*

ANSI/ASQC Z1.4-1993, *Sampling Procedures and Tables for Inspection by Attributes*

IEEE Std 4-1994, *IEEE Standard Techniques for High-Voltage Testing*

IEEE Std 100-1992, *IEEE Standard Dictionary of Electrical and Electronics Terms*

ANSI/ISA-S82.01-1988, *Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment, General Requirements.*

NEMA 250-1991, *Enclosures for Electrical Equipment (1000 Volts Maximum)*

ANSI/NFPA 70-1993, *National Electrical Code*

UL 50-1992, *UL Standard for Safety Enclosures for Electrical Equipment, 10th Edition*

ASTM-B117-94, *Standard Practice for Operating Salt-Spray (Fog) Testing Apparatus*

ANSI/IEEE Std 1-1986, *IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation. (Reaffirmed 1992)*

ANSI/IEEE C37.90.1-1989, *Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (Reaffirmed 1991)*

ANSI/IEEE C62.41-1991, *IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits*

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IEC 801 PT 4-1988, *Electromagnetic Compatibility for Industrial - Process Measurement and Control Equipment, Part 4: Electrical Fast Transient/Burst Requirements*

IEC 80-1964, *Fixed Capacitors for Direct Current Using Impregnated Paper/Plastic Film Dielectrics*

IEC 68 PT 2-6 (1982), *Basic Environmental Testing Procedures, Part 2: Tests, Test Fc and Guidance: Vibration (Sinusoidal), Amended 1983,1985*

ANSI/IEEE C63.4-1992, *Methods of Measurement of Radio-Noise Emissions From Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.*

Code of Federal Regulations (Telecommunication) CFR 47, *Part 15—Radio Frequency Devices, Subparts A—General and B—Unintentional Radiators*

ASTM D999-1991, *Standard Methods for Vibration Testing of Shipping Containers*

ASTM D775-1980 (Rev. 1986), *Standard Test Method for Drop Test for Loaded Boxes*

IEC 801 PT 2-1991, *Electromagnetic Compatibility for Industrial - Process Measurement and Control Equipment, Part 2: Electrostatic Discharge Requirements*

National Safe Transit Association, *Pre-Shipment Test Procedures, Test B.1, Vibration*

IEC 68 PT 2-27 (1987), *Basic Environmental Testing Procedures, Part 2: Tests, Test Ea and Guidance: Shock.*

National Safe Transit Association, *Pre-Shipment Test Procedures, Test B.2, Drop*

2 Definitions

The definitions given apply specifically to the subject as treated in this American National Standard. Most of them are grouped under general terms, such as watthour meter, and all are given numbers for identification. For additional definitions, see IEEE Std 100.

2.1 **accuracy:** The extent to which a given measurement agrees with the defined value.

2.2 **Blondel's theorem:** In a system of N conductors, N-1 meter elements, properly connected, will measure the active power or energy taken. The connection must be such that all voltage coils have a common tie to the conductor in which there is no current coil.

2.3 **calibration:** Comparison of the indication of the instrument under test, or registration of the meter under test, with an appropriate standard.

2.4 **coupling-capacitor voltage transformer (CCVT):** A voltage transformer comprised of a capacitor divider and an electromagnetic unit so designed and interconnected that the secondary voltage of the electromagnetic units is substantially proportional to, and in phase with, the primary voltage applied to the capacitor divider for all values of secondary burdens within the rating of the coupling-capacitor voltage transformer.

2.5 **class designation:** See watthour meter-class designation (2.91).

2.6 **creep:** A continuous apparent accumulation of energy in a meter with voltage applied and the load terminals open circuited.

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2.7 customer alert: A switching output used to indicate events or conditions.

2.8 demand: The average power or a related quantity over a specified interval of time. Demand is expressed in kilowatts, kilovolt-amperes, kilovars or other suitable units.

2.9 demand constant (pulse receiver K_d): The value of the measured quantity for each received pulse, expressed in kilowatts per pulse, kilovars per pulse, or other suitable units.

2.10 demand interval: The specified interval of time on which a demand measurement is based. Intervals such as 15, 30, or 60 minutes are commonly specified.

2.11 demand interval deviation: The difference between the measured demand interval and the specified demand interval, expressed as a percentage of the specified demand interval.

2.12 demand interval – rolling (RDI): An interval of time, the beginning which progresses in steps of sub-intervals and where the interval length is equal to an integer multiple of sub-intervals.

2.13 demand-maximum: The highest demand measured over a selected period of time.

2.14 demand meter: A metering device that indicates or records demand.

2.15 demand meter – block interval (integrating): A meter that integrates power or a related quantity over a fixed-time interval, and indicates or records the average.

2.16 demand meter – lagged: A demand meter with an approximately exponential response.

2.17 demand meter (lagged) – time characteristic: The nominal time required for 90% of the final indication, with constant load suddenly applied.

NOTE—The time characteristic of demand meters (lagged) describes the exponential response of the meter to the applied load. The response is continuous and independent of the selected discrete time intervals.

2.18 demand register: A device for use with an electricity meter, that indicates and/or records demand.

2.19 demand register – block interval: A demand register that indicates and/or records the maximum demand obtained by arithmetically averaging the meter registration over a regularly repeated time interval.

2.20 demand register – continuous cumulative: The sum of all previous billing period maximum demands and the highest demand to date for the present billing period.

2.21 demand register – cumulative: A register that indicates the sum of the previous maximum demand readings prior to reset.

NOTE—When reset, the present reading is added to the previously accumulated readings. The maximum demand for the present reading period is the difference between the present and previous readings.

2.22 demand register – indicating single-pointer form: An indicating demand register from which the demand is obtained by reading the position of a pointer relative to the markings on a scale.

NOTE—When reset, the single pointer returns to zero.

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2.23 demand register – dual range (single pointer form): An indicating demand register having an arrangement for changing the full-scale capacity from one value to another, usually by reversing the scale plate.

NOTE—For example, Scale Class 1/2; Scale Class 2/6. An interlock assures proper scale and scale-class relation.

2.24 demand register – full-scale value: The maximum scale capacity of the register. If a multiplier exists, the full-scale value will be the product of the maximum scale marking and the multiplying constant.

2.25 demand register – scale class: Denotes, with respect to single-pointer form, dual-range single-pointer form, or cumulative-form demand registers, the relationship between the full-scale value of the register and the test kVA rating of the meter with which the register is used.

2.26 distortion factor (harmonic factor): The ratio of the root-mean-square of the harmonic content (excluding the fundamental) to the root-mean-square value of the nonsinusoidal quantity, expressed as a percentage.

2.27 display: A means of visually identifying and presenting measured or calculated quantities and other information.

2.28 electricity meter: A device that measures and registers the integral of an electrical quantity with respect to time.

2.29 electronic register – alternate mode: A display sequence usually containing constants and diagnostic tests.

2.30 electronic register – load control: A switching control for external load management.

2.31 electronic register – test mode: A separately activated sequence that saves billing data while displaying test data. It reactivates the billing data to the register when the normal mode is resumed.

2.32 element: An element is the combination of signal sensing units, resulting in an output proportional to the measured quantities.

NOTES

1 For example, if one input signal is voltage and the other input signal is current, then the output is power (watts).

2 The term element is also referred to as stator.

3 Electricity meters normally include 1, 2, 2-1/2, or 3 elements.

4 The 2-1/2 element meter refers to 2 stator 4-wire wye meter as described in section A.2.7.2.

2.33 electronic storage register: An electronic circuit where data is stored for display and/or retrieval.

2.34 end-of-interval indicator (EOI): An indicator for the end of the demand interval for non-rolling(block)-interval demand, or the end of the sub-interval for rolling-interval demand.

2.35 energy: The integral of active power with respect to time.

2.36 energy flow: Energy flow from line to load terminals shall be considered as energy delivered to the load terminals of the meter. Energy in the opposite direction, i.e., from load to line terminals, shall be considered as received. The line and load terminals are as specified in the *Handbook for Electricity Metering*, (Chapter 13).

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2.37 firmware: A control program stored in read-only memory (ROM) and considered to be an integral part of an electronic device that cannot be changed in its operating environment.

2.38 interface: The means for transmitting information between the meter or register and peripheral equipment.

2.39 laboratory - meter: A laboratory responsible for maintaining reference standards and assigning values to the working standards used for the testing of electricity meters and auxiliary devices.

2.40 laboratory – independent standards: A standards laboratory maintained by, and responsible to, a company or authority that is not under the same administrative control as the laboratories or companies submitting instruments for calibration.

2.41 metering devices: Equipment used in energy revenue metering; such as watthour meters, demand meters, demand and TOU registers and various forms of pulse initiating, receiving and totalizing devices.

2.42 normal mode: The operating mode of the register usually displaying the billing data.

2.43 phase-shifting transformer: An assembly of one or more transformers intended to be connected to a polyphase circuit so as to provide voltages in the proper phase relations for energizing varmeters, varhour meters, or other measurement equipment. This type of transformer is sometimes referred to as a phasing transformer.

2.44 phasor: A complex number, associated with sinusoidally varying electrical quantities, such that the absolute value (modulus) of the complex number corresponds to either the peak amplitude or rms value of the quantity, and the phase (argument) to the phase angle at zero time. By extension, the term "phasor" can also be applied to impedance and related complex quantities that are not time-dependent.

2.45 power – active: The time average of the instantaneous power over one period of the wave.

NOTE—For sinusoidal quantities in a two-wire circuit, it is the product of the voltage, the current, and the cosine of the phase angle between them. For nonsinusoidal quantities, it is the sum of all the harmonic components, each determined as above. In a polyphase circuit, it is the sum of the active powers of the individual phases.

2.46 power – apparent: The product of rms current and rms voltage for any wave form in a two-wire circuit. For sinusoidal quantities, apparent power is equal to the square root of the sum of the squares of the active and reactive powers in both two-wire and polyphase circuits.

2.47 power – reactive: For sinusoidal quantities in a two-wire circuit, reactive power is the product of the voltage, the current, and the sine of the phase angle between them, using the current as reference.

2.48 power factor: The ratio of active power to the apparent power.

2.49 precision: The repeatability of measurement data, customarily expressed in terms of standard deviation.

2.50 pulse: A change of state of an electrical signal that conveys an event or information.

NOTE—A sudden change of voltage or current produced, for example, by the closing or opening of a contact.

2.51 pulse amplifier or relay: A device used to change the amplitude or waveform of a pulse for retransmission to another pulse device.

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2.52 pulse capacity: The number of pulses per demand interval that a pulse receiver can accept and register without loss.

2.53 pulse device (for electricity metering): The functional unit for initiating, transmitting, retransmitting, or receiving electric pulses, representing finite quantities, such as energy, normally transmitted from some form of electricity meter to a receiver unit.

2.54 pulse initiator: Any device, mechanical or electrical, used with a meter to initiate pulses, the number of which are proportional to the quantity being measured. It may include an external amplifier or auxiliary relay or both.

2.55 pulse-initiator output constant (K_e or KWHC): The value of the measured quantity for each outgoing pulse of a pulse initiator, expressed in kilowatt hours per pulse, kilovarhours per pulse, or other suitable units.

2.56 pulse-initiator output ratio (R/P or M_p): The number of revolutions of the meter rotor per output pulse of the pulse initiator.

2.57 pulse rate – maximum: The number of pulses per second at which a pulse device is nominally rated.

2.58 pulse receiver: The unit that receives and registers the pulses.

2.59 pulse recorder: A device that receives and records pulses over successive demand intervals.

2.60 pulse-recorder channel: One individual input, output, and intervening circuitry required to record pulse data.

2.61 Q-hour meter: An electricity meter that measures the quantity obtained by effectively lagging the applied voltage to a watthour meter by 60 degrees. This quantity is used with watthours in calculating quadergy (varhours).

2.62 quadergy: The integral of reactive power with respect to time.

2.63 shop – meter: A place where meters are inspected, repaired, tested, and adjusted.

2.64 simulated meter: A meter cover, base, and jumper bars constructed to represent the thermal characteristics of a specific class of watthour meter to be used in the testing of a meter socket and in determining the empirical temperature rise of the test meter for temperature rise at continuous ampere rating.

2.65 standards – national: Standard electrical quantities that are maintained by the National Institute of Standards and Technology (NIST).

2.66 standard watthour meter – basic current range: The current range of a multirange standard watthour meter designated by the manufacturer for its calibration (normally the 5 A range).

2.67 standard watthour meter – basic voltage range: The voltage range of a multirange standard watthour meter designated by the manufacturer for its calibration (normally the 120 V range).

2.68 standard watthour meter – rated current: The nameplate current for each range of a standard watthour meter.

NOTE—The main adjustment of the meter is ordinarily made with rated current on the basic current range.

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2.69 standard watthour meter – rated voltage: The nameplate voltage for a meter or for each range of a standard watthour meter.

NOTE—The main adjustment of the standard meter is ordinarily made with rated voltage on the basic voltage range.

2.70 test – acceptance: A test to demonstrate the degree of compliance of a device with the purchaser's requirements.

2.71 test accuracy – in-service: A test made during the period that the meter is in service. It may be made on the customer's premises with out removing the meter from its mounting, or by removing the meter for test either on the premises or in a laboratory or meter shop.

2.72 test – accuracy – referee: A test made by or in the presence of one or more representatives of a regulatory body or other impartial agency.

2.73 test – accuracy – request: A test made at the request of a customer.

2.74 test amperes (TA): The load current specified by the manufacturer for the main calibration adjustment.

2.75 test – approval: A test of one or more meters or other items under various controlled conditions to ascertain the compliance of the type of which they are a sample with the appropriate standard.

2.76 timebase primary: A timing system established from the frequency of the power line or other reference source.

2.77 timebase secondary: A timing system established from an alternate source when the primary source is not available.

2.78 time-of-use register: That portion of a watthour meter that, for selected periods of time, accumulates and may display amounts of electric energy, demand, or other quantities measured or calculated.

2.79 time-of-use register – period: A selected period of time during which a specified rate will apply to the energy usage or demand, typically designated as A, B, C, and D.

2.80 time-of-use register – switch point: The transition from one time-of-use period to another.

2.81 totalizing: A device used to receive and sum pulses from two or more sources for proportional transmission to another totalizing relay or to a receiver.

2.82 transducer: A device to receive energy from one system and supply energy (of either the same or of a different kind) to another system, in such a manner that the desired characteristics of the energy input appear at the output.

2.83 transformer-loss compensation: A method that adds to or subtracts from the meter registration to compensate for predetermined iron and/or copper losses of transformers and transmission lines.

2.84 varhour meter: An electricity meter that measures and registers the integral, with respect to time, of the reactive power of the circuit in which it is connected. The unit in which this integral is measured is usually the kilovarhour.

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2.85 varhour test constant: The expression of the relation between the reactive energy applied to the meter and corresponding value of the test output.

NOTE—For electromechanical meters, one test output equals one disk revolution.

2.86 voltage-withstand tests: Tests made to determine the ability of insulating materials and spacings to withstand specified overvoltages for a specified time without flashover or puncture.

2.87 watthour meter: An electricity meter that measures and registers the integral, with respect to time, of the active power of the circuit in which it is connected. The unit in which this integral is measured is usually the kilowatthour.

2.88 watthour meter – bottom-connected: A meter having a bottom-connected terminal assembly.

2.89 watthour meter – calibration: Adjustment to bring the percentage registration of the meter to within specified limits.

2.90 watthour meter – basic reference standards: Those standards with which the values of the watthour is maintained in the laboratory.

2.91 watthour meter – class designation: The maximum specified continuous load in amperes.

2.92 watthour meter – detachable (socket mounted): A meter having bayonet-type (blade) terminals arranged on the back side of the meter for insertion into matching jaws of a meter socket (or detachable meter-mounting device).

2.93 watthour meter – field standard: A portable meter that is used as a standard meter to calibrate the utility's billing meters and is traceable to NIST. This meter is also known as a portable standard or working standard.

2.94 watthour meter – form designation: An alphanumeric designation denoting the circuit arrangement for which the meter is applicable and its specific terminal arrangement. The same designation is applicable to equivalent meters of all manufacturers.

2.95 watthour meter – full load: Full load is a test condition using test amps, rated voltage and unity power factor.

2.96 watthour meter – gear ratio (R_g): The number of revolutions of the meter's rotor for one revolution of the first dial pointer.

2.97 watthour meter – induction: A motor-type meter in which currents induced in the rotor interact with magnetic fields to produce the driving torque.

2.98 watthour meter – light load: Light load is a test condition using rated voltage, 10% of test amps and unity power factor.

2.99 watthour meter – load range: The maximum range in amperes over which the meter is designed to operate continuously with a specified accuracy.

2.100 watthour meter – multistator: A watthour meter containing more than one stator.

2.101 watthour meter – percentage error: The difference between percentage registration and 100%.

NOTE—A meter whose percentage registration is 95% is said to be 5% slow, or its error is (-) 5%.

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2.102 watthour meter – percentage registration: The ratio of the actual registration of the meter to the true value of the quantity measured in a given time, expressed as a percentage.

2.103 watthour meter – reference performance: test, used as a basis for comparison with performances under other conditions of the test.

2.104 watthour meter – register: A device for use with an electricity meter that indicates or records units of electric energy or other quantity measured.

2.105 watthour meter – register constant (K_r): The multiplier used to convert the register reading to kilowatthours (or other suitable units).

NOTE—This constant takes into consideration the watthour constant, gear ratio, and instrument transformer ratios.

2.106 watthour meter – register ratio (R_r): The number of revolutions of the first gear of the register for one revolution of the first dial pointer.

2.107 watthour meter – registration: The amount of electric energy (or other quantity being measured) that was recorded by the meter.

NOTE—It is equal to the product of the register reading and the register constant. The registration during a given period is equal to the product of the register constant and the difference between the register readings at the beginning and the end of the period.

2.108 watthour meter – rotor: That part of an induction meter that is directly driven by electromagnetic action.

2.109 watthour meter – self contained: A meter in which the terminals are arranged for connection to the circuit being measured without using external instrument transformers.

2.110 watthour meter – single stator: A meter containing only one stator.

2.111 watthour meter – stator: An assembly of an induction watthour meter, which consists of a voltage circuit, one or more current circuits, so arranged that their joint effect, when energized, is to exert a driving torque on the rotor.

2.112 watthour meter – transport standard: Standard meters of the same or better level of uncertainty as the basic reference standard meters that are used for transferring the value of the watthour between standards.

2.113 watthour meter – test constant (K_t): The expression of the relationship between the energy applied to the meter and the corresponding occurrence of one test output indication expressed as watthours per test output indication.

2.114 watthour meter constant (K_h): The expression of the relationship between the energy applied to the meter and one disk revolution or equivalent, expressed as watthours per revolution or watthours per equivalent revolution.

3 Standards and standardizing equipment

3.1 Scope

To outline an appropriate chain of intermediate steps between the national standards and watthour meters.

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3.2 Final authority

The duties of the National Institute of Standards and Technology (NIST) (formerly named the National Bureau of Standards), U.S. Department of Commerce, include the following functions assigned by Public Law 619 of the 81st Congress (63 Stat 371, 5USC 271-286): "The custody, maintenance, and development of the national standards of measurements, and the provision of means and methods for making measurements consistent with these standards." In addition, Public Law 617 (Section 12) of the 81st Congress (Title 15, USCA Sec 223, 223) reads as follows: "It shall be the duty of the National Bureau of Standards to establish the values of the primary electric units in absolute measure, and the legal values for these units shall be those represented by, or derived from, national reference standards maintained by the National Bureau of Standards."

3.3 Traceability paths to NIST

It is the responsibility of the utility to establish and maintain the traceability of the watthour standard to the national standard either directly or indirectly. This traceability plan should document the relationship between the billing meter and the national standard. Described below are some common methods for establishing this traceability.

3.3.1 Direct transfer

A watthour transport standard is sent directly to NIST for comparison with the national standard.

3.3.1.1 NIST MAP program

NIST provides a service using their own transport standard in a measurement assurance program (MAP) to aid in the achievement of measurement quality control and to link the measurements in the laboratory to national standards.

3.3.1.2 Independent laboratory

An independent standards laboratory able to document traceability to NIST may be used by a utility that does not carry out the entire chain of sequential measurements between the national standards and the local energy standard. An independent laboratory may include another utility with a qualified laboratory.

3.3.1.3 Meter laboratory transport standard comparison to NIST

The utility selects a transport standard which is sent to NIST or an independent laboratory for intercomparison to the national standard. When the transport standard is returned to the utility, it is intercompared with the basic reference standards to provide traceability to NIST.

3.3.1.4 Indirect transfer

The method of establishing the watthour from the volt and ohm is rarely practiced today because it is more expensive and is susceptible to greater uncertainty in the typical laboratory than any of the other transfer methods described in Section 3.3 (Refer to Appendix B for a description of the indirect transfer method.)

3.4 Meter laboratory

The meter laboratory is concerned with two functions:

a) Maintaining standards whose calibration values are traceable to national standards.

b) Assigning calibration values (correction factors) to working standards.

It may be equipped and staffed to make calibration tests at some or all of the sequential steps intermediate between the national standards of resistance, EMF, and time interval, and a local reference standard of energy measurement (such as a group of watthour meters).

3.4.1 Laboratory conditions

In a meter laboratory it is essential that ambient conditions, such as temperature and humidity, be maintained at values and within limits appropriate to the measurements made in the laboratory. Other

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ambient factors that could interfere with proper measurement, such as atmospheric contaminations, mechanical disturbances, electrical and magnetic interference, and noise, be held to such levels that normal measurement techniques and results are not adversely affected.

3.4.2 Reference temperature and humidity

The ambient temperature in the meter laboratory shall be 23°C, with tolerances that depend upon the effects of temperature on the standards used and the apparatus under test. This temperature should be held constant not only during a test or calibration procedure, but also for a preceding period sufficient to ensure effective temperature equilibrium in the test equipment and in the device being tested. Relative humidity shall not exceed 80% noncondensing.

3.4.3 Laboratory power sources

Alternating current supplies used in the laboratory for calibration of instruments or meters, or for the measurement of voltage, current, or power, should be closely regulated, since fluctuations in the value being held can affect the accuracy of a calibration or measurement.

Alternating current supplies should be substantially free from waveform distortion, and the phase relation of combined current and voltage supplies should be capable of close regulation.

3.5 Meter shop

The meter shop is concerned with the routine testing, repair, and calibration of electricity meters and the auxiliary devices and equipment essential to the metering of electric energy and power.

3.6 Laboratory standards

Laboratory standards are those standard meters that are used to verify the accuracy of working standards. The standards in the laboratory are the basic reference standards and the transport standards.

3.6.1 Basic reference standards

Those standards with which the accuracy of the watthour is maintained in the laboratory. Ideally, the basic reference standards of a laboratory should be maintained in groups of three or more separate individual units that can be intercompared readily. Three standards are the minimum for which a change in one can be both detected and located by intercomparison.

3.6.2 Transport standards

Transport standards are standards of the same nominal accuracy class as the basic reference standards of a laboratory. Such standards are regularly intercompared with the basic reference standards to maintain a history of their behavior. The main purpose of the transport standard is to establish traceability from outside the utility and transfer traceability within the utility.

3.7 Periodic verification of reference standards

Watthour meters used as reference standards to maintain the unit of energy should be intercompared at appropriate intervals.

3.8 Portable/field/working standard watthour meters

Portable/field/working standards are commonly used interchangeably. These standard watthour meters are in constant use and accuracy should be verified at least annually.

3.9 Performance records

Historical records should be kept of the performance of each standard. Where this record shows excessive variation between tests, the standard should then be subjected to special investigation to determine the cause of the variation. If the cause cannot be determined and corrected, use of the standard should be discontinued.

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3.10 Performance requirements for standard watthour meters

3.10.1 General test conditions

The standard meter under test shall be in good operating condition and have established adequate records for performance. The stability can be established through manufacturer's specifications or can be established through historical test records.

3.10.1.1 Test voltage

The test voltage shall be held constant to within ±1.0%.

3.10.1.2 Test current

The test current shall be held constant to within ±1.0%.

3.10.1.3 Test phase angle

The test phase angle shall be held constant to within ±2°.

3.10.1.4 Test frequency

The test frequency shall be held constant to within ±0.2%.

3.10.1.5 Waveform distortion

The total harmonic distortion (THD) of the applied voltage and current shall not exceed 2.0%.

3.10.1.6 Ambient temperature

The ambient temperature shall be 23°C with tolerances that depend upon the effects of temperature on the standards used and the apparatus under test.

3.10.1.7 External magnetic field

Strong magnetic fields may affect performance of standard meters. Care should be taken to avoid placing the meters in proximity to energized transformers and loops of current test leads.

3.10.2 Accuracy tests for portable and reference standards

3.10.2.1 Insulation

The insulation between current-carrying parts of separate circuits and between current-carrying parts and other metallic parts shall be capable of withstanding the application of a sinusoidal voltage of 2.3 kV rms, 60 Hz for 1 minute with the leakage current not to exceed 0.005 A per circuit.

3.10.2.2 Accuracy specification for the effect of variation of voltage and current

3.10.2.2.1 Reference conditions

Voltage	120V
Current	5.0 A
Frequency	60 Hz
Power Factor	Unity and 0.5 Lagging
Temperature	23°C

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3.10.2.2.2 Performance requirements

At these reference points, the error, after the application of the calibration values of the portable and reference standards, shall not exceed:

	Percent Error	
	@ 1.00 PF	@ 0.5 PF
Portable Standard	0.1%	0.2%
Reference Standard	0.05%	0.1%

3.10.2.2.3 Variation from reference condition

The error of the standard shall not deviate more than an additional 0.05% from the reference percent error over the design range of voltage and current.

3.10.2.2.4 Effect of variation of ambient temperature

The maximum temperature influence shall not exceed 50 ppm/°C.

4 Acceptable performance of new types of electricity metering devices and associated equipment

4.1 General

4.1.1 Acceptable metering devices

New types of metering devices, in order to be acceptable, shall conform to requirements specified in 4.7 which are intended to determine their reliability and acceptable accuracy insofar as these qualities can be demonstrated by laboratory tests.

4.1.2 Adequacy of testing laboratory

Tests for determining the acceptability of the types of metering devices under these specifications shall be made in a laboratory having adequate facilities, using instruments of an order of accuracy at least equal to that of the shop instruments and standards described in Section 3. These instruments should be checked against the laboratory secondary standards before and after the tests, or more often as required. The tests shall be conducted only by personnel who have thorough practical and theoretical knowledge of metering devices and adequate training in the making of precision measurements.

4.2 Types of metering devices

4.2.1 Basic type

Metering devices are considered to be of the same basic type if they are produced by the same manufacturer, bear a related type designation, are of the same general design, and have the same relationship of parts.

4.2.2 Variations within the basic type

Metering devices of the same basic type may vary according to the service for which they are designed, namely: Voltage rating; Class and test-ampere rating; Frequency; Form designation; Method of mounting; Demand interval; Scale capacity; Number of channels; Pulse devices; 12, 24, or 72 hour clock; Battery carry over; input/output configurations; terminal arrangements; scaling factors.

4.2.3 Type designation

Metering devices of the same basic type, but differing in the number of elements, shall be assigned type designations that will identify both the basic type and number of elements. In addition, two-elements three-wire meters, two-elements four-wire delta meters, and two-elements four-wire-wye meters shall be assigned different type designations.

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4.2.4 Acceptance of basic types in whole or part
A basic type of metering device may be accepted as a whole or as a restricted variation.

4.2.5 Minor variations
Minor variations in the physical construction, which do not affect the operation of the metering device are permitted without a basic type change.

4.2.6 Special types
In the case of a type of metering device that comes within the scope of these specifications, but is of such design that some of the tests specified are inapplicable or can not be made under the specified conditions, limited approval may be granted subject to appropriate restrictions.

4.3 Specifications for design and construction

4.3.1 Sealing
Metering devices shall be provided with facilities for sealing to detect unauthorized entry.

4.3.2 Enclosures
The enclosure, if intended for indoor application, shall meet the performance specifications described in NEMA Standards Publication 250, for Type 2 enclosures. If intended for outdoor application, enclosures shall meet the performance specifications for Type 3R enclosures described in the same publication.

4.3.3 Terminals and markings
The terminals of the metering device shall be so arranged that the possibility of short circuits is minimized when the cover is removed or replaced, connections are made, or the metering device is adjusted.

All leads and terminals shall be identified either on the device or in manufacturer's literature. For pulse initiators only one KYZ relay should have leads with the following color code:

— K = red

— Y = yellow

— Z = black

4.3.4 Construction and workmanship
Metering devices shall be substantially constructed of good material in a workmanlike manner, with the objective of attaining stability of performance and sustained accuracy over long periods of time and over wide ranges of operating conditions with a minimum of maintenance.

4.3.5 Provision for adjustment
Connections and parts requiring adjustment in service shall be easily accessible after the cover is removed.

4.4 Selection of metering devices for approval tests

4.4.1 Samples to be representative of the basic type
The metering devices to be tested shall be representative of the basic type and shall represent the average commercial product of the manufacturer.

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4.4.2 Number to be tested

A minimum of three metering devices shall be subjected to each test. When the devices representing a given basic type include:

a) Different current ratings—there shall be one device of each of the representative current ratings.
b) Different voltage ratings—there shall be one device of each of the representative voltage ratings.
c) Different number of elements—there shall be one device of each representative number of elements.
d) Four-wire-wye and four-wire delta metering devices of the two-element type—there shall be one device for each configuration.

4.5 Conditions of test

4.5.1 Tests to be applied

The tests specified in 4.7 are to be conducted on the number of devices specified in 4.4.2. Each individual device is not required to be subjected to all tests. Devices for special services or modifications to a type that have already been subjected to these tests, may be exempted from certain tests. Replacement devices can be used for those devices that are found to fail some tests, be defective, or be damaged during test.

4.5.2 Configuration

Metering devices shall be complete assemblies.

4.5.3 Metering devices for special services

Devices designed for specific types of service may be tested on the type of circuit for which the devices are designed, or by using single-phase circuits provided that the devices meet the requirements of the test for independence of elements. In such case, the testing laboratory may modify the procedures outlined herein to meet the requirements for single-phase tests on such types of devices. Examples are as follows:

a) Volt-square-hour devices shall be tested at 80%, 100%, and 120% of nameplate voltage.

b) Devices used to measure quantities, such as varhours or Q-hours, may be tested in accordance with the test specifications for watthour metering devices, insofar as the tests apply.

4.5.4 Metering devices of non-standard classes

When devices of a class other than 10, 20, 100, 200, and 320 are tested for acceptance, the currents for all tests under the sections on performance requirements shall be those recommended by the manufacturer.

4.5.5 Metering devices with wide voltage range

When devices with voltage ratings encompassing more than one of the rated voltages of 120, 240, 277, and 480 are tested for acceptance, each test shall be performed at the lowest rated voltage and at the highest rated voltage unless otherwise specified.

4.6 Rules governing the acceptance of types

4.6.1 Replacements

Replacements or repairs may be made if physical defects of a minor nature become apparent during the tests. Any device that has failed due to manufacturing defect shall be replaced and the test repeated. If, during the test of a metering device, significant defects in design or manufacture become apparent, the test shall be terminated.

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4.6.2 Tolerances

Due to possible errors in observations and in the standards employed, a tolerance should be applied to the specified limits of percent deviation for any test condition involving a determination of the accuracy of the device. A device should be considered to be within the allowable limits if the measured deviation does not exceed the specified maximum deviation from reference performance by 0.1% or by one tenth of the maximum deviation, whichever is greater.

4.7 Performance requirements

4.7.1 Test conditions

The metering device shall be mounted on a support that is free from vibration. All alternating current tests shall be conducted on a circuit supplied by a sine-wave source with a distortion factor not greater than 3%. Where the metering device has more than one voltage and current circuit, it shall be tested with the voltage circuits effectively in parallel and the appropriate current circuit(s) energized effectively in series, unless otherwise specified.

All tests shall be made at 23°C ±5°C, rated voltage ±3%, rated frequency ±1 Hz, test amperes ±3%, and unity power factor ±2°, unless otherwise indicated in specific tests. The metering device shall be stabilized at ambient temperature before performance tests are made.

4.7.2 Accuracy Tests—Internal Influences

4.7.2.1 Test No. 1: No Load

The metering device with the voltage circuit(s) energized and current circuit(s) open shall not make one complete revolution of the rotor or more than one equivalent revolution in watthours within 10 minutes and no additional complete revolutions of the rotor or test output indications in the next 20 minutes.

4.7.2.2 Test No. 2: Starting Load

The metering device shall operate continuously with a load current as specified in table 1. The lowest rated voltage value should be used for wide voltage ranging metering devices.

Table 1 – Starting load test

Current Class	Current in Amperes
10	0.025
20	0.025
100	0.15
200	0.30
320	0.50

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4.7.2.3 Test No. 3: Load Performance

The performance of the metering device shall not deviate from the reference registration by an amount exceeding the maximum deviation specified in table 2, except that the tests for conditions (9) through (11) shall be omitted for two-element four-wire wye metering devices.

TABLE 2 – Load performance test

	Current Class					Maximum Deviation in Percent from Reference Performance
	10	20	100	200	320	
Condition	Current in Amperes					
(1)	0.15	0.15	1	2	3	±2.0
(2)	0.25	0.25	1.5	3	5	±1.0
(3)	0.5	0.5	3	6	10	±1.0
(4)	1.5	1.5	10	20	30	±1.0
(5)	2.5	2.5	15	30	50	Reference
(6)	–	5	30	60	75	±1.0
(7)	5	10	50	100	100	±1.5
(8)	7.5	15	75	150	150	±2.0
(9)	–	18	90	180	250	±2.0
(10)	10	–	100	200	300	±2.0
(11)	–	20	–	–	320	±2.5

4.7.2.4 Test No. 4: Effect of variation of power factor

Each element of a multi-element metering device shall be tested as a single-element metering device, except that all voltage circuits shall be effectively in parallel.

4.7.2.4.1 Single-element meters

The effect of variation of power factor upon performance of the metering device shall not exceed the maximum deviation specified in table 3.

Table 3 – Effect of variation of power factor for single-element meters

	Current Class					Maximum Deviation in Percent from Reference Performance
	10	100	200	320	Power Factor	
Condition	Current in Amperes					
Reference performance for Condition (1)	0.25	1.5	3	5	1.0	Reference
Condition (1)	0.5	3	6	10	0.5 lag	±2.0
Reference performance for Condition (2)	5	50	100	150	1.0	Reference
Condition (2)	5	50	100	150	0.5 lag	±2.0
Reference performance for Condition (3)	10	100	200	320	1.0	Reference
Condition (3)	10	100	200	320	0.5 lag	±2.0

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4.7.2.4.2 Two-element network meters, two-element three-phase three-wire meters, two-element three-phase four-wire delta meters, and two-element two-phase five-wire meters
The effect of variation of power factor upon the performance of the metering device shall not exceed the maximum deviation specified in table 4.

Table 4 – Effect of power factor for two-element meters: network, three-phase three-wire, three phase four-wire delta, and two-phase five-wire

Condition	Current Class 10	20	100	200	320	Power Factor	Maximum Deviation in Percent from Reference Performance
	Current in Amperes						
Reference performance for Condition (1) and (2)	0.5	0.5	3	6	10	1.0	Reference
Condition (1)	0.5	0.5	3	6	10	0.866 lead	±2.0
Condition (2)	1.0	1.0	6	12	20	0.5 lag	±2.0
Reference performance for Condition (3)	2.5	2.5	15	30	50	1.0	Reference
Condition (3)	2.5	2.5	15	30	50	0.866 lead	±1.0
Reference performance for Conditions (4) and (5)	5	10	50	100	150	1.0	Reference
Condition (4)	5	10	50	100	150	0.866 lead	±1.0
Condition (5)	5	10	50	100	150	0.5 lag	±1.5
Reference performance for Conditions (6) and (7)	10	20	100	200	320	1.0	Reference
Condition (6)	10	20	100	200	320	0.866 lead	±1.5
Condition (7)	10	20	100	200	320	0.5 lag	±2.0

4.7.2.4.3 Two-element three-phase four-wire wye meters
The effect of variation of power factor upon the performance of the metering device shall not exceed the maximum deviation specified in table 5. Load current shall not be applied to the current circuit that is common to both elements.

Table 5 – Effect of variation of power factor for two-element three-phase four-wire wye meters

Condition	Current Class 10	20	100	200	Power Factor	Maximum Deviation in Percent from Reference Performance
	Current in Amperes					
Reference performance for Conditions (1) & (2)	1	1	6	12	1.0	Reference
Condition (1)	1	1	6	12	0.866 lead	±2.0
Condition (2)	2	2	12	24	0.5 lag	±2.0
Reference performance for Condition (3)	5	10	30	60	1.0	Reference
Condition (3)	5	10	30	60	0.866 lead	±1.0
Reference performance for Conditions (4) & (5)	10	20	100	200	1.0	Reference
Condition (4)	10	20	100	200	0.866 lead	±1.0
Condition (5)	10	20	100	200	0.5 lag	±1.5

4.7.2.4.4 Three-element three-phase four-wire wye meters
The effect of variation of power factor upon the performance of the metering device shall not exceed the maximum deviation specified in table 6.

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Table 6 – Effect of variation of power factor for three-element three-phase four-wire wye meters

Condition	Current Class 10	20	100	200	320	Power Factor	Maximum Deviation in Percent from Reference Performance
	Current in Amperes						
Reference performance for Condition (1)	0.5	0.5	3	6	10	1.0	Reference
Condition (1)	1.0	1.0	6	12	20	0.5 lag	±2.0
Reference performance for Condition (2)	5	10	50	100	150	1.0	Reference
Condition (2)	5	10	50	100	150	0.5 lag	±1.5
Reference performance for Condition (3)	10	20	100	200	320	1.0	Reference
Condition (3)	10	20	100	200	320	0.5 lag	±2.0

4.7.2.5 Test No. 5: Effect of variation of voltage

The effect of variation of voltage upon the performance of the metering device shall not exceed the maximum deviation specified in table 7.

Table 7 – Effect of variation of voltage

Condition	Current Class 10	20	100	200	320	Maximum Deviation in Percent from Reference Performance
	Curent in Amperes					
Reference performance 100% of calibration voltage for Condition (1) and (2)	0.25	0.25	1.5	3	5	Reference
Condition (1) 90% of calibration voltage	0.25	0.25	1.5	3	5	±1.0
Condition (2) 110% of calibration voltage	0.25	0.25	1.5	3	5	±1.0
Reference performance 100% of calibration voltage for Conditions (3) and (4)	2.5	2.5	15	30	50	Reference
Condition (3) 90% of calibration voltage	2.5	2.5	15	30	50	±1.0
Condition (4) 110% of calibration voltage	2.5	2.5	15	30	50	±1.0

4.7.2.6 Test No. 6: Effect of variation of frequency

The effect of variation of frequency upon the registration of a metering device shall not exceed the maximum deviation specified in table 8.

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Table 8 – Effects of variation of frequency

Condition	Current Class 10	20	100	200	320	Percent Rated Frequency	Maximum Deviation in Percent from Reference Performance
	Current in Amperes						
Reference performance for Conditions (1) & (2)	0.25	0.25	1.5	3	5	100	Reference
Condition (1)	0.25	0.25	1.5	3	5	98	±1.0
Condition (2)	0.25	0.25	1.5	3	5	102	±1.0
Reference performance for Conditions (3) & (4)	2.5	2.5	15	30	50	100	Reference
Condition (3)	2.5	2.5	15	30	50	98	±1.0
Condition (4)	2.5	2.5	15	30	50	102	±1.0

4.7.2.7 Test No. 7: Equality of current circuits

4.7.2.7.1 Single-element meters

The effect of variation of power factor upon performance of the metering device shall not exceed the maximum deviation specified in table 9.

Table 9 – Equality of current circuits for single-phase meters

Condition	Connections of Current Circuits	Current Class 10	20	100	200	320	Maximum Deviation in Percent from Reference Performance
		Current in Amperes					
Reference performance for Conditions (1) & (2)	Both Circuits	0.2	0.25	1.5	3	5	Reference
Condition (1)	Circuit A only	5	0.5	3	6	10	±1.0
Condition (2)	Circuit B only	0.5	0.5	3	6	10	±1.0
Reference performance for Conditions (3) & (4)	Both Circuits	2.5	2.5	15	30	50	Reference
Condition (3)	Circuit A only	5	5	30	60	100	±1.0
Condition (4)	Circuit B only	5	5	30	60	100	±1.0

4.7.2.7.2 Multi-element metering device

— In a multi-element, polyphase metering device, the change in performance produced by using only one current circuit of the three-wire element, as compared with the performance when both current circuits of the three-wire element are used, shall not exceed the maximum deviation specified in table 10. These tests shall be made on each element separately with no current flowing in the current circuits of the remaining element(s) but with the voltage circuits of all elements energized effectively in parallel.

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Table 10 – Equality of current circuits for multi-element meters having one or more three-wire elements

Condition	Connections of Current Circuits	Current Class 10	20	100	200	320 (Current in Amperes)	Maximum Deviation in Percent from Reference Performance
Reference performance for Conditions (1) & (2)	Both Circuits	0.5	0.5	3	6	12	Reference
Condition (1)	Circuit A only	1	1	6	12	20	±1.0
Condition (2)	Circuit B only	1	1	6	12	20	±1.0
Reference performance for Conditions (3) & (4)	Both Circuits	5	5	30	60	100	Reference
Condition (3)	Circuit A only	10	10	60	120	200	±1.0
Condition (4)	Circuit B only	10	10	60	120	200	±1.0

— In a multi-element, polyphase metering device, the change in performance produced by using only one current circuit of the three-wire element, as compared with the performance when both current circuits of the three-wire element are used, shall not exceed the maximum deviation specified in table 11. The current circuits that are not common to both elements of a two-element, three-phase, four-wire wye metering device shall be loaded with twice the test current specified. The current circuits of any three-wire element shall be connected in series and treated as one circuit.

Table 11 – Equality of current circuits for multi-element meters

Condition	Connections of Current Circuits	Current Class 10	20	100	200	320 (Current in Amperes)	Maximum Deviation in Performance from Reference Performance
Reference performance for Conditions (5), (6), (7), (8), etc.	All Circuits	0.25	0.25	1.5	3	5	Reference
Condition (5)	Circuit A only	0.25N*	0.25N*	1.5N*	3N*	5N*	±1.5
Condition (6)	Circuit B only	0.25N*	0.25N*	1.5N*	3N*	5N*	±1.5
Condition (7), (8), etc.	Circuits C, D, etc.	0.25N*	0.25N*	1.5N*	3N*	5N*	1.5
Reference performance for Conditions (9), (10), (11), (12), etc.	All Circuits	2.5	2.5	15	30	50	Reference
Condition (9)	Circuit A only	2.5	2.5	15	30	50	±1.5
Condition (10)	Circuit B only	2.5	2.5	15	30	50	±1.5
Condition (11),(12),etc.	Circuits C, D, etc.	2.5	2.5	15	30	50	±1.5

*N represents the number of elements in the metering device

4.7.2.8 Test No. 8: Meter losses

The loss in each current circuit of a metering device shall not exceed 0.5 VA for Class 10 and Class 20 metering devices or 1.0 VA for Class 100, Class 200, and Class 320 metering devices. For two-element, three-phase, four-wire wye Class 10 and Class 20 metering devices, loss in the current circuit common to both elements shall not exceed 1.0 VA. The loss in each voltage circuit of a metering device shall neither

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exceed 5 watts or 20 VA. The losses in auxiliary devices that are powered by the meter power supply or connected to the line side terminals are not included.

4.7.2.9 Test No. 9: Temperature rise

The test shall be made with the specified current applied to all current circuits in series adding. This test shall be applied to one metering device of each class.

The temperature rise of any of the current-carrying parts of the watthour metering device, tested under specified conditions, shall not exceed 55°C, except that a higher temperature rise is permissible when suitable insulating materials are used in conformance with the general principles of temperature rating as specified by ANSI/IEEE Std 1.

All tests shall be performed in a room essentially free from drafts with the metering device cover in place. The metering device shall be mounted in a conventional manner on a suitably rated meter mounting device. Not less than 4 ft (8 ft jumper between terminals) of stranded, insulated, copper conductor shall be connected to the line and load current terminals of the metering device or socket. For detachable (type "S") metering devices, the opening where the conductors enter and leave the socket and any other openings shall be closed with suitable material to prevent drafts. The conductor size, test current, and, where applicable, the socket rating and simulated metering device are specified in table 12.

Table 12 – Temperature-rise test specifications

Meter Class	Wire-Size* (AWG Copper)	Current in Amperes	Detachable Meters	
			Socket Rating in Amperes	Simulated Meter
10	No. 10	10	20 (min)	None
20	No. 10	20	20 (min)	None
100	No. 2	100	100	Fig. 1
200	No. 4/0	200	200	Fig. 2
320	1-500 MCM or 2-4/0	320	320	Fig. 3

*Wire sizes for 100, 200, and 320 A are those specified in ANSI/NFPA 70 for 60°C temperature rating.

4.7.2.9.1 Test on class 10, 20, 100, 200, and 320 meters

The temperature-rise test shall be made by means of temperature detectors in intimate contact with the metal of the current circuit and located at its approximate center.

In the case of metering devices provided with terminal compartments (type "A"), the test shall be conducted under the test conditions specified in 4.7.2.9 until the current-circuit temperatures have stabilized. The temperature rise shall be considered the difference in degrees Celsius between the stabilized temperature and ambient (room) temperature. For detachable metering devices (type "S") Class 100, 200, and 320, the test installation shall be standardized using a simulated meter as specified in figures 1, 2, and 3. The simulated meter shall have the same cover and number of current jumper bars as current circuits in the metering device to be tested. A temperature-rise test shall be conducted on the simulated meter by applying the test current to all jumper bars in series until the temperature as indicated by the temperature detector has stabilized. This temperature shall then be recorded and the simulated metering device replaced by the metering device to be tested. When the temperatures of the metering device current circuits have stabilized, the temperatures shall be measured and the empirical temperature-rise values of the meter device current circuits shall be calculated as follows:

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$$\text{Empirical temperature rise} = \theta_m - (\theta_s - 55°C)$$

where:

θ_m= Measured final temperature rise of current circuit of metering device under test

θ_s= Measured final temperature rise of current circuit of simulated meter jumper bar for the same current phase

NOTE—The foregoing tests shall not be considered conclusive if θ_s exceeds 65°C.

4.7.2.9.2 Test on class 10 and class 20 meters (optional method)

The temperature-rise test may be made by determining the increase in resistance of the current circuits when copper or aluminum conductors are used.

Before the metering is energized, the resistances of the metering device current circuits and the ambient temperature shall be determined. The resistance measurements shall be made by a means capable of determining the change in resistance to an accuracy of ±0.5% or better. The metering device shall be energized at the specified conditions for a minimum period of 2 hrs. At the end of the prescribed period, the meter device shall be de-energized, and the time that this action was taken shall be noted. Resistance readings shall be taken on each current circuit and recorded along with the time at which each measurement was taken. The resistance and time readings shall be repeated until three sets of data have been obtained for each current circuit. These readings shall be taken as quickly as practicable. In no case, however, should the overall time between de-energization and the last resistance reading exceed 5 minutes.

The temperature rise of the current circuit corresponding to each resistance reading should be calculated by the following formulas:

$$T - 258\left(\frac{R}{r} - 1\right) \text{ for copper windings}$$

$$T - 251\left(\frac{R}{r} - 1\right) \text{ for aluminum windings}$$

where:

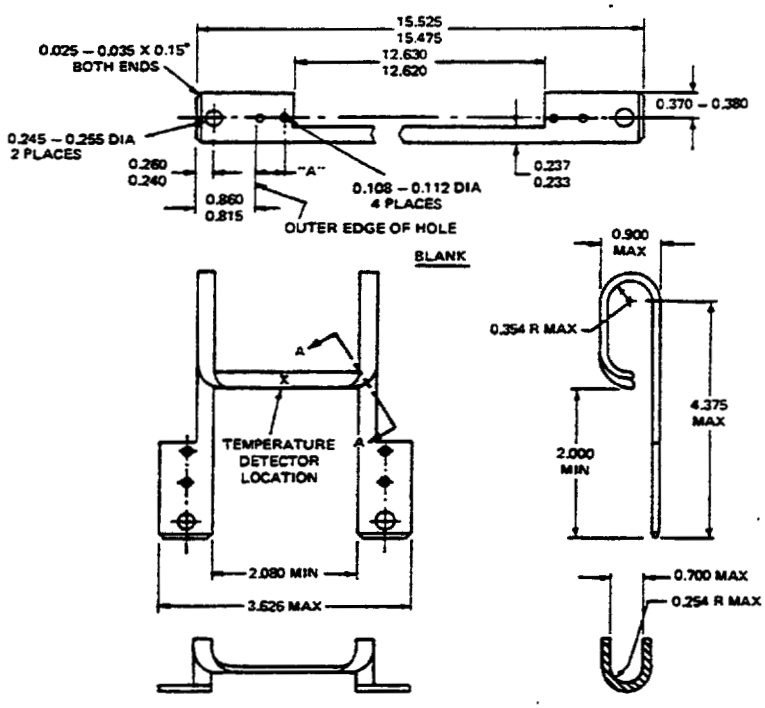
T = temperature rise in degrees Celsius
R = hot resistance
r = cold resistance

To determine the temperature rise at the time of de-energization, the temperature rise corresponding to the resistance values for each current circuit shall be plotted against time. The graph shall be extrapolated to the time of de-energization.

4.7.2.10 Test No. 10: Effect of register friction

The change in meter registration after removal of a pointer-type register shall not exceed ±0.5% at 10% of test amperes (TA). This test may be omitted for solid-state metering devices.

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NOTES: (1) Material is 0.094 ± 0.002 by 0.750 ± 0.005 inch round edge copper with electro-tin plate 0.0002 - 0.0005 inch thick.

(2) Select dimension "A" and retaining lugs or cotter pin holes to suit meter baseplate used.

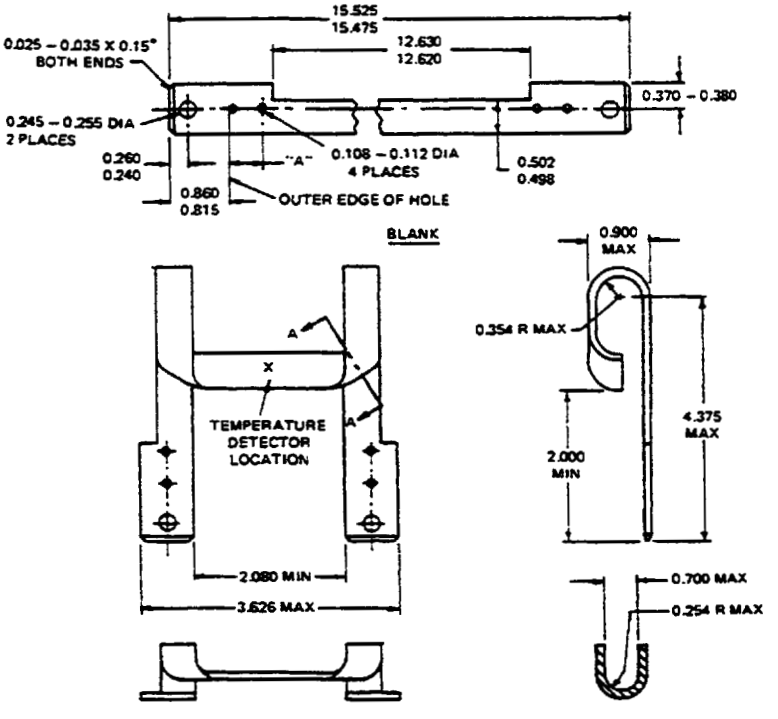
(3) The temperature detectors shall be so attached and shall be of such type that their presence will not appreciably affect the temperature rise of the jumper bars.

(4) All dimensions are in inches.

(5) ***Metric conversion:*** Multiply inches by 25.4 to obtain millimeters. Round off to nearest 0.02 mm.

Figure 1 – Dimensions for jumper bars of simulated meter temperature-rise test for single-phase and polyphase meters (maximum rating 100 A)

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NOTES: (1) Material is 0.094 ± 0.002 by 0.750 ± 0.005 inch round edge copper with electro-tin plate 0.0002–0.0005 inch thick.

(2) Select dimension "A" and retaining lugs or cotter pin holes to suit meter baseplate used.

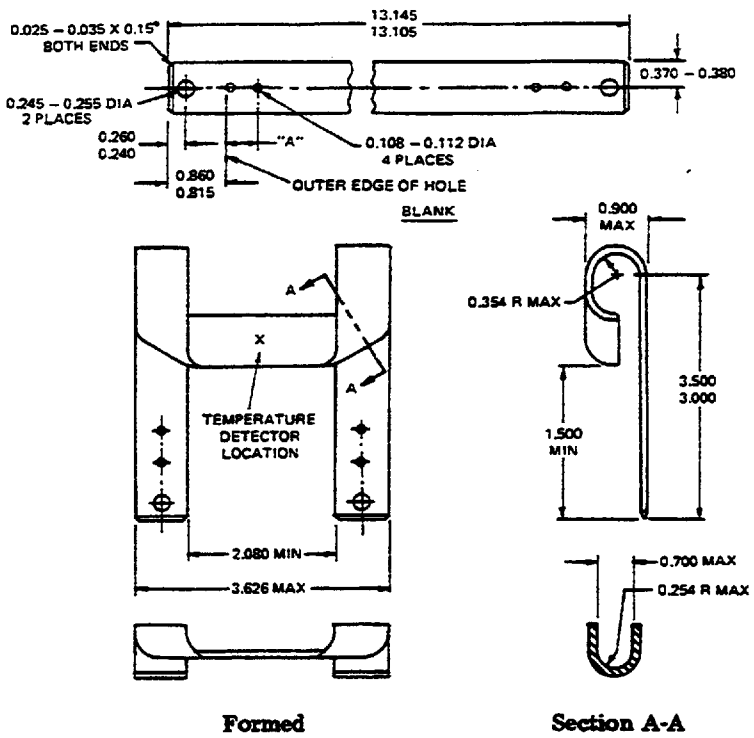
(3) The temperature detectors shall be so attached and shall be of such type that their presence will not appreciably affect the temperature rise of the jumper bars.

(4) All dimensions are in inches.

(5) *Metric conversion:* Multiply inches by 25.4 to obtain millimeters. Round off to nearest 0.02 mm.

Figure 2 – Dimensions for jumper bars of simulated meter temperature-rise test for single-phase and polyphase meters (maximum rating 101 – 200 A rating)

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NOTES: (1) Material is 0.094 ± 0.002 by 0.750 ± 0.005 inch round edge copper with electro-tin plate 0.0002-0.0005 inch thick.

(2) Select dimension "A" and retaining lugs or cotter pin holes to suit meter baseplate used.

(3) The temperature detectors shall be so attached and shall be of such type that their presence will not appreciably affect the temperature rise of the jumper bars.

(4) All dimensions are in inches.

(5) *Metric conversion:* Multiply inches by 25.4 to obtain millimeters. Round off to nearest 0.02 mm.

Figure 3 – Dimensions for jumper bars of simulated meter temperature-rise test for single-phase and polyphase meters (maximum rating 201 – 320 A rating)

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4.7.2.11 Test No. 11: Effect of internal heating

The test shall be made with the metering device mounted in a conventional manner on a suitably rated meter mounting device and wired with not less than 4 ft. of conductor (8 ft. jumper between terminals) of a size adequate for the load range of the metering device. Openings around the conductor, and any other openings, shall be closed with suitable material to prevent drafts. The effect of internal heating upon the performance of a metering device shall not exceed the maximum deviation specified in table 13.

Table 13 – Effect of internal heating

Condition	Current Class					Maximum Deviation in Percent from Reference Performance
	10	20	100	200	320	
	Current in Amperes					
Reference performance for conditions (1),(2), and (7)	10	20	100	200	320	Reference
Reference performance for conditions (3) and (5)	0.25	0.25	1.5	3	5	Reference
Reference performance for conditions (4) and (6)	2.5	2.5	15	30	50	Reference
Condition (1) One-half hour after application of load	10	20	100	200	320	±1.0
Condition (2) One hour after application of load	10	20	100	200	320	±1.5
Condition (3) Immediately following test for condition (2)	0.25	0.25	1.5	3	5	±1.5
Condition (4) Immediately following test for condition (3)	2.5	2.5	15	30	50	±1.5
Condition (5) Two hours after test for condition (4) with meter at no load current during the two-hour interval	0.25	0.25	1.5	3	5	±1.5
Condition (6) Immediately following test for condition (5)	2.5	2.5	5	30	50	±1.0
Condition (7) Immediately following test for condition (6)	10	20	100	200	320	±1.0

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4.7.2.12 Test No. 12: Effect of tilt

The top of the metering device shall be tilted at an angle of 4° from the vertical: (1) forward, (2) backward, (3) left, and (4) right. The effect of tilt upon the registration of a metering device shall not exceed the maximum deviation specified in table 14. This test may be omitted for solid-state metering devices.

Table 14 – Effect of tilt

Conditions	Current Class					Maximum Deviation in Percent from Reference Performance
	10	20	100	200	320	
	Current in Amperes					
Reference performance for conditions (1), (2), (3), and (4)	0.25	0.25	1.5	3	5	Reference
Condition (1) Top of meter tilted 4 degrees forward	0.25	0.25	1.5	3	5	±1.0
Condition (2) Top of meter tilted 4 degrees backward	0.25	0.25	1.5	3	5	±1.0
Condition (3) Top of meter tilted 4 degrees left	0.25	0.25	1.5	3	5	±1.0
Condition (4) Top of meter tilted 4 degrees right	0.25	0.25	1.5	3	5	±1.0
Reference performance for conditions (5), (6), (7), and (8)	2.5	2.5	15	30	50	Reference
Condition (5) Top of meter tilted 4 degrees forward	2.5	2.5	15	30	50	±0.5
Condition (6) Top of meter tilted 4 degrees backward	2.5	2.5	15	30	50	±0.5
Condition (7) Top of meter tilted 4 degrees left	2.5	2.5	15	30	50	±0.5
Condition (8) Top of meter tilted 4 degrees right	2.5	2.5	15	30	50	±0.5

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4.7.2.13 Test No. 13: Stability of performance

The metering device shall be operated continuously. The percentage registration shall be determined at 10% of test amperes at the start of the test and at 10 successive intervals at least 24 hours apart within a period of 2 weeks. The change in percentage registration from performance at the start of the test shall not exceed 1.0% on any subsequent test.

Available nominal voltage and current can be used for the duration of this test except when the metering device is undergoing the specified accuracy test.

4.7.2.14 Test No. 14: Independence of elements

Metering devices without independent elements may use isolation transformers or the electronic equivalent for this test.

4.7.2.14.1 Two-element meter test

The test shall be made on a three-phase circuit. Throughout the test, the voltage and current circuits of one element (Element A) of the metering device shall be connected to phase 1 of a three-phase circuit. For test conditions (1) through (6) listed in table 15, the current circuit of the other element (Element B) shall not be connected. The voltage circuit of Element B shall be connected as follows:

Reference performance	—	Phase 1 direct
Conditions (1) and (2)	—	Phase 1 reversed
Conditions (3) and (4)	—	Phase 2 direct
Conditions (5) and (6)	—	Phase 2 reversed

For test conditions (7) through (12) in table 15, a current shall be applied to Element B. The currents in Element A and Element B shall be equal in magnitude, and each shall be substantially in phase with the voltage applied to the respective element. For these test conditions, both the voltage circuit and the current circuit of Element B shall be connected as follows:

Reference performance	—	Phase 1 direct
Conditions (7) and (8)	—	Phase 1 reversed
Conditions (9) and (10)	—	Phase 2 direct
Conditions (11) and (12)	—	Phase 2 reversed

For a two-element three-phase four-wire wye metering device, the current circuit common to both elements shall not be connected. The currents used shall be twice the values indicated in table 15. The circuits of any three-wire element shall be connected in series and shall be tested as one circuit.

The difference between the performance of the metering device under the test conditions specified and the applicable reference performance shall not exceed the maximum deviation in table 15.

4.7.2.14.2 Three-element meters

The test shall be made on a three-phase four-wire wye circuit. Throughout the test, the voltage and current circuits of one element (Element A) of the metering device shall be connected to phase 1 of the three-phase circuit. For test conditions (1) through (4) listed in table 16, the current circuits of the other elements (Element B and Element C) shall not be connected. The voltage circuit of Element B and Element C shall be connected as follows:

Reference performance	—	Both Element B and Element C, Phase 1 direct
Conditions (1) and (2)	—	Element B, Phase 2 direct; Element C, Phase 3 direct
Conditions (3) and (4)	—	Element B, Phase 3 direct, Element C, Phase 2 direct

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Table 15 – Test for independence of elements in two-element meters

Conditions	Current Class					Maximum Deviation in Percent from Reference Performance
	10	20	100	200	320	
	Current in Amperes					
Reference performance for conditions (1), (3), and (5)	1	1	6	12	20	Reference
Reference performance for conditions (2), (4), and (6)	5	5	30	60	100	Reference
Condition (1)	1	1	6	12	20	±1.0
Condition (2)	5	5	30	60	100	±1.0
Condition (3)	1	1	6	12	20	±1.0
Condition (4)	5	5	30	60	100	±1.0
Condition (5)	1	1	6	12	20	±1.0
Condition (6)	5	5	30	60	100	±1.0
Reference performance for conditions (7), (9), and (11)	0.5	0.5	3	6	10	Reference
Reference performance for conditions (8), (10) and (12)	2.5	2.5	15	30	50	Reference
Condition (7)	0.5	0.5	3	6	10	±1.0
Condition (8)	2.5	2.5	15	30	50	±1.0
Condition (9)	0.5	0.5	3	6	10	±1.0
Condition (10)	2.5	2.5	15	30	50	±1.0
Condition (11)	0.5	0.5	3	6	10	±1.0
Condition (12)	2.5	2.5	15	30	50	±1.0

For test conditions (5) through (8) in table 16 current shall be applied to the current circuits of Element B and Element C.

These currents shall be equal in magnitude with the current applied to Element A, and each shall be substantially in phase with the voltage applied to the respective element. For these test conditions, both the voltage and current circuits of Element B and, similarly, the voltage and current circuits of Element C shall be connected as follows:

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Reference performance	—	Both Element B and Element C, Phase 1 direct
Conditions (5) and (6)	—	Element B, Phase 2 direct; Element C, Phase 3 direct
Conditions (7) and (8)	—	Element B, Phase 3 direct; Element C, Phase 2 direct

The difference between the performance of the metering device under the test conditions specified and the applicable reference performance shall not exceed the maximum deviation in table 16.

Table 16 – Test for independence of elements in three-element meters

Conditions	Current Class 10	20	100	200	320	Maximum Deviation in Percent from Reference Performance
	Current in Amperes					
Reference performance for conditions (1) & (3)	1.5	1.5	9	18	30	Reference
Reference performance for conditions (2) & (4)	7.5	7.5	45	90	150	Reference
Condition (1)	1.5	1.5	9	18	30	±1.0
Condition (2)	7.5	7.5	45	90	150	±1.0
Condition (3)	1.5	1.5	9	18	30	±1.0
Condition (4)	7.5	7.5	45	90	150	±1.0
Reference performance for conditions (5) & (7)	0.5	0.5	3	6	10	Reference
Reference performance for conditions (6) & (8)	2.5	2.5	15	30	50	Reference
Condition (5)	0.5	0.5	3	6	10	±1.0
Condition (6)	2.5	2.5	15	30	50	±1.0
Condition (7)	0.5	0.5	3	6	10	±1.0
Condition (8)	2.5	2.5	30	30	50	±1.0

4.7.3 Accuracy tests – external influences performance verification

Time, program and register readings shall be stored in the metering device and/or register to be used as reference for tests 4.7.3.1 through 4.7.3.24. After each test, proper operation of the metering device and/or register shall be verified by time, program, and register reading check, and the metering device shall show no damage and shall operate correctly in accordance with the requirement of the standard. Any change in energy and power quantities shall be limited to ±1 least significant digit (LSD) displayed, except for test with load current applied.

4.7.3.1 Test No. 15: Insulation

With the metering device voltage and current circuits de-energized, the insulation between current carrying parts of separate circuits and between current-carrying parts and other metallic parts shall be capable of withstanding the application of a sinusoidal voltage of 2.5 kV rms, 60 Hz for 1 minute. The input circuit of the pulse initiators with independent power supplies shall be tested at 1.5 kV rms, 60 Hz for one minute. For both the 1.5 and 2.5 kV rms test, the leakage current shall not exceed 0.005 Amps

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per circuit. Low-voltage electronic circuits, operating at less than 40 V rms, and all output relay terminals, shall not be subjected to this test.

4.7.3.2 Test No. 16: Voltage interruptions test
No current shall be applied to the metering device current coils. Voltage shall be completely interrupted for six power line cycles (100 ms). The voltage interruption shall be applied ten times within an interval of no more than 10 seconds. This test may be omitted for electromechanical meters and registers.

4.7.3.3 Test No. 17: Effect of high voltage line surges
The metering device shall meet the AC Line Surge Requirements of ANSI/IEEE C62.41 for a Category A and B location. The two required standard Surge-Testing waveforms are the 100 kHz Ring Wave and the 1.2/50 micro second - 8/20 microseconds Combination Wave. These waveforms shall be applied at angular injections of 0°, 90°, and 270° of the fundamental voltage waveform. This test may be omitted for electromechanical meters and registers.

The metering device shall be energized.

These waveforms will be applied in both the transverse and common mode with the AC voltage and current inputs to the metering device. Self-contained meters are to be tested with the links closed and the load side of the current circuits open. Transformer rated meters are to be tested with the polarity side of the current circuits connected to the line and the non-polarity side open circuited.

4.7.3.3.1 100 kHz ring wave

The standard 0.5 μs – 100 kHz Ring Wave applied to the metering device, shall be for Location Category B3 and System Exposure High, as described in ANSI/IEEE C62.41, table 3.

This test subjects the power input of the meter device to a 100 kHz Ring Wave with a Peak Voltage of 6 kV and Short-Circuit Peak Current of 0.5 kA.

4.7.3.3.2 1.2/50 microsecond – 8/20 microsecond Combination Wave

The standard 1.2/50 μs – 8/20 μs combination wave applied to the metering device shall be for location category B3 and system exposure high, as described in ANSI/IEEE C62.41, table 4.

This test subjects the AC power input of the metering device to a 1.2/50 μs – 8/20 μs combination wave with a peak voltage of 6 kV and peak current of 3 kA.

4.7.3.4 Test No. 18: Effect of external magnetic field
The test shall be applied to one metering device of each class. The external alternating magnetic field of the same frequency as that of the testing current shall be produced by a straight conductor 6 ft. long with return leads arranged to form a 6 ft square. A current in phase with the voltage applied to the meter device shall be passed through this conductor. The return leads of the conductor shall be so arranged that the loop that they form does not surround or include the meter device. The straight 6 ft. conductor shall be placed in each of the following positions:

— Condition (1). Behind the test board in a horizontal position and parallel to the back of the metering device. The middle of the conductor shall be 10 inches directly behind and on a level with the center of the metering device. The loop shall be in a horizontal plane perpendicular to the test board.

— Condition (2). Directly behind the center-line of the metering device in a vertical position. The middle of the conductor shall be 10 inches directly behind and on a level with the center of the metering device. The loop shall be in a vertical plane perpendicular to the test board.

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— Condition (3). Vertically at the same distance in front of the test board as the center of the metering device. The middle of the conductor shall be on the same level with the center of the metering device and 10 inches to the right or left. The loop shall be in a vertical plane parallel to the test board.

For conditions (1) through (3), the change produced in the performance of a metering device by application of a 100 ampere-turn external magnetic field shall not exceed the maximum deviation specified in table 17.

Table 17 – Effect of external magnetic field

Condition	Current Class 10 / Current in Amperes	20	100	200	320	Position of Conductor	Maximum Deviation in Percent from Reference Performance
Reference performance for conditions (1), (2), and (3)	0.25	0.25	1.5	3	5	—	Reference
Condition (1)	0.25	0.25	1.5	3	5	Condition (1) in Paragraph 4.7.3.4	±1.0
Condition (2)	0.25	0.25	1.5	3	5	Condition (2) in Paragraph 4.7.3.4	±1.0
Condition (3)	0.25	0.25	1.5	3	5	Condition (3) in Paragraph 4.7.3.4	±1.0

4.7.3.5 Test No. 19: Effect of variation of ambient temperature

The test shall be applied to three metering devices. The metering devices shall be placed in a space having a temperature of 23°C ±5°C and allowed to stand for not less than 2 hours with the voltage circuits of the metering devices energized. Reference performance at each of the loads specified in table 18 shall be obtained after operating the metering devices for 1 hour at the specified load. The metering devices shall then be operated and tested at each of the following conditions:

— Conditions (1) through (6). These tests shall be made with the metering device placed in a space having a temperature of 50°C ± 5°C. After energizing the voltage circuits of the metering devices for a period of not less than 2 hours, the appropriate test currents at the power factors listed for conditions (1) through (6) of table 18 shall be sequentially applied to the metering devices. Each condition shall be maintained for a period of at least 1 hour before tests are made to determine the deviation from reference performance.

  Available nominal voltage and current can be used for the duration of this test except when the metering device is undergoing the specified accuracy test.

— Conditions (7) through (12). Repeat conditions (1) through (6), respectively, except that metering devices shall be placed in a space having a temperature of -20°C ±5°C. The effect of variation of temperature upon the performance of the metering devices shall not exceed the maximum deviation specified in table 18. Available nominal voltage and current can be used for the duration of this test except when the metering device is undergoing the specified accuracy test.

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Table 18 – Effect of variation of ambient temperature

Condition	Current Class / Current in Amperes					Power Factor	Ambient Temperature	Max. Deviation in % from Reference Performance at Nominal Temperature Difference*
	10	20	100	200	320			
Reference performance for conditions (1) and (7)	0.25	0.25	1.5	3	5	1.0	23°C±5°C	Reference
Reference performance for conditions (2) and (8)	2.5	2.5	15	30	50	1.0	23°C±5°C	Reference
Reference performance for conditions (3) and (9)	5	10	50	100	150	1.0	23°C±5°C	Reference
Reference performance for conditions (4) and (10)	0.5	0.5	3	6	10	0.5 lag	23°C±5°C	Reference
Reference performance for conditions (5) and (11)	2.5	2.5	15	30	50	0.5 lag	23°C±5°C	Reference
Reference performance for conditions (6) and (12)	5	10	50	100	150	0.5 lag	23°C±5°C	Reference
Condition (1)	0.25	0.25	1.5	3	5	1.0	50°C±5°C	±2.0
Condition (2)	2.5	2.5	15	30	50	1.0	50°C±5°C	±1.0
Condition (3)	5	10	50	100	150	1.0	50°C±5°C	±1.0
Condition (4)	0.5	0.5	3	6	10	0.5 lag	50°C±5°C	±3.0
Condition (5)	2.5	2.5	15	30	50	0.5 lag	50°C±5°C	±2.0
Condition (6)	5	10	50	100	150	0.5 lag	50°C±5°C	±2.0
Condition (7)	0.25	0.25	1.5	3	5	1.0	20°C±5°C	±3.0
Condition (8)	2.5	2.5	15	30	50	1.0	20°C±5°C	±2.0
Condition (9)	5	10	50	100	150	1.0	20°C±5°C	±2.0
Condition (10)	0.5	0.5	3	6	10	0.5 lag	20°C±5°C	±4.0
Condition (11)	2.5	2.5	15	30	50	0.5 lag	20°C±5°C	±3.0
Condition (12)	5	10	50	100	150	0.5 lag	20°C±5°C	±3.0

*When the actual temperature difference between two tests differs from the nominal temperature difference specified for the two tests, the deviation shall be adjusted proportionally.

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4.7.3.6 Test No. 20: Effect of temporary overloads

4.7.3.6.1 Effect on accuracy

Self-contained meter devices shall be subjected to a symmetrical short-circuit current of 7000 A peak, 60 Hz, for not less than one cycle, or for more than six cycles. For this test, current circuits of the metering devices shall be connected series adding. The effect of short-circuit current on the performance of a metering device should not exceed the maximum deviation specified in table 19. To eliminate residual effects, condition (1) shall be conducted before tests of condition (2).

Table 19 – Effect of temporary overloads on accuracy

Condition	Current Class			Maximum Deviation in Percent from Reference Performance
	100	200	320	
	Current in Amperes			
Reference performance for Condition (1)	15	30	50	Reference
Reference performance for Condition (2)	1.5	3	5	Reference
Condition (1)	15	30	50	±1.5
Condition (2)	1.5	3	5	±1.5

4.7.3.6.2 Effect on magnetic bearing

A minimum of 0.003 inch down-travel shall remain after the application of the short-circuit current stipulated in 4.7.3.6.1. This test may be omitted for solid-state metering devices.

4.7.3.6.3 Effect on mechanical structure and insulation

The metering device shall withstand, for a duration of 4 cycles, a 60 Hz symmetrical fault current as follows without damage to the mechanical structure or reduction in the insulation level:

— Class 100: 10 000 A rms
— Class 200: 12 000 A rms
— Class 320: 12 000 A rms

4.7.3.7 Test No. 21: Effect of current surge in ground conductor

Three metering devices shall be subjected to one transient surge of 20 000 A (20/50 microsecond wave) of either polarity through a conductor placed vertically 1.5 inches behind the flat portion of the base of the metering device, with a socket in place. This test shall not apply for metering devices with terminal compartments (Type A) or for Class 10 or Class 20 metering devices. The effect of current surge upon the performance of a metering device shall not exceed the maximum deviation specified in table 20.

Table 20 – Effect of current surge in ground conductor

Condition	Current Class			Maximum Deviation in Percent from Reference Performance
	100	200	320	
	Current in Amperes			
Reference performance	15	30	50	Reference
Condition (1)	15	30	50	±1.0

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4.7.3.8 Test No. 22: Effect of superimposed signals
A metering device shall be subjected to signals superimposed on the power line having a frequency of 0.2 kHz and 15 kHz at an amplitude of 10% of the applied voltage for one minute each.

This test may be omitted for electromechanical meters and registers.

4.7.3.9 Test No. 23: Effect of voltage variation-secondary time base
With the battery disconnected for a minimum of 2 hours and an auxiliary dc power supply connected to the battery carryover circuit, the accuracy of the secondary time base shall be within ±0.02% (2 minutes per week) with a voltage variation of ±5% of nominal battery voltage.

4.7.3.10 Test No. 24: Effect of variation of ambient temperature-secondary time base
This test shall be conducted with the metering device in the battery carryover mode. The accuracy of the secondary time shall be within ±0.02% (2 minutes per week) at ambient temperatures of -30°C ±5°C and 70°C ±5°C. The metering device shall be exposed to each specified temperature for not less than 2 hours prior to testing.

4.7.3.11 Test No. 25: Electrical fast transient/burst test
The metering device shall meet the Fast Transient Surge Test requirements of IEC 801 PT 4.

This test subjects the power inputs and the I/O circuits of the metering device to repetitive bursts of 5 ns rise time, 50 ns duration electrical fast transients.

The test shall be carried out according to IEC 801 PT 4, under the following conditions:

1) test severity level: 4
2) test voltages on the voltage and current circuits: 4 kV
3) test voltage on I/O signal, data and control lines: 2 kV
4) duration of the test: minimum 60 seconds
5) voltage and auxiliary circuits energized with reference voltage
6) without any current in the current circuits and the current terminals should be open circuit

This test shall be conducted on all metering devices containing solid-state components excluding LED voltage indicators.

This test may be omitted for electromechanical meters and registers.

4.7.3.12 Test No. 26: Effect of radio frequency interference
This test shall be conducted with all cables connected, with all options and accessories specified, in a configuration closely resembling typical field in-service connections.

This test shall be conducted on all metering devices containing solid-state components excluding LED voltage indicators.

This test may be omitted for electromechanical meters and registers.

4.7.3.12.1 Basic radiation susceptibility test
Each test sample shall be subjected to a linearly polarized wave of both vertical and horizontal polarization over the frequency range of 200 kHz to 1 GHz with a field strength of 15 ±5 V/m and a frequency scan rate not to exceed 0.005 octaves per second. A single scan with a circularly polarized source (e.g., log-spiral antenna) may be used in place of independent vertical and horizontal polarized scans over those frequency ranges where circularly polarized sources are available. Test samples shall be tested in the most sensitive orientation. For frequencies below 50 MHz, the signal shall be amplitude

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modulated at a 90% level, with a 1 kHz sine wave not synchronized with any digital clock frequency within the test sample.

4.7.3.13 Test No. 27: Radio frequency conducted and radiated emission test
The metering device shall conform to all applicable requirements of the Code of Federal Regulations (CFR) 47, Part 15—Radio Frequency Devices, Subparts A—General and B—Unintentional Radiators issued by the Federal Communications Commission for Class "B" digital devices. (Refer to ANSI C63.4).

The test shall be conducted with all cables connected, with all options and accessories specified, in a configuration closely resembling typical field in-service connections.

This test shall be conducted on all metering devices containing solid-state components excluding voltage indicators.

This test may be omitted for electromechanical meters and registers.

4.7.3.14 Test No. 28: Effect of electrostatic discharge (ESD)
This test shall be carried out according to IEC 80 PT 2, under the following conditions:

- test severity level: 4
- test voltage: 15 kV; (through air)
- number of discharges: 10
- voltage and auxiliary circuits energized with reference voltage
- without any current in the current circuits and the current terminals should be open circuit

Discharges shall be applied only to such points and surfaces of the metering device that are normally accessible with the cover on. Discharges shall not be applied to any point that is accessible only for maintenance purposes.

This test shall be conducted on all metering devices containing solid-state components excluding voltage indicators.

4.7.3.15 Test No. 29: Effect of storage temperature
The metering device shall not be damaged and shall conform to the manufacturer's specification after being subjected to the following tests. The storage temperatures are as specified by the manufacturer. If the operating temperature range is the same as the storage temperature range, then this test can be omitted.

- The metering device enclosure door or cover shall be closed (normal operating position) for the duration of the test.
- The metering device shall not be powered nor operating for the duration of the test.
- The test duration shall be 168 hours.
- The temperature shall be cycled once each 24 hours, as described below. The temperature ramping shall be smooth and continuous. The rate of temperature change during ramping shall not exceed 20°C, per hour.
- The daily temperature cycle shall be conducted as follows:
  - Ramp up from room ambient to the Maximum Storage Temperature, $T_{Stor-Max}$ in approximately 3 hours.
  - Soak at $T_{Stor-Max}$ for approximately 11 hours.
  - Ramp down to Minimum Storage Temperature, $T_{Stor-Min}$ in approximately 6 hours.

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- Soak at $T_{stor-min}$ for approximately 3 hours
- Ramp up to room ambient, in approximately 2 hours

4.7.3.16 Test No. 30: Effect of operating temperature
The metering device shall operate continuously when exposed to the temperature extremes specified by the manufacturer.

- The metering device enclosure door or cover shall be closed (normal operating position) for the duration of the test.
- The metering device shall be powered and operating in a normal manner for the duration of the test.
- The test duration shall be 168 hours.
- The temperature shall be cycled once each 24 hours, as described below. The temperature ramping shall be smooth and continuous. The rate of temperature change during ramping shall not exceed 20°C, per hour.
- The daily temperature cycle shall be conducted as follows:
  - Ramp up from room ambient to the maximum operating temperature, $T_{oper-Max}$ in approximately 3 hours.
  - Soak at $T_{oper-Max}$ for approximately 11 hours.
  - Ramp down to minimum storage temperature, $T_{Stor-Min}$ in approximately 6 hours.
  - Soak at $T_{stor-min}$ for approximately 3 hours
  - Ramp up to room ambient, in approximately 2 hours
  - If present, the battery carry-over function shall be tested by removing the external power for any 48 hour period during the temperature test.

Available nominal voltage and current can be used for the duration of this test except when the metering device is undergoing the specified accuracy test.

4.7.3.17 Test No. 31: Effect of relative humidity
This test shall be conducted as follows:

- The metering device enclosure door or cover shall be closed (normal operating position) for the duration of the test.
- The metering device shall be powered and operating in a normal manner for the duration of the test.
- The test duration shall be 24 hours at 85°C and 95% ±4% relative humidity or 72 hours at 40°C and 95% ±4% relative humidity.
- The temperature shall be cycled once at 85°C and 95% ±4% relative humidity or three times at 40°C and 95% ±4% relative humidity, as described below. The temperature ramping shall be smooth and continuous. The rate of temperature change during ramping shall not exceed 20°C,

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per hour. The relative humidity shall be held at 95% ±4% during the peak temperature soak period.

— There shall be no condensation on the components and assemblies of the metering device. Relative humidity need not be controlled during ramping, except to prevent condensation.

— Each temperature/humidity cycle shall be conducted as follows:

  — Ramp up from room ambient to 40°C or 85°C in approximately 3 hours.

  — Soak at 95% ±4% relative humidity at 40°C or 85°C for approximately 18 hours.

  — Ramp down to room ambient, in approximately 3 hours.

Available nominal voltage and current can be used for the duration of this test except when the metering device is undergoing the specified accuracy test.

4.7.3.18 Test No. 32: Mechanical shock
This test shall be conducted as described in IEC 68-2-27 revision 1987 based on the following conditions:

— The metering device shall not be operating and shall be without packaging

— The metering device shall be rigidly mounted to a test fixture and the reference point for the control accelerometer shall be attached to the test fixture.

— Half sine pulse applied 3 times in each direction, for each of the 3 mutually perpendicular axis, for a total of 18 shocks.

— Peak acceleration shall be 15 g (150 m/s^2) with a duration of 11 ms with a corresponding velocity change of 1.0 m/s.

4.7.3.19 Test No. 33: Transportation drop
This test shall be conducted as described in the National Safe Transit Association, Pre-Shipment Test Procedures, Test B.2, Drop.

— The metering device shall be in its intended final packaging.

— The metering device shall be exposed to ten drops to a concrete floor in accordance with ASTM D775 method A.

4.7.3.20 Test No. 34: Mechanical vibration
This test shall be conducted as described in IEC 68 PT 2-6 revision 1982 based on the following conditions:

— The metering device shall not be operating and shall be without packaging

— The metering device shall be rigidly mounted to a test fixture and the reference point for the control accelerometer shall be attached to the test fixture.

— The test shall be run over a frequency range of 30 to 350 Hz, with a sweep time of one octave per minute at 5 m/s^2 (0.5 g) along each of three mutually perpendicular axes.

— The sweep duration shall be 30 minutes along each axis.

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4.7.3.21 Test No. 35: Transportation vibration

The metering device, packaged in its intended final packing container shall pass the test requirements described in the National Safe Transit Association, Pre-Shipment Test Procedures, Test B.1, Vibration.

This test exposes the metering device, packaged for shipment, to transportation vibration, for approximately one hour, and is in accordance with ASTM D999.

4.7.3.22 Test No. 36: Weather simulation test

This test is intended for devices used in outdoor applications. The metering device shall be mounted in the normal operating position in the weathering apparatus. Meters shall be tested in a suitable mounting device with the conduit holes sealed against moisture. Meter devices shall then be exposed to a series of 18 minute cycles for 14 days to the following weathering apparatus conditions:

— Direct ultraviolet radiation throughout approximately 93% of weathering apparatus cycle.

— Fresh-water spray applied to the front and top of the meter throughout approximately 7% of the weathering apparatus cycle

After this test, covers, terminal covers, etc., shall be readily removable. There shall be no progressive corrosion or electrolytic action that will adversely affect the functioning of any part of the apparatus. Also, there shall be no evidence of deleterious discoloration or fading of finishes or materials.

4.7.3.23 Test No. 37: Salt-spray test

This test is intended for devices used in outdoor applications. The metering device shall be mounted in its normal operating position in a salt-spray chamber and subjected to a 25 hour salt-spray test in accordance with the current edition of ASTM B117. The metering device shall be tested with a suitable mounting device with the conduit holes sealed against moisture.

After this test, covers, terminal covers, etc., shall be readily removable. There shall be no progressive corrosion or electrolytic action that will adversely affect the functioning of any part of the apparatus.

4.7.3.24 Test No. 38: Raintightness

When mounted in its normal operating position in or on a meter mounting intended for outdoor installation, a metering device shall pass the test described in UL 50.

5 Standards for in-service performance

New metering devices shall be either 100% tested by the utility, sample tested by the utility, or 100% tested by the manufacturer.

5.1 Watthour meters and electronic registers

5.1.1 Purpose

The purpose of this section is to establish accuracy limits, test plans, and inspection procedures for alternating-current revenue watthour meters.

Watthour meters placed into service or returned to service shall meet the provisions as set forth in this Section.

All watthour meters and their associated equipment shall be thoroughly inspected at the time of installation to assure safe and accurate operation.

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5.1.2 Accuracy requirements

5.1.2.1 Test loads

Full load shall be approximately 100% of test amperes at unity power factor, light load approximately 10% of test amperes at unity power factor and power factor 100% test amperes 50% lagging power factor. For meters used with current transformers, full load shall be approximately 100% of either meter test amperes or the secondary current rating of the current transformers; light load shall be approximately 10% of the selected full load current.

5.1.2.2 Acceptable performance

The performance of all watthour meters is considered to be acceptable when the percent registration is not less than 98% or more than 102% as determined in 5.1.5.

5.1.2.3 Adjustment limits

Watthour meters shall be adjusted when the error in registration exceeds 1% at either light load or full load or when the error in registrations exceeds 2% at power factor. The registration of the watthour meter shall be adjusted within these limits as close to 100% as practical.

5.1.2.4 Acceptable performance for electronic registers

The performance of a watthour meter with an electronic register when tested for other than kilowatthour registration shall be acceptable when the error measured does not exceed ±2% of reading.

5.1.3 Tests

5.1.3.1 As-found tests

As-found tests are done to determine the watthour meter accuracy before recalibration.

5.1.3.2 As-left tests

As-left tests shall be conducted after all adjustments are completed and are in accordance with 5.1.2.3.

5.1.3.3 Meters removed from service

Meters removed from service may be retired without test. Meters may be returned to service without being tested if they are covered by an in-service test plan.

5.1.4 Performance tests

5.1.4.1 General

The performance of watthour meters should be verified by an annual test program such as one of the three plans listed below. Records shall be maintained on each watthour meter tested. Subsequently, an analysis of the test results for each group of watthour meters shall be made and appropriate action shall be taken. The generally accepted plans for testings are:

a) Periodic interval plan
b) Variable interval plan
c) Statistical sampling plan

5.1.4.2 Objectives

The primary purpose of performance testing is to provide information on which the utility may base a program to maintain meters in an acceptable degree of accuracy throughout their service life.

5.1.4.3 Test plans

The periodic interval plan is a schedule of testing for watthour meters at various set intervals.

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The variable-interval plan provides for the division of watthour meters into homogeneous groups. The establishment of a testing rate for each group is based on the results of performance tests made on watthour meters longest in service without test.

The statistical sampling plan provides for the division of watthour meters into homogeneous groups. The annual selection process is random where each watthour meter within each group has an equal chance of being selected.

5.1.4.3.1 Periodic interval plan
The selected periodic interval for testing a watthour meter depends on the size of the service, complexity of the metering system, reliability of the type of watthour meter and/or manufacturer's recommendations. The plan listed below is an example of accepted periodic maintenance schedules:

Schedule by watthour meter and attachments:

a) Meters without surge-proof magnets—8 years
b) All other meters—16 years

NOTE—A more detailed example of a schedule is listed in Appendix D, which is not a part of this standard, but is included for information only.

5.1.4.3.2 Variable-interval plan
The Variable Interval Test Plan allows the utility to divide the meter population into homogeneous groups for testing. Meters to be tested shall be representative of those longest in service without test. The percentage of meters to be tested in each group during the year shall be dependent upon the results of the performance test made during the preceding year (or up to the three preceding years). The percentage of meters to be tested shall be determined by the percentage of meters found outside the acceptable performance limits specified in section 5.1.2.2 and table 21.

TABLE 21 – Variable Interval Plan

Percent of Meters with Registration Outside Acceptable Limits	Percent of Population to Be Tested
0–3%	12.5%
> 3%	25.0%

The minimum number of meters to be tested in each group shall be 200 meters or 12.5% of that group, whichever is less.

5.1.4.3.3 Statistical sampling plan
The statistical sampling plan used shall conform to accepted principles of statistical sampling based on either variables or attributes methods. Meters shall be divided into homogeneous groups, such as manufacturer and manufacturer's type. The groups may be further divided into subdivision within the manufacturer's type by major design modifications.

NOTE—Examples of statistical sampling plans can be found in ANSI/ASQC Z1.9, the ANSI version of MIL-STD-414 and ANSI/ASQC Z1.4, the ANSI version of MIL-STD-105.

5.1.4.3.4 Test records
The recommended data to be recorded for each of these plans in each group are:

a) the number of meters in each group at the beginning of the test year

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b) the number of meters tested

c) the analyzed test results

d) any necessary corrective action

5.1.5 Determination of average percentage registration

The percentage registration of a watthour meter is, in general, different at light loads than at full loads, and may have still other values at other loads. The determination of the average percentage registration of a watthour meter is not a simple matter, since it involves the characteristics of the meter and the loading. Various methods are used to determine a single figure that represents the average percentage registration, the method being prescribed by commissions in many cases. Three methods, described in 5.1.5.1–5.1.5.3 are used for determining the average percentage registration (commonly called "average accuracy" or "final average accuracy").

5.1.5.1 Method 1

Average percentage registration is the weighted average of the percentage registration at light load (LL) and at full load (FL), giving the full load registration a weight of four. By this method

$$\text{weighted percentage registration} = \frac{4FL + LL}{5}$$

5.1.5.2 Method 2

Average percentage registration is the average of the percentage registration at light load (LL) and at full load (FL). By this method

$$\text{average percentage registration} = \frac{FL + LL}{2}$$

5.1.5.3 Method 3

Average percentage registration is the registration at a single point when this single point represents the registration within the load range.

5.2 Mechanical and lagged demand registers and pulse recorders

5.2.1 Accuracy requirements

5.2.1.1 Acceptable performance

The performance of a mechanical or lagged demand register shall be acceptable when the error in demand registration does not exceed ±4 percent in terms of full-scale value when tested at any point between 25% and 100% of full-scale.

Under usual operating conditions, the performance of a pulse recording device shall be acceptable when the kilowatthours calculated from the pulse count do not differ by more than 2% from the corresponding kilowatthour meter registration. The device's timing error shall be no more than ±2 minutes per week.

5.2.1.2 Test points

Mechanical or lagged demand registers should be tested at load points at or above 50% of full scale.

5.2.1.3 Adjustment limits

When a test of a mechanical or lagged demand register indicates that the error in registration exceeds that specified in 5.2.1.1, the demand register shall be adjusted to within ±2% of full-scale value. When a timing element also serves to keep a record of the time of day at which the demand occurs, it shall be corrected if it is found to be in error by more than ±2 minutes per week.

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5.3 Instrument transformers (magnetic)

5.3.2.1 Pre-installation tests, (section 5 shall apply)
Prior to installation, all new instrument transformers shall be tested for voltage withstand, ratio correction factor, and phase angle. These tests shall be performed in accordance with the criteria established in IEEE C57.13.

5.3.2.2 Instrument transformers removed from service
Instrument transformers removed from service can be retired or returned to service without further testing.

5.3.3 Performance tests

5.3.3.1 Periodic test schedules
Experience has demonstrated that instrument transformers maintain their accuracies, consequently, the periodic testing of instrument transformers is considered to be unnecessary.

5.3.3.2 Inspection
When metering installations are inspected the instrument transformers associated with the installations should receive a close visual inspection for correctness of connections and evidence of any damage.

5.3.3.3 Heavy burden test
Current transformers may be tested, with a suitable variable burden device, to determine whether the windings of the secondary circuit have developed an open circuit, short circuit, or unwanted grounds.

5.3.3.4 Secondary voltage test
When the primary voltage is known, voltage transformers may be tested by measuring the secondary voltage and current to reveal defects in the transformer or secondary circuit that appreciably affect accuracies.

5.4 Coupling-capacitor voltage transformers

5.4.1 Performance tests
A program for testing of the transformers should be established in coordination with the testing program for the associated watthour devices.

6 Auxiliary pulse devices for electricity metering

6.1 General
The usual form of pulse initiators is that of an attachment to a meter device so arranged that the number of pulses produced is proportional to the quantity measured.

6.1.1 Information to be shown on pulse initiator

a) Manufacturer's name or trademark
b) Type identification
c) Pulse-initiator output ratio (M_p, R/P, or P/DR)
d) Voltage rating (not applicable to mechanical pulse devices)
e) Frequency rating (not applicable to mechanical pulse devices)
f) Type of output (two-wire or three-wire)

6.1.2 Information to be shown on pulse amplifier or relay

a) Manufacturer's name or trademark
b) Type identification
c) Type of input (two-wire or three-wire)

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d) Type of output (two-wire or three-wire)
e) Voltage
f) Frequency
g) Wiring diagram

6.1.3 Information to be shown on pulse totalizers

a) Manufacturer's name or trademark
b) Type identification
c) Input-to-output pulse ratio
d) Number of additive and subtractive elements. If both are present, each must be clearly identified
e) Type of input (two-wire or three-wire)
f) Type of output (two-wire or three-wire)
g) Voltage
h) Frequency

6.2 Tests to be applied

Each pulse initiator, relay, or totalizer shall be subjected to the tests as specified in 6.3, except those that are a modification of a type already subjected to the tests or selected for special services may be exempted from certain tests.

6.3 Performance requirements

6.3.1 Test conditions

The pulse initiators, relays, or totalizers shall be mounted on a support free from vibration.

All tests shall be made at 23°C ± 5°C, rated voltage ±3%, rated frequency ±1 Hz, test current ±3%, and unity power factor ±2%, unless otherwise indicated in specific tests. The metering device should be stabilized at ambient temperature before performance tests are made.
After each test, a sufficient time interval shall be allowed for the pulse device to come to a stable condition before making the next observation or test.

6.3.2 Initial conditions

Pulse initiators, relays, or totalizers shall be connected so as to initiate or receive pulses, or both, and the pulse output shall be connected to a counter for the purpose of recording the total pulses transmitted.

6.3.3 Mechanical load

The mechanical load imposed on the meter by the pulse initiator shall be within the adjustment range of the meter. This load shall be a nearly constant as practical throughout the entire cycle of operation of the pulse initiator.

6.3.4 Insulation

With the meter device voltage and current circuits de-energized, the insulation between current carrying parts of separate circuits and between current-carrying parts and other metallic parts shall be capable of withstanding the application of a sinusoidal voltage of 2.5 kV rms, 60 Hz for 1 minute. The input circuit of the pulse initiators with independent power supplies power supply shall be tested at 1.5 kV rms, 60 Hz for one minute. The leakage current shall not exceed 0.005 A per circuit. For both the 1.5 and 2.5 kV rms test, low-voltage electronic circuits, operating at less than 40 V rms, and all output relay terminals, shall not be subjected to this test.

6.3.5 Performance test

The pulse device shall be placed in a space having a temperature of 23°C ± 5°C and allowed to stand for not less than 2 hours with the voltage circuits energized at approximately nameplate voltage. This operation shall be repeated at the temperatures shown in table 22.

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The pulse device shall operate at each test condition for at least 1 hour. An acceptable pulse device shall not gain but may lose one pulse when all pulse circuits are energized under any of the test conditions in table 22 at 85%, 100%, and 110% of nameplate voltage.

Table 22 – Performance test—pulse devices

Condition	Test Point in Approximate Percent of Rated Pulse Capacity	Ambient T°
1	10	23°±5°C
2	100	23°±5°C
3	10	50°±5°C
4	100	50°±5°C
5	10	-20°C±5°C
6	100	-20°C±5°C

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APPENDIX A
(Informative)
Measurement of Power, Energy, and Related Quantities

A.1 Measurement of power

A.1.1 Introduction
The growth in the use of electric power and energy has made necessary the adoption of polyphase alternating-current transmission and distribution systems. Such a system is a circuit or network to which are applied two or more voltages of the same frequency but displaced in phase by a fixed amount relative to one another. The individual circuits making up the polyphase network are called phases. The correct measurement of power, energy, and related quantities in polyphase circuits requires the proper selection and application of meters and meter elements. It is not the intention to present in this standard a complete test of all the methods of measurement of power and energy. The material contained herein is intended to cover the basic methods of measurement of power, energy, and related quantities as accomplished by acceptable commercial practice.

A.1.2 Blondel's theorem
In any system of N wires the true power may be measured by connecting a wattmeter in each line except one (N - 1 wattmeters), the current coil being in series with the line and the voltage coil connected between that line and the line containing no current coil. The total power for any load condition is the algebraic sum of the readings of all wattmeters so connected, provided that a grounded neutral connection to load or source is held equivalent to the addition of another wire. All methods of measuring power or energy discussed in the remainder of Appendix A constitute applications of Blondel's theorem, with the foregoing limitations.

A.1.3 Direct-current circuits

A.1.3.1 Two-wire direct-current circuits
The total power in a two-wire direct-current circuit may be measured by one wattmeter. On grounded circuits, the current coil of the wattmeter must be connected in the ungrounded side of the circuit. It is generally preferable to connect the voltage coil leads across the terminals of the receiving circuit and, if greater accuracy is desired, the wattmeter reading may be corrected for its voltage-coil losses. If it is desired to minimize any possible effect of stray fields, the mean of reversed readings should be used.

A.1.3.2 Three-wire direct-current circuits
The total power in a three-wire direct-current may be measured by two wattmeters, the current coils being connected one in each of the outside wires and the voltage leads of each wattmeter connected between its current coil wire, preferably on the receiving circuit side, and the third, common or neutral wire.

A.1.3.3 Ammeter and voltmeter method
In direct-current circuits, an ammeter and a voltmeter may be used in place of a wattmeter. Under steady-state conditions, the product of their readings is the total power in the receiving circuit in which the instruments are connected.

A.1.4 Single-phase alternating-current circuits

A.1.4.1 Single-phase two-wire circuits
The total power in a single-phase two-wire circuit may be measured by one wattmeter connected as in A.1.3.1 except that the mean of reversed readings is not necessary.

A.1.4.2 Single-phase three-wire circuits
The total power in a single-phase three-wire circuit may be measured by two wattmeters connected as in A.1.3.2.

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A.1.5 Two-phase circuits

A.1.5.1 Two-phase three-wire circuits

The power in a two-phase three-wire circuit may be measured by two wattmeters, the current coils being connected one in each of the phase conductors and the voltage coil of each wattmeter connected between its current coil conductor and the common return. This method is correct for all conditions of load.

A.1.5.2 Two-phase four-wire circuits

The power in a two-phase four-wire circuit may be measured by two wattmeters, one of which is connected in each of the two phases as in A.1.4.1. This method is correct for all conditions of load, provided that the mid points of the two phases are not interconnected or grounded.

A.1.5.3 Two-phase five-wire Circuits

The power in a two-phase five-wire circuit may be measured by means of four wattmeters, each having its current coils connected one in each of the phase conductors and the voltage coils connected between the corresponding phase conductor and the common conductor, or the neutral. This method is correct for all conditions of load.

A.1.5.4 Balanced two-phase circuits

The power in a balanced two-phase three- or four-wire circuit may be measured by connecting a wattmeter in one phase, as in A.1.4.1, and multiplying its readings by two.

A.1.6 Three-phase circuits

A.1.6.1 Three-wattmeter method

If the three loads are accessible as single-phase two-wire loads, the total power may be measured as the sum of the readings of the three wattmeters, each connected to one of the three loads as described in A.1.4.1. This method is correct for all conditions of loading. This method is also correct for three-phase four-wire circuits, except that the voltage coil of each wattmeter is connected between the line conductor in which its current coil is connected and the common conductor, or the neutral.

A.1.6.2 Two-wattmeter method

The total power in a three-phase three-wire circuit may be measured by means of two wattmeters, having the current coils connected one in each of two line conductors and the voltage coils connected between the line conductor in which its current coil is connected and the third line conductor. The algebraic sum of the readings of the two wattmeters indicates the total power supplied to any type of loading on the three conductors. This method is correct for any balanced or unbalanced load and for any power factor, but does not apply to three-phase four-wire circuits.

A.1.6.3 Balanced three-phase circuits

The power in a balanced three-phase three- or four-wire wye circuit may be measured by one wattmeter by connecting its current coil in one phase conductor and its voltage coil between that conductor and neutral, real or artificial, and multiplying its readings by three.

A.2.1 Basic considerations

In general, electric energy is measured in the same way as electric power, by substituting an integrating watthour meter for a wattmeter.

A.2.1.1 Voltage-coil connection

For measurements of power, it is generally preferable to connect the voltage coil leads across the terminals of the receiving circuit, as indicated in A.1.3.1. However, for measurement of energy, it is standard practice to connect the voltage-coil leads on the line side of the meter current coils so that the consumer does not pay for the power consumed by the voltage coil.

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A.2.1.2 Application of Blondel's theorem

Under certain circumstances, for economic reasons, slight departures from Blondel's theorem are permissible, depending upon the degree of unbalance between two or more of the voltages in a polyphase circuit. Care must be exercised concerning the degree to which limits of the unbalance conditions are met in any specific case, in order to insure that the accuracy of the metering lies within acceptable metering practice. An acceptable limit of metering accuracy or voltage unbalance may be defined as one in which the metering device reliably registers the electrical quantity that is being measured in compliance with the requirements of this standard.

A.2.1.3 Watthour meter stator

In referring to watthour meters, it is convenient to refer to each complete electromagnetic structure containing current and voltage windings as a stator, each stator being comparable to a single-phase wattmeter. Each such stator may consist of a voltage coil and a single current coil, or a voltage coil and two current coils. The single-stator two-wire meter has one voltage coil and one current coil. The single-stator three-wire meter has one voltage coil and two current coils, each of the latter having one half the number of turns of the current coil in a two-wire meter. Meters may have one or more stators, each of which may be of the two-wire or three-wire type.

A.2.2 Direct-current or single-phase circuits

A.2.2.1 Two-wire direct-current and single-phase circuits

The energy in a two-wire direct-current or single-phase circuit may be measured by means of one watthour meter. If the circuit is grounded, the current coil should be connected in the ungrounded side of the circuit.

A.2.2.2 Three-wire direct-current and single-phase circuits

The energy in a three-wire direct-current or single-phase circuit may be measured by two watthour meters, dc or ac, respectively. The meters are connected as were the wattmeters in A.1.3.2 and A.1.4.2, respectively. The total energy is the sum of the registrations of the two meters. The two meters may be arranged in a single housing and their combined registration recorded on a single register as in a two-stator meter.

A.2.2.3 Single-phase three-wire circuits with balanced voltages

A departure from Blondel's theorem may be used in a three-wire direct-current or single-phase circuit, provided that the voltages are balanced within acceptable limits. Under these conditions a single-stator three-wire meter may be used, having one voltage coil connected between the two ungrounded wires, and a two-section current winding consisting of two coils wound in opposite directions on a common core. Thus, when each of the current coils is connected in series with each of the line wires of the three-wire circuit, the magnetic effects of the currents flowing in the two coils are additive. The total number of turns of the two coils is the same as would be used on a single-winding two-wire stator of the same current rating. The accuracy of this method is independent of current or power factor balance, but it is dependent on voltage balance.

A.2.2.4 Large-capacity or high-voltage direct-current meters

In direct-current circuits carrying heavy currents, shunt-type meters may be used. In circuits operating above 240 V, resistors are used in the voltage-coil circuit of the meter to reduce the values of current and voltage applied to the meter in known and definite ratios that bring the current and voltage within the range of a meter having normal current and voltage ratings.

A.2.2.5 Large-capacity or high-voltage alternating-current meters

In alternating-current circuits carrying heavy currents or operating at high voltages, transformers are used to reduce the value of current and voltage applied to the meter. These transformers have definite ratios that bring the current and voltage within the range of a meter's normal current and voltage ratings. Current transformers should be used in all high-voltage metered circuits for purposes of insulation and safety, regardless of whether the value of the current necessitates their use.

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A.2.3 Open wye circuits

The measurement of energy in a three-wire 120/208 V distribution circuit (two lines and a neutral) obtained from a four-wire wye three-phase system requires a two-stator meter to satisfy Blondel's theorem. A departure from this theorem may be used to meter this circuit provided that the line-to-neutral voltages are balanced in magnitude and phase angle within acceptable limits.

There are two basic designs of a single-stator meter, called a network meter, that may be used for this purpose. Both designs utilize one voltage coil and two current coils. Depending on whether the voltage coil is energized from the line-to-neutral or the line-to-line voltage, one or two phase-shifting networks are employed to shift the phase of the current in one or both of the current coils in the proper amount and in the right direction to enable them magnetically to react correctly with the line-to-neutral or line-to-line voltage, respectively.

In the design utilizing a voltage coil energized by line-to-line voltage, the number of voltage-coil turns is reduced from that of a 240 V coil to compensate for the reduction in voltage from 240 V to 208 V. Either meter will register correctly on loads of any connection or power factor as long as the voltages are balanced, symmetrical, and in the correct phase sequence. Since a particular phase sequence is essential to the correct registration of this meter, a visual phase-sequence indicator is a built-in feature.

A.2.4 Two-phase circuits

A.2.4.1 Two-phase three-wire circuits

The energy in a two-phase, three-wire circuit may be metered by means of two watthour meters connected in the same way as the two wattmeters described in A.1.5.1.

A.2.4.2 Two-phase four- or five-wire circuits

The energy in a two-phase four- or five-wire circuit may be metered by substituting a watthour meter for each wattmeter specified in A.1.5.2 and A.1.5.3, and any two or more meters can be combined in a single housing and their combined registration recorded on a single register, as described in A.2.2.2.

A.2.4.3 Two-phase five-wire circuits with balanced voltages

A departure from Blondel's theorem may be used in the two- phase five-wire circuit if the voltages are balanced within acceptable limits. Two single-stator three-wire single-phase watthour meters, and described in A.2.2.3, may be used. In this case the current coils of one meter are inserted, one in each of the phase wires of one of the two phases, and the voltage coil of the meter is connected between the same two wires. The second meter is connected similarly in the other pair of phase wires. The accuracy of this method is independent of current and power factor balance, but is dependent on voltage balance. The two three-wire meters may be combined in a single housing and their combined registration recorded on a single register.

A.2.5 Three-phase circuits, all types

A.2.5.1 Methods comparable to power measurements

Using watthour meters, the energy in any form of a three-phase circuit may be metered in accordance with the methods specified for power measurements by means of wattmeters described in A.1.6.1, A.1.6.2, or A.1.6.3.

A.2.6 Three-phase, three-wire circuits

A.2.6.1 Two-stator method

The energy in a three-phase, three-wire circuit may be metered by means of a two-stator meter having its current coils connected in any two of the line conductors and the voltage coils connected between the line conductors in which the current coils are connected and the third line conductor. This method is correct for all conditions of load or voltage unbalance and for any power factor.

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A.2.6.2 Three-stator method

The energy in a three-phase three-wire circuit may be metered by means of three single-stator meters, or with one three-stator meter by establishing an artificial wye neutral for obtaining the phase voltages. Delta-wye-connected voltage transformers may be used for establishing these voltages.

A.2.6.3 Balanced voltage and load

In addition to the methods mentioned in A.2.5.1, A.2.6.1, and A.2.6.2, and under the conditions of balanced voltage and balanced load of any power factor (as long as the power factor is the same in all phases), energy in a three-phase three-wire system may be measured by a single-stator three-wire watthour meter, having its current coils connected in any two of the line conductors and its voltage coil across the same two conductors, and multiplying its reading by two. This method is useful in measuring energy used by motors or other loads having balanced characteristics.

A.2.7 Three-phase four-wire wye circuits

A.2.7.1 Three-stator four-wire wye meter

The energy in a three-phase four-wire wye-connected circuit may be metered by a three-stator wye meter. The common point of the voltage circuits should be connected to the neutral conductor. This method is accurate for all conditions (balanced or unbalanced) of load, power factor, or voltage.

A.2.7.2 Two-stator four-wire wye meter

The energy in a three-phase four-wire wye-connected circuit may be metered by a two-stator four-wire meter. According to Blondel's theorem, such a circuit would require a three-stator meter as described in A.2.7.1. However, if the voltages between each line and neutral are balanced within acceptable limits, the accuracies generally are considered to be satisfactory. Such a meter has one voltage coil and a two-section current winding on each stator. This winding consists of two coils wound in opposite directions on a common core. Thus when each of the coils is connected in its respective circuit, the magnetic effects of the currents in the two sections of the winding are additive. These windings are connected as follows: One current coil of the first stator is inserted in one line conductor and its flux reacts with the flux of the voltage coil connected between that conductor and the neutral. Similarly, one current coil of the second stator is inserted in another line conductor and its flux reacts with the flux of the voltage coil connected between that conductor and the neutral. The remaining current coils, one on each stator, are connected in series and inserted in the remaining phase conductor.

A.2.8 Three-phase four-wire delta circuits

A.2.8.1 Possible methods of metering

The energy in a three-phase, four-wire open or closed delta-connected circuit, with the neutral formed by a tap to the midpoint of one of the phase windings, may be metered either by a three-stator meter or by a two-stator, four-wire delta meter in several arrangements, provided that, in the latter case, the tapped phase voltages are balanced within acceptable limits.

A.2.8.2 Three-stator four-wire delta meter

In a three-stator meter for three-phase, four-wire delta circuits, one of the stators may have one-half the current and twice the voltage rating of the other two stators, but all three stators may be of the same rating provided that current transformers and voltage transformers of suitable different ratios are connected into the circuit. All three stators may also have the same ratings if the meter is properly calibrated to the voltages that are to be used in service, or if modern voltage coils are employed having an acceptable operating range that includes all voltages to be used.

The two current coils of equal rating are connected one in each of the conductors that have the neutral between them and their associated voltage coils connected between these phase conductors and the neutral. The one-half-rated current coil is connected in the remaining phase conductor and its double-rated voltage coil is connected between that phase conductor and the neutral. This method is accurate for all conditions of loading and power factor with or without voltage balance.

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A.2.8.3 Two-stator four-wire delta meter

If the neutral is a true mid-tap (namely, the voltages from it to each associated line conductor are equal within acceptable limits), then a two-stator meter may be used, one stator of which has a three-wire current coil or the instrument transformer equivalent thereof. The two current coils of the three-wire stator are connected one each in the two line conductors having the neutral between them and their voltage coil connected between these same two line conductors. The current coil of the two-wire stator is connected in the third line conductor and its associated voltage coil between that conductor and the neutral.

A.2.9 Three-phase seven-wire double wye-connected circuits

A.2.9.1 Three single-phase three-wire stators

The energy in a three-phase, seven-wire double wye-connected circuit may be measured by means of three single-phase, three-wire watthour meters, or their polyphase equivalent. This method is correct for all values of balanced or unbalanced current and power factor, provided that the voltages are symmetrical and balanced within acceptable limits.

A.2.10 Basic meter design considerations

The designers and manufacturers of induction watthour meters have always placed great emphasis on attaining as high a degree of inherent accuracy as is economically feasible. Induction watthour meters using modern materials and techniques are designed to function satisfactorily over a very wide load range. For these meters the terms nominal or rated load, or some multiple or fraction thereof, have no specific meaning. As a result, present-day practice classifies such a meter as Class 100 or Class 200. This means that a Class 100 meter is designed to operate continuously with acceptable accuracy up to a maximum current of 100 A, and a Class 200 meter to 200 A.

Since, however, this maximum current is not a suitable value to use when calibrating or testing a meter, the manufacturer designates the recommended value of amperes, called the 'test amperes,' to be used when calibrating the meter. For example, a Class 100 meter might have a test-ampere designation of 15 A, abbreviated as 'TA 15,' and a Class 200 meter might have a TA 30 nameplate rating. Because modern meters are frequently required to perform with acceptable accuracies at values of current, voltage, and frequency, that may differ appreciably from those used to calibrate the meter, compensating devices have been developed to maintain, within acceptable limits, the calibration accuracy at the calibrating points and over wide variations therefrom. Moreover, such devices are used to compensate for environmental conditions, such as changes in ambient temperature, and for other conditions that are not always ideal. No compensating device is perfect, but all in current use perform well within acceptable limits.

A.2.11 Factors affecting induction meter accuracy

A.2.11.1 Light loads

Due to certain nonlinear properties of even the best magnetic materials, the accuracy at very light loads (10% of Test Ampere value or less) would not be generally satisfactory if a device were not provided to correct for this nonlinearity. This is the primary function of the so-called light-load adjustment. When properly set, the accuracy at even very light loads is well within acceptable limits. In addition, this device will also compensate for any constant inherent friction or for any excess friction that might result from requiring the meter to drive auxiliary equipment such as pulse devices.

A.2.11.2 Variations in voltage

The configuration of the electromagnetic voltage current in the modern induction meter is such as to minimize the error due to variations in voltage. Even with variations as large as 50% less than rated voltage, the error is within acceptable limits, and for all variations of the order of ±10% to ±15% the variation in accuracy is usually negligible.

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A.2.11.3 Variations in power factor

An induction meter registers correctly at power factors less than unity only when a specific phase relation exists between certain of the torque-producing voltages, currents, and fluxes. This specific phase relationship is attained by means of a plate or coil, which initially can be adjusted by a calibration procedure. When correctly set, the accuracy of the meter, even at low power factors, is well within acceptable requirements. If this calibration is made with a lagging power factor and the meter is then operated at a leading power factor, a slight difference in its accuracy, usually negligible, may result.

A.2.11.4 Variations in frequency

Frequency variations in a modern power system under normal operating conditions are insignificant. Any inaccuracies that might result from variations that occur are entirely negligible. However, the presence of voltage harmonics or current harmonics created by nonlinear loads may cause measurable inaccuracies. In the vast majority of metering installations, the accuracy is still within ±2%. Cases of severe harmonic distortion must be analyzed on an individual basis.

A.2.11.5 Variations in temperature

The modern practice of placing meters outdoors has subjected meters to a wide range of ambient temperatures. Fortunately, before this practice had become general, means of compensating the induction meter for the detrimental effects of changes in ambient temperature had been developed and incorporated in all modern meters. It may be assumed with confidence that all modern meters will function satisfactorily under all reasonable variations in ambient temperature.

A.2.11.8 Surges

Meters installed in rural areas are more exposed to the elements than those in the more congested urban areas. As a result, atmospheric electrical disturbances have a greater opportunity to affect adversely the proper functioning of such meters. These disturbances are capable of producing, under certain circumstances, very large currents of short duration, called surge currents. These currents may go to ground through or in the vicinity of the meter. When this happens, the excessively large magnetic field created may affect the strength of the permanent magnets in the meter, thereby resulting in registration errors.

Present-day permanent magnets are designed to have a very strong ability to resist demagnetization. Thus, with modern meters, over-registration caused by surge currents is a rare occurrence.

In addition to surge proofing of the permanent magnets, a modern meter has built-in surge proofing for its insulation. For both voltage and current coils, built-in protective gaps to ground are used. In addition, the voltage coil has increased surge resistance across the coil.

A.2.11.9 Adverse environmental conditions

Another result of installing a meter outdoors without any protective cover, other than its own enclosure, is that the meter may be exposed to dust and corrosive atmospheres such as salt spray. Modern meters have been designed to minimize the detrimental effect of such exposures. Better sealing techniques, elimination of dissimilar metals, the use of protective coatings, stainless steels, and anodizing of aluminum are some of the precautions taken to counter the effect of adverse environmental conditions.

A.3 Measurement of power factor

A.3.1 Single-phase two-wire circuits

When the power is measured by one wattmeter in accordance with A.1.4.1, the power factor may be determined by connecting an additional wattmeter with its current coil in series with that of the first wattmeter, and with its voltage coil connected to an equal voltage displaced 90° from that applied to the wattmeter connected for the power measurement. The additional wattmeter then measures reactive power in vars. Instruments in which the required 90° shift in phase is provided internally (or by means of

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accessories), are known as varmeters. From the measurements so obtained the power factor may be determined from the following formula for sinusoidal quantities:

$$\text{power factor} = \frac{P}{\sqrt{P^2 + Q^2}}$$

where:

P = active power
Q = reactive power

A.3.2 Single-phase and polyphase circuits

When the power is measured by one or more wattmeters in accordance with A.1.4, A.1.5, or A.1.6.1, the power factor of each measured phase is equal to the power, in watts, indicated by each wattmeter divided by the product of the voltage across the voltage circuit of the wattmeter and the current in the current coil of the wattmeter.

A.3.3 Balanced three-phase three-wire circuits

In the case of a balanced three-phase three-wire circuit, where the power is measured by two wattmeters (see A.1.6.2), the readings of the two wattmeters will be unequal when the power factor is less than unity, and if the power factor is less than 0.5 lag, the reading of one wattmeter will be negative.

A.3.4 System power factor

When both voltages and currents are balanced in any three-phase circuit, the system power factor may be determined from the following formula:

$$\text{power factor} = \frac{P}{\sqrt{3}\,EI}$$

where:

P = active power
E = line-to-line voltage
I = line current

A.3.5 Interval Power Factor

When a polyphase system is unbalanced in any manner, the system power factor ceases to have a specific physical meaning, such as the cosine of some particular phase angle. However, a numerical ratio can be obtained, called the interval power factor, and is defined as follows:

$$\text{power factor} = \frac{P_t}{\sqrt{(P_t)^2 + (Q_t)^2}}$$

where:

Q_t = product of total reactive power and time (as measured by a varhour meter)
P_t = product of total active power and time (as measured by a watthour meter)

The quantity thus defined is not, in general, equal to the average value of the power factor during the interval, but may be referred to as the interval power factor.

A.4 Measurement of quadergy (varhours)

A.4.1 Electromechanical meters

Single-phase quadergy (varhours) may be measured with a varhour meter, usually a watthour meter with the current through the voltage coil displaced 90° in phase from normal. A polyphase varhour meter, or an unmodified polyphase watthour meter used with an appropriate phase-shifting transformer, may be used to measure polyphase quadergy. If both leading and lagging quadergy are to be measured, two

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such meters with opposite displacements, and equipped with detents to prevent backward rotation, are usually required. To avoid this, a polyphase Q-hour meter, in which the voltages are lagged by 60° can be used, along with a polyphase watthour meter. The voltage shift for a Q-hour meter can be obtained by either internal or external connections to the polyphase circuit. The Q-hour meter rotates in its normal direction for load phase angles from 30° lead to 150° lag. Quadergy in varhours, for a balanced-voltage system, can be computed from the meter reading with the formula:

$$\text{varhours} = \frac{(Q-\text{hours}) - (\text{watthours} \times \cos 60°)}{\sin 60°}$$

A.4.2 Electronic Meters

Electronic meters provide measurements of reactive energy (quadergy) along with active energy in one multifunction meter. The required 90° phase shift is accomplished internally by electronic means, eliminating the phase-shifting transformers or cross-connections needed to measure reactive energy with electromechanical meters. Multiple registers are usually provided to measure reactive energy flow in both directions. The phase angle of the current with respect to the voltage is expressed in terms of leading or lagging power factor.

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APPENDIX B
(Normative)
Standards and Standardizing Equipment

B.1 General
The purpose and scope of this section is to specify the standards of electrical measurement and of time interval to which the metering of electric energy shall be referred, and to outline an appropriate chain of intermediate steps between the national standards of measurement and the watthour meters used in the meter shop.

B.2 Final authority
The duties of the National Bureau of Standards,9 US Department of Commerce, include the following function assigned by Public Law 619 of the 81st Congress (64 Stat 371, 5USC 271-286): "The custody, maintenance, and development of the national standards of measurements, and the provision of means and methods for making measurements consistent with these standards." In addition, Public Law 617 (Section 12) of the 81st Congress (Title 15, USCA Sec 223, 224) reads as follows: "It shall be the duty of the National Bureau of Standards to establish the values of the primary electric units in absolute measure, and the legal values for these units shall be those represented by, or derived from, national reference standards maintained by the National Institute of Standards and Technology (NIST)."

B.2.1 Electrical units
The present units, as stated in Public Law 617 of the 81st Congress (Title 15, USCA Sec 223, 224) are defined in terms of the cgs (centimeter-gram-second) electromagnetic units, as follows:

B.2.1.1 The unit of electrical resistance shall be the ohm, which is equal to one thousand million units of resistance in the centimeter-gram-second system of electromagnetic units.

B.2.1.2 The unit of electric current shall be the ampere, which is one-tenth of the unit of current in the centimeter-gram-second system of electromagnetic units.

B.2.1.3 The unit of electromotive force (emf) and of electric potential shall be the volt, which is the electromotive force that, steadily applied to a conductor whose resistance is one ohm, will produce a current of one ampere.

B.2.1.4 The unit of electric quantity shall be the coulomb, which is the quantity of electricity transferred by a current of one ampere in one second.

B.2.1.5 The unit of electrical capacitance shall be the farad, which is the capacitance of a capacitor which is charged to a potential of one volt by one coulomb of electricity.

B.2.1.6 The unit of electrical inductance shall be the henry, which is the inductance in a circuit such that an electromotive force of one volt is induced in the circuit by variation of an inducing current at the rate of one ampere per second.

B.2.1.7 The unit of power shall be the watt, which is equal to ten million units of power in the centimeter-gram-second system, and which is the power required to cause an unvarying current of one ampere to flow between points differing in potential by one volt.

B.2.1.8 The units of energy shall be (a) the joule, which is equivalent to the energy supplied by a power of one watt operating for one second, and (b) the kilowatthour, which is equivalent to the energy supplied by a power of one thousand watts operating for one hour.

B.2.1.9 The unit of time interval is the atomic second, defined in 1967 by international agreement as a certain number of periods of a specified atomic transition of cesium 133.

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B.3 National Standards

The national standards of electrical measurement are those that are maintained by the National Institute of Standards and Technology. (See Figure B1 for a traceability-path diagram.)

B.3.1 Standard of Resistance

The standard of resistance is maintained by the National Institute of Standards and Technology (NIST) and is based on absolute measurements in terms of length and time. The value of the national standard of resistance (the NIST representation of the ohm) is maintained in terms of the average of a reference group of stable one-ohm resistors the values of which are periodically monitored using the quantized Hall effect. This effect produces resistances proportional to h/e^2 where h equals Planck's constant and e equals the charge of the electron. The value of h/e^2 is assigned by international agreement.[1]

B.3.2 Standard of Electromotive Force

The standard of electromotive force maintained by the National Institute of Standards and Technology is based on absolute measurements by various national laboratories of the ohm and the ampere in terms of mass, length, current, and time. The value of the national standard of emf (the NIST representation of the volt) is maintained in terms of physical constants by means of the Josephson effect that is used to check the stability of a reference group of saturated mercury-cadmium-amalgam standard cells. The Josephson effect produces voltages proportional to 2e/h, where e equals the charge of the electron and h equals Planck's constant. The value of 2e/h is assigned by international agreement.

B.3.3 Other Electrical Standards

The values of the national standards for other electrical quantities, such as energy, are derived either directly or indirectly from the values of the national standards of resistance and emf, or (in the case of capacitance) obtained directly from computable standards constructed for absolute-ohm determinations.

B.3.4 Standard of Time Interval

Standard frequencies and time intervals are broadcast continuously by the National Institute of Standards and Technology and the Naval Observatory. The time- interval signals as broadcast and received are of very high accuracy (much better than one part in a million), and are appropriate to use without corrections in verifying the rate of a laboratory standard clock or other reference interval timer.

B.4 Establishing a Local Reference Standard of Energy

Calibrations and tests whose purpose is the establishment or maintenance of a local reference standard of energy measurement (see B.6.9) shall be carried out in a location and manner capable of maintaining the accuracy required of the standards used in verifying electricity meters. The sequential steps intermediate between the national standard of resistance and electromotive force and the local means of measuring energy are carried out at several functional levels, which may, but need not, be within the capabilities of a single laboratory. In many cases some or all of the steps may be carried out in the local meter laboratory. In others the local reference standard of energy may be compared (often by transport standards) with the national standard of electric energy or with standards of an independent laboratory that have been properly verified.

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[1] Guidelines for implementing the New Representations of the Volt and Ohm Effective January 1, 1990, NIST Technical Note 1263, June 1989.

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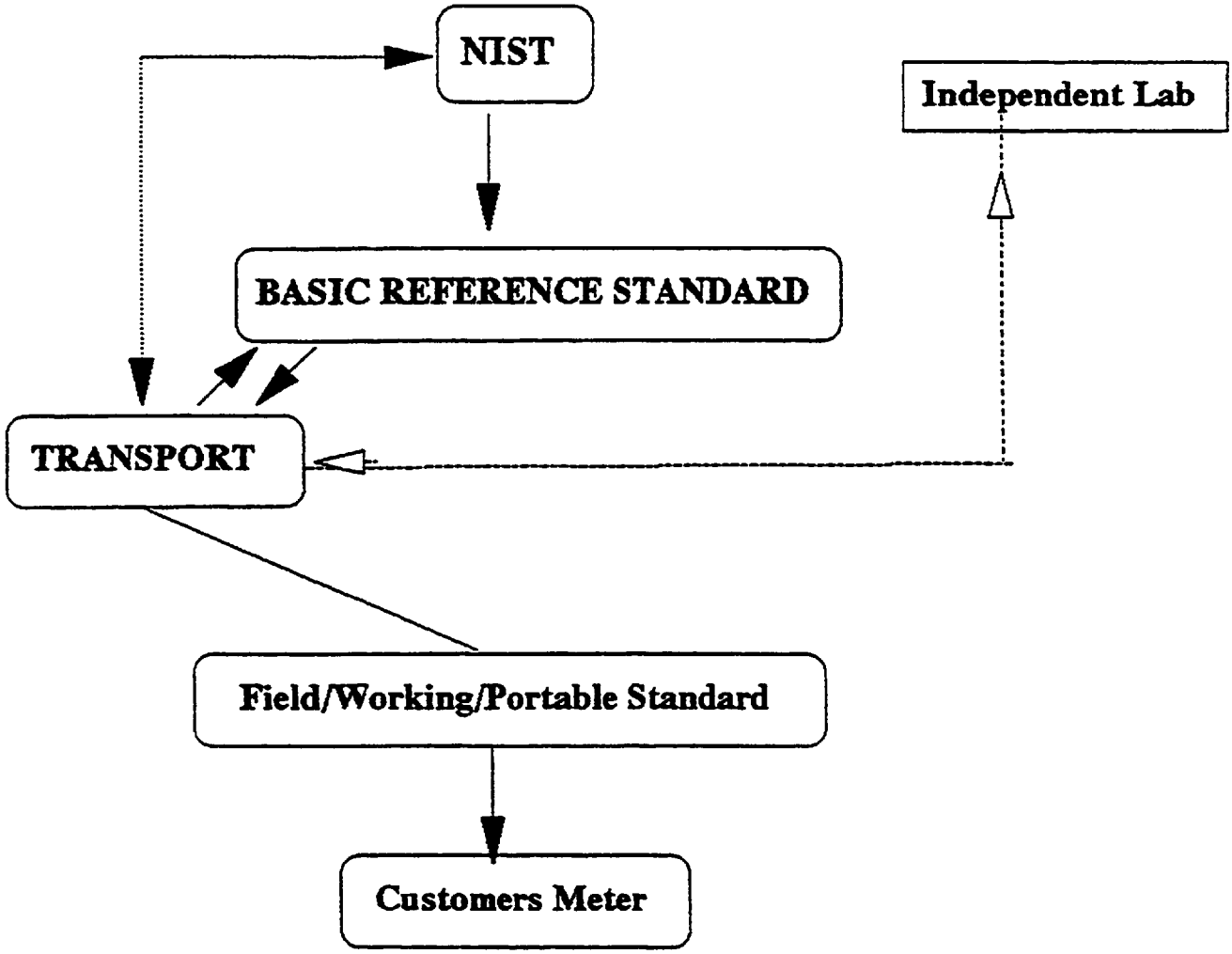


Figure B1 – Traceability path diagram

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B.4.1 Meter laboratory[2]

The meter laboratory is concerned with two functions:

— Maintaining standards whose values are assigned either directly or indirectly in terms of the national standards.

— Assigning values to the working standards essential to the measurement of electrical quantities.

It may be equipped and staffed to make calibration tests at some or all of the sequential steps intermediate between the national standards of resistance, emf, and time interval, and a local reference standard of energy measurement (such as a group of watthour meters).

B.4.2 Meter shop

The meter shop is concerned with the routine testing, repair, and calibration of electricity meters and of the auxiliary devices and equipment essential to the metering of electric energy and power.

B.4.3 Independent standards laboratory

An independent standards laboratory is maintained by and responsible to a company or authority other than the one that maintains the particular meter laboratory under consideration. If a meter laboratory does not carry out the entire chain of sequential measurements between the national electrical standards and the local energy standard, it must depend on an independent standards laboratory to make some of the required calibrations in this measurement chain. Alternatively, interlaboratory comparisons of reference standards with an independent standards laboratory are always informative and, in some instances, are needed to maintain the integrity of the local reference standards. In B.6 the equipment required for a standards laboratory to make all of the sequential calibration steps of interest in a meter laboratory is listed. This listing may be of assistance in determining whether a particular standards laboratory is adequately equipped to perform a specific calibration task.

B.5 Laboratory conditions

In a meter laboratory it is essential that ambient conditions, such as temperature and humidity, be maintained at values and within limits appropriate to the measurements made in the laboratory; and that other ambient factors that could interfere with proper measurement, such as atmospheric contaminations, mechanical disturbances, electrical and magnetic interference, and noise, be held to such levels that normal measurement techniques and results are not adversely affected.

B.5.1 Reference temperature and humidity

The ambient temperature in the meter laboratory shall be 23°C,13 with tolerances that depend upon the effects of temperature on the standards used and the apparatus under test. This temperature should be held constant not only during a test or calibration procedure, but also for a preceding period sufficient to ensure effective temperature equilibrium in the test equipment and in the device being tested. When the reference standards of a laboratory are assigned or checked at a temperature different from that at which they will be used, temperature corrections should be known and applied where significant.

The ambient relative humidity should be kept to values low enough that electrical insulation in the equipment used will not be affected. Relative humidities below 55% should be adequate for this purpose. In the absence of adequate shielding and guarding of laboratory instruments and circuits, the effects of bound electrostatic charges may be troublesome at very low humidities. However, shielding may well be a simpler and better solution to this problem than an attempt to hold humidity above some specified minimum value, say 40%. Any system that controls laboratory humidity within specified upper and lower limits should be designed to avoid excessive humidity in the event of the failure of the control element.

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[2] NCSL RP-10-1991 Establishment and Operation of an Electrical Utility Metrology Laboratory, Recommended Practice, National Conference of Standards Laboratories.

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B.5.2 Laboratory power sources

Direct- and alternating-current supplies used in the laboratory for calibration of instruments or meters, or for the measurement of voltage, current, or power, should be closely regulated, since fluctuations in the value being held can limit the accuracy of a calibration or measurement.

Rectified direct-current supplies should be substantially free from ripple, since the presence of ripple and its waveform have different effects on instruments having peak, average, or rms response.

Alternating-current supplies should be substantially free from waveform distortion, and the phase relation of combined current and voltage supplies should be capable of close regulation, since these factors may also influence calibration and measurement accuracy. For the most accurate watthour meter calibrations, the third harmonic in the current wave should not exceed 0.5% of the fundamental, and other harmonics in the current and voltage waves should not exceed 1.0%.

B.6 Laboratory reference standards

Laboratory reference standards are those standards that are used to assign and check the values of laboratory secondary standards.

B.6.1 Stability of reference standards

One of the most important characteristics of a reference standard is its stability; that is, the constancy of its assigned value with time.

The use of reference standards should be limited to assigning and checking the values of secondary standards. Reference standards should not be exposed to the hazards of accidental misuse that occasionally occur in routine measurements. Further advantages may accrue if the basic reference standards of a laboratory never leave it; that is, are never subjected to transportation hazards. In this case, special transport standards must be available for the periodic interlaboratory comparison tests that act as a check on the stability of the basic reference standards.

B.6.2 Basic reference standards

The basic reference standards of a laboratory are those standards with which the values of the electrical units are maintained in the laboratory, and that serve as the starting point of the chain of sequential measurements carried out by the laboratory. If the laboratory is to perform the entire sequence of measurements between the national electrical standards and the local standard of energy measurement, its basic reference standards are standard cells (preferably saturated cells) and appropriate resistance standards.

B.6.2.1 Intercomparison

Ideally, the basic reference standards of a laboratory should be maintained in groups of three or more separate individual units that can be intercompared readily, since three is the minimum number of units for which a change in one of them can be both detected and located by intercomparison.

B.6.3 Transport standards

Transport standards are standards of the same nominal value as the basic reference standards of a laboratory, and preferably of equal quality. Such standards are regularly intercompared with the basic group to maintain a history of their behavior, and are reserved for periodic inter-laboratory comparison tests that act as checks on the stability of the basic reference group.

In some cases, specially calibrated transport standards are used in a Measurement Assurance Program (MAP) to aid in the achievement of measurement quality control and to link the measurements in the laboratory to national standards.

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B.6.4 Voltage references

Both electrochemical and solid-state voltage references are widely used to maintain the unit of voltage in the laboratory.

B.6.4.1 Standard cells

For meter laboratories, the best practical reference standard of emf is a group of saturated mercury-cadmium-amalgam standard cells maintained at a constant temperature in a stirred oil bath or in a constant-temperature air bath. In either case, adequately sensitive and stable means should be available to check the bath temperature and its constancy.

B.6.4.2 Unsaturated standard cells

A group of unsaturated cells, each of which has been allowed to come to equilibrium in a container designed to minimize temperature gradients, provides a standard that is generally adequate for meter laboratories, if the cells are intercompared frequently to guard against changes brought about by misuse or accident and if the emfs of at least two of the cells have been checked against a saturated-cell reference standard within the preceding 12 months. (The emf of an unsaturated of an unsaturated cell generally decreases slowly with time, usually less than 100 μV a year.) The emf of each cell in the local unsaturated group should be reassigned in terms of the transport cells checked against the saturated reference group, after they have been intercompared to ensure that they have not been damaged in transportation and have recovered stable values.

B.6.4.3 Solid-state voltage standards

Carefully selected solid- state devices with appropriate auxiliary circuitry can provide predictable voltage values with stabilities approaching those of saturated standard cells.

B.6.5 Standard resistors

Minimum requirements should include reference standards at the 1 Ω level, and at decimal multiples and submultiples of the ohm, over the range of resistance required for both resistance and current measurement. Generally, standards covering the range from 10^{-6} to 10^{4} Ω are useful, unless the range of measurements to be undertaken in the laboratory is specifically known to be less.

Additional standards having the following intermediate values of 0.002, 0.005, 0.02, 0.05, 0.2, 0.5, 2, 5, and 20 Ω are convenient since they permit the calibration of most values of current shunts by direct substitution techniques without the precise calibration of bridge ratio arms. Alternatively, a precise 2:1 ratio can be established from the combinations of three nominally equal standards.

B.6.6 DC ratio devices

A dc ratio device is an arrangement of resistors for establishing one or more ratios in an accurately known way. Devices of this kind are used to compare the ratio of two resistors or of two direct voltages. An essential requirement of a dc reference ratio standard is that it be stable with time, and minimally affected by ambient conditions or by loading.

B.6.6.1 Reference standard volt box

A reference standard volt box is one in terms of which the ratios of other volt boxes can be accurately assigned. It must have the following characteristics:

— It must be subdivided to facilitate internal self-calibration.

— Its components must be guarded or otherwise be adequate to eliminate errors from leakage currents across insulating members.

— It must be designed to avoid or minimize changes in ratio resulting from self-heating at rated voltage or from ambient temperature changes.

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B.6.6.2 Reference voltage dividers
Reference voltage dividers are networks of 4-terminal resistors of nominally equal value that are connected permanently in series and in which the resistors can be placed in parallel or series-parallel combinations to achieve 10:1 or 100:1 resistance transfer ratios that are capable of accuracies of the order of 1 part in 10^8.

B.6.6.3 Universal ratio set and Kelvin-varley divider
These are means for calibrating dc potentiometers and other adjustable resistance-type voltage dividers.

B.6.6.4 Resistance bridges
The Wheatstone bridge for two-terminal resistance measurements and the Kelvin bridge for four-terminal measurements are indispensable intermediate-level calibration tools. Such bridges, of high quality and proven stability, can be used in substitution techniques for the intercomparison of reference standard resistors or for the assignment of working standard resistors of nominally equal values. For the general assignment of resistance values where substitution techniques are not applicable, such bridges require periodic calibration using standards of high quality with an appropriate technique.

B.6.6.5 Direct-current comparator
Appropriately designed direct-current comparators based on the equality of ampere-turns in two or more windings on a modulated magnetic core are means for making dc ratio, resistance, and voltage measurements.

B.6.7 AC ratio devices
Current and voltage ratios are usually established in terms of instrument transformers. The ratio of the primary to secondary current (or voltage) and the phase angle between them are dependent on the frequency and the magnitude of the primary quantity and on the burden of the secondary circuit. The ratio and phase-angle corrections of reference transformers shall be established at the expected operating level and for the burden with which the transformer will be used.

B.6.7.1 Transformer test set
A transformer test set is a means of determining the corrections of an instrument transformer in terms of either an alternating-current comparator or a reference standard transformer, usually having the same nominal ratio.

B.6.8 AC-DC transfer standards
A transfer device is required to establish the equality of an rms alternating current or voltage, or the average value of alternating power, with the corresponding steady-state dc quantity that can be referred to the basic standards through scaling techniques. Such transfer standards for use at power frequencies employ electrothermic, electrodynamic, electrostatic, or electronic operating principles.

B.6.8.1 Stability
The transfer characteristics of an ac-dc transfer standard (that is, its ac-dc differences) are functions of its geometry, its electrical parameters, and its operating level, and should not change significantly with time. Hence, the transfer characteristics of an instrument need be determined infrequently, unless the components of its measuring circuit are modified or replaced, or their physical arrangement altered. However, the dc calibration of a transfer instrument should be verified periodically.

B.6.9 Reference standard of energy
One or more highly stable standard watthour meters operating under closely controlled conditions can be used to maintain the unit of energy in the laboratory and to calibrate the next level of standards. Such an energy standard is maintained in many laboratories as an essential part of their reference equipment, frequently in conjunction with instrument transformers having appropriate ratios, such that the reference standard watthour meter can always be operated at the same current and voltage level, regardless of the

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current or voltage requirements of the meters compared with the reference meters. Usually such standards are housed in a temperature-controlled environment and are continuously energized.

B.6.10 Time interval

The reference standard of time interval in a laboratory may be a clock or other counting device whose rate is controlled by an appropriately compensated pendulum, or by a crystal or tuning-fork oscillator in a suitably controlled environment. Its operation should be such that the time-interval signals for laboratory use are produced without significant reaction on the rate-regulating mechanism. Such a standard can be checked at any time, or continuously monitored, using signals broadcast by the National Bureau of Standards or the Naval Observatory.

B.6.11 Periodic verification of reference standards

B.6.11.1 Standard cells and solid-state voltage references

The voltage references with which the value of the volt is maintained in a laboratory should be intercompared at frequent intervals, and should be compared at suitable intervals with appropriate voltage references maintained by an independent standards laboratory of recognized standing, preferably using special transport standards. If the local reference group consists of unsaturated cells, they should be compared with saturated reference cells at intervals not to exceed 1 year. If the reference group consists of saturated cells, the interval between comparisons with an independently maintained group of saturated cells may be increased after the stability of the group has been established.

B.6.11.2 Resistance standards

The reference standard resistors, with which the resistance unit is maintained in a laboratory, should be intercompared frequently, and should be verified by an independent standards laboratory at intervals not longer than 2 years.

B.6.11.3 Ratio and transfer standards

Ratio standards (either ac or dc) and ac-dc transfer standards should be verified periodically or whenever there is reason to suspect a change in their performance, and when self-checking features do not eliminate the uncertainty in question.

B.6.11.4 Reference standard of energy

Watthour meters used as reference standards to maintain the unit of energy should be intercompared at frequent intervals. In addition, their registrations shall be determined periodically by appropriate calibrations.

B.7 Laboratory secondary standards

The secondary standards of a laboratory are those that are used in the routine calibration tasks of the laboratory. They are checked in terms of the laboratory reference standards, and are used for calibration of shop instruments and meters, as well as for other routine measurement tasks for which moderately high accuracy is required.

B.7.1 Voltage measuring equipment

The basic working standard equipment of a meter laboratory should include one or more high-quality digital voltmeters and shunts having ranges and accuracies appropriate for all required voltmeter and wattmeter calibration checks.

B.7.2 Indicating instruments

B.7.2.1 Accuracy classes

It should be realized that the accuracy class designation (see ANSI C39.1) of an analog instrument is a specification of its performance under reference conditions and immediately after its circuit is energized. When the instrument is used under other than reference conditions, the stated class accuracy may not be realized; in particular, the influence of sustained operation on the instrument response may be

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significant. Hence, for best accuracy the conditions under which the dc calibration is checked should approximate the use condition as nearly as practicable. The difference between the ac response and the average of reversed dc indications for a signal of equivalent magnitude should not be significantly affected by time in circuit, so ac-dc differences need not be redetermined for difference use situations. The rated accuracy of a digital voltmeter applies over fairly wide operating conditions (see the manufacturer's specifications). Some ac digital voltmeters respond to the average rather than the rms value, and should be used with caution on distorted waveforms.

B.7.2.2 Instrument bearings or suspensions

Secondary standard instruments having pivot-and-jewel bearings should have permanent locations in the laboratory, and should be moved as little as possible to avoid bearing damage with consequent increased friction. Instruments having taut-band suspensions are free from frictional errors and are not generally damaged by reasonable laboratory handling.

B.7.2.3 Range extension

The range of ac instruments may be extended by the use of instrument transformers whose corrections are known for the particular instrument burden with which they are to be used. The range of ac instrument voltage circuits may also be extended by use of series resistors, but this means of range extension is usually limited to 600 V.

B.7.3 Watthour meters

Secondary standard watthour meters of appropriate ranges, compensated as fully as practicable for the various known sources of error, are often required for determining the accuracy of registration of the portable standard watthour meters used in shop and field testing and adjustment operations.

B.7.4 Calibration checks

Even when the secondary standards of a laboratory have been demonstrated to be stable, the hazards of accidental change or injury through misuse in the daily operation of the laboratory may be present. Hence, frequent calibration checks constitute insurance against faulty measurements remaining undetected for an extended period.

B.7.4.1 Voltage measuring accessories

Secondary standard resistors for current measurements (shunts), volt boxes, and standard cells should be verified at frequent and regular intervals in terms of the appropriate laboratory reference standard.

B.7.4.2 Digital voltmeter (multimeters) calibrations

Digital voltmeters (multimeters) should be calibrated with external standards at intervals recommended by the manufacturer, but not less than once a year. Built-in self-test features should be used each day measurements are made; these tests complement but do not replace calibrations with external standards.

B.7.4.3 Calibration of indicating instruments

One or more cardinal points of the dc calibration of secondary standard indicating instruments should be verified using a digital voltmeter of appropriate accuracy or potentiometrically at intervals of 2 weeks to 3 months, depending on frequency of use; and a complete dc check throughout their working range should be made at intervals of 3 months to a year. Direct- and alternating-current calibration consoles (adjustable, direct-reading power supplies) are very convenient for routine testing of instruments. The periodic calibrations of such consoles (usually with dc potentiometers and dc-ac transfer standards) should be carefully considered.

B.7.4.4 Watthour meters

Watthour meters used as secondary standards should be intercompared at frequent and regular intervals, and their registration errors redetermined by a power-time integration procedure or by comparison with reference-standard watthour meters (see B.6.9) at intervals not to exceed six months.

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B.8 Shop instruments

Shop instruments are instruments and meters that are used in regular routine shop or field operations. Their calibrations should be verified in terms of appropriate laboratory secondary standards.

B.8.1 Indicating instruments

Portable ammeters, voltmeters, and wattmeters used in the regular operation of the meter shop should be of good quality and of appropriate ranges. Analog instruments should not be operated at less than one third of their end-scale value. Depending on the accuracy desired for the particular measurement being made, Classes 0.25 or 0.5 (or in some instances even 1.0) may be appropriate. The corrections to shop instruments should be regularly and frequently redetermined, using laboratory secondary-standard instruments.

B.8.2 Portable standard watthour meters

Portable standard watthour meters that are in constant use should be checked at least twice a month on a commonly used current and voltage range. Corrective action should be taken such as complete recalibration or repair, when the registration at the commonly used check points deviates by more than acceptable limits.

B.9 Performance records

Continuing records should be kept of the performance of each instrument and standard in the laboratory or shop. Where this record shows excessive variation between tests, the equipment should be subjected to special investigation to determine the cause of the variation. If the cause cannot be determined and corrected, use of the instrument or standard should be discontinued.

B.9.1 Importance of records

Continuing records of the performance of instruments and standards are important for a number of reasons:

— They can be informative as to the quality of the laboratory equipment and the competence of laboratory personnel.

— The value of a standard increases as proof of its stability accumulates.

— Continuous performance records assist in decisions whether to keep, demote, or discard a standard or instrument.

— Continuous records assist in decisions concerning the interval between calibration or verification tests of an instrument or standard.

B.10 Abnormal conditions

Whenever a standard is suspected of having been subjected to abnormal conditions or treatment, it should be checked regardless of the time that has elapsed since its last calibration check. Resistance apparatus that has suffered an abrupt change in value because of misuse will sometimes drift during a few weeks or months before stabilizing at a different value.

B.11 Instrument specification

ANSI C39.1 is suggested as a guide in specifying the quality and performance characteristics of portable and laboratory standard indicating instruments.

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B.12 Acceptable performance of standard watthour meters

B.12.1 General

B.12.1.1 Acceptable standard watthour meters

In order to be acceptable, new standard watthour meters shall be capable of conforming to mechanical requirements as specified in B.12.2 (Portable Standard Meters) or B.12.3 (Reference Standard Meters), and the performance requirements as specified in B.13.2 (Portable Standard Meters) or B.13.3 (Reference Standard Meters), and Table B.1 and B.2, which are intended to determine their reliability and acceptable accuracy insofar as these qualities can be demonstrated by laboratory tests. In general, all of the listed tests should be made on each new type of standard watthour meter and most of them should be made on each new standard meter of the same type, dependent on the needs of the particular laboratory. Two kinds of standard watthour meters are recognized: portable standard watthour meters, which are used for shop and field tests, and reference standard watthour meters, which are used to maintain the unit of energy in the meter laboratory.

B.12.1.2 Adequacy of testing laboratory

Tests for determining the acceptability of the types of standard meters under these specifications shall be made in a laboratory having adequate facilities, using instruments of an order of accuracy and precision capable of verifying conformance to the specifications. These instruments should be checked against the laboratory reference standards before and after the tests. The tests shall be conducted by personnel who have thorough practical and theoretical knowledge of meters and adequate training in making precision measurements.

B.12.1.3 Tolerances

The standard meter under test shall be considered to be within the specified limit unless the test result exceeds the limit by more than the value of the measurement uncertainty assigned to cover the possible errors in the laboratory reference standards, observations, and procedures.

B.12.2 Mechanical requirements for portable standard meters

B.12.2.1 General

All parts that are subject to corrosive influence under normal working conditions shall be effectively protected against corrosion due to atmospheric causes. Any protective coating shall not be liable to damage by ordinary handling or injuriously affected by exposure to air under ordinary conditions. The construction of the meter shall be suitable for its purpose in all respects, and shall give assurance of permanence in all mechanical, electrical, and magnetic adjustments.

B.12.2.2 Adjusting devices

Adjusting devices shall be self-locking or, alternatively, shall be capable of being locked in position, and the action of such locking devices should not alter the adjustment of the standard meter. All mechanical, electrical, and magnetic adjustments shall be capable of fine control, and shall be of such design as will give assurance of permanence.

B.12.2.3 Optional leveling means for induction-type meters

A level indicator may be provided on the top of the standard meter in a position easily read when the standard meter is in use. The sensitivity of the indicator shall be such that a departure from level of 0.5° is readily detectable. Facilities for adjusting the level of the standard meter shall be provided.

B.12.2.4 Case

The case shall be of sufficient strength to afford to the working parts adequate protection against damage under normal conditions of handling, usage, and transport; and it shall afford to the interior substantial protection against the entry of dust. Portable standard meters should be fitted with a detachable cover to enclose the readout, terminals, and controls, and be equipped with a substantial carrying strap. The inside of the cover should include a means for attaching a calibration card.

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B.12.2.5 Sealing
Provision shall be made for the sealing of the standard meter to detect unauthorized access to working parts and to electrical and magnetic adjusting devices.

B.12.2.6 Window
A window of glass or other suitable transparent material shall be provided to permit a clear view of the readout. It shall be substantially dusttight and shall be replaceable.

B.12.2.7 Terminals
Terminal identification shall be adjacent to each terminal and shall be of a permanent nature.

B.12.2.8 Register (counting mechanism)

B.12.2.8.1 Register scales
For standard watthour meters with pointer and dial-type readouts, the register shall have a sweep-hand scale and not less than two totalizing scales. The tip of the sweep hand shall traverse its scale in such a manner as will permit accuracy of reading. One revolution of the sweep hand shall represent one revolution of the rotor. It shall be so designed as to minimize parallax error and be readable to 1/100 of a revolution. Totalizing scales shall be graduated and suitably marked in multiples of 10 and shall totalize to not less than 100 revolutions of the sweep hand.

B.12.2.8.2 Provision for photoelectric sensing
The sweep hand of standard watthour meters with pointer and dial-type readouts shall be provided with a reflective area suitable for external photoelectric sensing.

B.12.2.8.3 Digital readouts
Standard watthour meters with digital readout shall have a resolution corresponding to at least 1/1000 of a revolution of a pointer-type register for a meter of similar current and voltage ranges, and shall be capable of totalizing at least 100 equivalent revolutions. Alternatively, they shall have a readout in other suitable units, such as percentage registration, with an equivalent resolution.

B.12.2.8.4 Readout reset
A readily accessible reset device shall be fitted so that all pointers or the digits of the readout may be simultaneously reset to zero by a single operation. Such operation shall not permanently distort the spindles of the pointers (where applicable).

B.12.2.8.5 Register lubrication
The register gear train shall not require lubrication.

B.12.2.9 Optional provision for pulse output
A pulse output may be provided such that the number of pulses is proportional to the energy measured. Connections to the pulse output shall be readily accessible on the outside of the standard meter.

B.12.2.10 Overcurrent protection
Current coils may be protected by a fuse or other means. If a fuse is used, it shall be replaceable from the outside.

B.12.2.11 Nameplate
A nameplate shall be provided on the outside of the case to show all necessary information, including manufacturer, type, serial number, voltage ratings, current ratings, frequency, model number, and watthour constant (K_h) or energy constant (K_e) at basic voltage and current ratings.

B.12.2.12 Rotor brake (induction-type meters)
A suitable rotor brake shall be provided to prevent rotor drift when current only is applied.

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B.12.3 Mechanical requirements for reference standard meters

B.12.3.1 General
All parts that are subject to corrosive influence under normal working conditions shall be effectively protected against corrosion due to atmospheric causes. Any protective coating shall not be liable to damage by ordinary handling or injuriously affected by exposure to air under ordinary conditions. The construction of the meter shall be suitable for its purpose in all respects, and shall give assurance of permanence in all mechanical, electrical, and magnetic adjustments.

B.12.3.2 Adjusting devices
Adjusting devices shall be self-locking or, alternatively, shall be capable of being locked in position, and the action of such locking devices should not alter the adjustment of the standard meter. All mechanical, electrical, and magnetic adjustments shall be capable of fine control, and shall be of such design as will give assurance of permanence.

B.12.3.3 Leveling means for induction-type meters
A level indicator shall be provided on the top of the standard meter in a position easily read when the standard meter is in use. The sensitivity of the indicator shall be such that a departure from level of 0.5° is readily detectable. Facilities for adjusting the level of the standard meter shall be provided.

B.12.3.4 Case
The case shall be of sufficient strength to afford to the working parts adequate protection against damage under normal conditions of handling, usage, and transport; and it shall afford to the interior substantial protection against the entry of dust.

B.12.3.5 Sealing
Provision shall be made for the sealing of the standard meter to detect unauthorized access to working parts and to electrical and magnetic devices.

B.12.3.6 Window
A window of glass or other suitable transparent material may be provided, if applicable, to permit a clear view of the readout. It shall be substantially dusttight and shall be replaceable.

B.12.3.7 Terminals
Terminal identification shall be adjacent to each terminal and shall be of a permanent nature.

B.12.3.8 Digital readouts
Standard watthour meters with a digital readout shall have a resolution corresponding to at least 1/1000 of a revolution of a pointer-type register for a meter of similar current and voltage ranges, and shall be capable of totalizing at least 100 equivalent revolutions. Alternatively, they shall have a readout in other suitable units, such as percentage registration, with an equivalent resolution.

B.12.3.8.1 Readout reset
A readily accessible reset device shall be fitted so that the digits of the readout may be simultaneously reset to zero by a single operation.

B.12.3.9 Provision for pulse output
A pulse output shall be provided such that the number of pulses is proportional to the energy measured. Connections to the pulse output shall be readily accessible on the outside of the standard meter.

B.13 Performance requirements for standard watthour meters

B.13.1 General test conditions
The standard meter under test shall be in good operating condition, and its registration on the basic current and voltage ranges shall be adjusted as nearly as practicable to 100% with 25% and 100% rated

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current at 1.0 power factor, and with 100% rated current at 0.5 power factor. The meter shall be energized on the basic range at 100% rated current and voltage for at least 1 hour prior to test. Unless otherwise specified, all tests shall be made of the basic range, and the conditions listed in B.13.1.1 through B.13.1.8 shall apply. All tests at other that unity power factor are with current lagging, unless otherwise noted.

B.13.1.1 Applied voltage
The applied voltage shall be constant to within ±1.0%.

B.13.1.2 Applied current
The applied current shall be constant to within ±1.0%.

B.13.1.3 Phase angle
The phase angle shall be constant to within ±2°.

B.13.1.4 Frequency
The frequency shall be 60 Hz and be constant to within ±0.2%.

B.13.1.5 Waveform distortion
The total harmonic distortion of the applied voltage and current shall not exceed 2.0%.

B.13.1.6 Ambient temperature
The ambient temperature shall be 23°C ±2°C.

B.13.1.7 Level
Standard watthour meters of the induction type shall be level to within ±0.5°.

B.13.1.8 External magnetic field
Strong magnetic fields may affect performance of standard meters. Care should be taken to avoid placing the meters in proximity of transformers and loops of current test leads.

B.13.1.9 Insulation
The insulation between current-carrying parts of separate circuits and between current-carrying parts and other metallic parts shall conform to ANSI/ISA S82.01, Section 9.12, and shall be capable of withstanding the application of a sinusoidal voltage of 2.3 kV rms, 60 Hz, for 1 minute.

B.13.2 Performance requirements for portable standard meters

B.13.2.1 Drift
Test Condition (1): With 250% rated current and with the voltage circuit open, the indication must not change perceptibly in 1 min.

Test Condition (2): With 100% rated current, the braking device on standard watthour meters of the induction type shall immediately release the rotor when 70% rated voltage is applied.

B.13.2.2 Effect of a variation of current at 1.0 power factor
Test Condition (1): With 50%, 150%, and 200% of rated current, the registration shall not differ from the value at 100% of rated current by more than the amount specified in Table B1.

B.13.2.3 Effect of variation of current at 0.5 power factor
Test Condition (1): With 50% and 200% of rated current, the registration shall not differ from the value at 100% of rated current by more than the amount specified in Table B1.

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B.13.2.4 Effect of variation of voltage at the power factors indicated in table B1
Test Condition (1): With 25% of rated current at 1.0 power factor, the registration at 90% and 110% of rated voltage shall not differ from the value at 100% of rated voltage by more than the amount specified in table B1.

Test Condition (2): With 100% of rated current, at 1.0 and 0.5 power factors, the registration at 90% and 110% of rated voltage shall not differ from the value at 100% of rated voltage by more than the amount specified in table B1.

NOTE—When a meter is furnished with an external multiplier for the purpose of extending the voltage range, this test shall include the extended voltage rating with the multiplier connected in the circuit.

B.13.2.5 Equality of current and voltage ranges

B.13.2.5.1 Equality of current ranges
The standard shall be tested with rated current at 1.0 and 0.5 power factors for each current range at 100% of rated voltage. On all current ranges, the registration shall not differ from the registration on the basic current range by more than the amount specified in table B1.

B.13.2.5.2 Equality of voltage ranges
The standard meter shall be tested with rated voltage at 1.0 and 0.5 power factors for each voltage range with 100% of rated current of the basic current range. On all voltage ranges, the registration shall not differ from the registration on the basic voltage range by more than the amount specified in table B1. When a meter is furnished with an external multiplier for the purpose of extending the voltage range, this test shall include the extended voltage rating with the multiplier connected in the circuit.

B.13.2.6 Effect of variation of ambient temperature
The test conditions are as follows: The standard meter shall be placed in a space having a temperature of 23°C ±2°C and allowed to stand for not less than 2 hours with the voltage circuit energized. The meter shall then be tested with 100% of rated current at 1.0 and 0.5 power factors.

Test Condition (1): The portable standard meter shall be placed in a space having a temperature of 0°C ±5°C for not less than 2 hours with the voltage circuit energized. The meter shall be tested with 100% of rated current at 1.0 and 0.5 power factors.

Test Condition (2): Repeat condition (1), except that the portable standard meter shall be placed in a space having a temperature of 50°C ±5°C. At 0°C ±5°C and 50°C ±5°C the registration shall not differ from the value at 23°C ±2°C by more than the amount specified in table B1.

B.13.2.7 Effect of internal heating
The basic range of the portable standard meter shall be tested with 100% of rated current at 1.0 and 0.5 power factors. Then, 200% rated current shall be applied to the highest current range for 2 hours and the basic range shall be retested immediately afterward with 100% of rated current at 1.0 and 0.5 power factors. The change in registration shall not exceed the amount specified in table B1.

B.13.2.8 Effect of tilt (induction-type meters only)
The basic range of the portable standard meter shall be tested with 25% and 100% of rated current at 1.0 power factor. The meter shall be tilted 1° forward, backward, to the left, and to the right, and tested in each position with 25% and 100% of rated current at 1.0 power factor. The change in registration of any of these positions shall not exceed the amount specified in table B1 .

B.13.2.9 Repeatability of performance
The standard meter shall be placed in a space having a temperature of 23°C ±2°C, and operated continuously with 10% of rated current at 1.0 power factor for a period of 1 week. The percentage registration, at rated voltage, at 25% and 100% of rated current shall be determined at the start of the

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test and at four successive intervals, at least 24 hours apart, during the week. The change in percent registration shall not differ from that at the start of the test by more than the amount specified in table B1.

Table B1 – Portable standard watthour meter

Test	Test Conditions				
	%V	%I	PF	Other	% Maximum Deviation
Reference Conditions B.13.1	100 100 100	100 25 100	1.0 1.0 1.0		0 0 0
Drift B.13.2.1	open	250	—	see text	0 in 1 min.
Current Variation B.13.2.2	100 100 100 100 100	50 150 200 50 200	1.0 1.0 1.0 0.5 0.5		0.25 0.25 0.25 0.40 0.60
Voltage Variation B.13.2.4	90 110 90 110 90 110 90 110	25 25 25 25 100 100 100 100	1.0 1.0 0.5 0.5 1.0 1.0 0.5 0.5		0.20 0.20 0.40 0.40 0.20 0.20 0.40 0.40
Current Ranges B.13.2.5.1	100 100		1.0 0.5	100% on all Current Ranges 100% on all Current Ranges	0.20 0.20
Voltage Ranges B.13.3.5.2		100 100	1.0 0.5	100% on all Voltage Ranges 100% on all Voltage Ranges	0.20 0.25
Ambient Temperature B.13.2.6	100 100 100 100	100 100 100 100	1.0 0.5 1.0 0.5	see text 0°C 0°C 50°C 50°C	0.30 0.50 0.30 0.50
Internal Heating B.13.2.7	100 100	100 100	1.0 0.5	see text	0.20
Tilt B.13.2.8	100 100	25 100	1.0 1.0	see text	0.20 0.20
Repeatability B.13.2.9	100 100	25 100	1.0 1.0	see text	0.20 0.20

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B.13.3 Performance requirements for reference standard meters

B.13.3.2 Effect of a variation of current at 1.0
Power Factor Test Condition (2): With 90% and 110% of rated current, the registration shall not differ from the value at 100% of rated current by more than the amount specified in table B2.

B.13.3.3 Effect of variation of current at 0.5 power factor
Test Condition (2): With 90% and 100% of rated current, the registration shall not differ from the value at 100% of rated current by more than the amount specified in table B2.

B.13.3.4 Effect of variation of voltage at the power factors indicated in table B2
Test Condition (2): With 100% of rated current, the registration at 90% and 110% of rated voltage shall not differ from the value at 100% of rated voltage by more than the amount specified in table B2.

B.13.3.5 Equality of current and voltage ranges

B.13.3.5.1 Equality of current
Ranges. The standard shall be tested with rated current at 1.0 and 0.5 power factors for each current range from 100% of rated voltage. On all current ranges, the registration shall not differ from the registration of the basic current range by more than the amount specified in table B2.

B.13.3.5.2 Equality of voltage ranges
The standard meter shall be tested with rated voltage at 1.0 and 0.5 power factors for each voltage range with 100% of rated current on the basic current range. On all voltage ranges, the registration shall not differ from the registration of the basic voltage range by more than the amount specified in table B2.

B.13.3.6 Effect of variation of ambient temperature
The test conditions are as follows:

The standard meter shall be placed in a space having a temperature of 23°C ±2°C and allowed to stand for not less than 2 hours with the voltage circuit energized. The meter shall then be tested with 100% of rated current at 1.0 and 0.5 power factors.

Test Condition (3): The reference standard meter shall be placed in a space having a temperature of 11°C ±2°C for not less than 2 hours with the voltage circuit energized. The meter shall then be tested with 100% of rated current at 1.0 and 0.5 power factors.

Test Condition (4): Repeat condition (3), except that the reference standard meter shall be placed in a space having a temperature of 35°C ±2°C. At 11°C ±2°C and 35°C ±2°C the registration shall not differ from the value at 23°C ±2°C by more than the amount specified in table B2.

B.13.3.7 Repeatability of performance
The standard meter shall be placed in a space having a temperature of 23°C ±2°C, and operated continuously with 10% of rated current at 1.0 power factor for a period of 1 week. The percentage registration, at rated voltage, at 25% and 100% of rated current shall be determined at the start of the test and at four successive intervals, at least 24 hours apart, during the week. The change in percent registration shall not differ from that at the start of the test by more than the amount specified in Table B2.

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Table B2 – Reference Standard Watthour Meters

Test	Test Conditions				
	% V	%I	PF	Other	% Maximum Deviation
Reference Conditions B.13.1	100 100 100	100 25 100	1.0 1.0 0.5		0 0 0
Current Variation B.13.2.2 B.13.3.3	100 100 100 100	90 110 90 110	1.0 1.0 0.5 0.5		0.10 0.10 0.10 0.10
Voltage Variation B.13.2.4	90 110 90 110	100 100 100 100	1.0 1.0 0.5 0.5		0.10 0.10 0.15 0.15
Current Ranges B.13.2.5.1	100 100		1.0 0.5	100% on all Current Ranges 100% on all Current Ranges	0.10 0.10
Voltage Ranges B.13.3.5.2		100 100	1.0 0.5	100% on all Voltage Ranges 100% on all Voltage Ranges	0.10 0.10
Ambient Temperature B.13.3.6	 100 100 100 100	 100 100 100 100	 1.0 0.5 1.0 0.5	see text 11°C 11°C 35°C 35°C	 0.10 0.15 0.10 0.15
Repeatability B.13.3.7	100 100	25 100	1.0 1.0	see text	0.05 0.05

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Appendix C
(Normative)
Registering Mechanism and Meter Constants for Electro-mechanical Meters

C.1 General
Descriptions have been given of methods for determining the accuracy of a meter as far as the speed of the rotor is concerned, and for physically checking register and gear ratios. It is equally important that it be determined mathematically that the relations between the register (dial) constant, watthour constant, register ratio, and gear ratio are correct. The register constant should always appear on the face of the register when other than one, the register ratio will be found marked on the register or on the nameplate, and the watthour constant usually will be found marked on the nameplate or on the disk. Manufacturers generally use one standard shaft reduction for all ratings of meters of the same type, but the information does not appear on the meter. The gear ratio is dependent on the shaft reduction and also the register ratio. The gear ratio information also does not appear on the meter.

C.2 Symbols
K_h (watthour constant): The number of watthours per revolution of the meter rotor (disk).

K_r (register, or dial, constant): The multiplier used to convert the register reading to kilowatthours.

R_g (gear ratio): The number of revolution of the rotor (disk) for one revolution of the first dial pointer.

R_r (register ratio): The number of revolutions of the first gear of the register for one revolution of the first dial pointer.

R_s (shaft reduction): The number of revolutions of the meter rotor (disk) for one revolution of the first gear of the register.

C.3 Shaft Reduction
In some meters a single-pitch worm is used on the rotor, meshing with a worm wheel of 100 teeth on the register, thus, the shaft reduction is 100. A single-pitch worm is sometimes used with a 50-tooth worm wheel to give a shaft reduction of 50.

In others, a double-pitch worm is used on the rotor, meshing with a worm wheel of 100 teeth on the register, thus, the shaft reduction is 50.

In still others, pinions on the rotor meshing with gears on registers result in shaft reductions of 6-1/4, 8-1/3, etc.

Transfer gearing between the disk shaft and the register is used in a few types of meters. In some, it is of 1:1 ratio and has no effect on the shaft reduction. There are instances, however, where the transfer gearing is either 16-2/3 to 15 or 16-2/3 to 30.

The shaft reduction may be determined from the manufacturer's literature, from tables, by counting teeth in gears and pinions, or by test.

C.4 Formulas
When the register constant (K_r), watthour constant (K_h), and shaft reduction (R_s) are known, the register ratio (R_r) may be determined by the following formula:
For example, if $K_r = 1$, $K_h = 3.6$, and $R_s = 100$,

then

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$$R_r = \frac{1 \times 10{,}000}{3.6 \times 100} = 27-7/9$$

Other useful formulas are as follows:

Registration of one revolution of first dial pointer

$$= \frac{K_h \times R_r \times R_s}{1000} = \text{kilowatthours}$$

$$R_g = R_r \bullet R_s$$

$$K_r = \frac{K_h \times R_r \times R_s}{10 \times 1{,}000} = \frac{K_h \times R_g}{10{,}000}$$

$$K_h = \frac{K_r \times 10 \times 1{,}000}{R_r \times R_s}$$

$$R_s = \frac{K_r \times 10 \times 1{,}000}{K_h \times R_r}$$

In the foregoing formulas, 10 is the numerical value of one revolution of the first dial pointer.

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APPENDIX D
(Normative)
Periodic Testing Schedule

An example of a detailed periodic testing schedule by watthour meter and attachments:

		Years Between Testing
(1)	Graphic watthour demand	2
(2)	Electromechanical Watthour Meters without surge-proof magnets	8
(3)	Thermal Lagged Demand Meters	16
(4)	Magnetic Tape Demand Recorders	12
(5)	Electromechanical Watthour Meters with surge-proof magnets and:	
	(a) Mech KWH Register	16
	(b) Mech Demand Registers	8–12
	(c) Electronic Demand Register	16
	(d) Mech Cam Pulse Initiator	2
	(e) Mech Gear Shutter Pulse Initiator	8
	(f) Electronic Pulse Initiator	12
	(g) Electronic Remote Registers	8
	(h) Electronic TOU Register	16
(6)	Electronic Meter	16
(7)	Electronic Recorders	16

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APPENDIX E
(Normative)
Phase-Shifting Transformers

E.1 Definition
For definition of a phase-shifting transformer, see Section 2.

E.2 Types Defined
Phase-shifting transformers are considered to be of the same type if they are produced by the same manufacturer, bear the manufacturer's same type designation, are of the same general design, and have the same relationship of parts. They shall have the same phasor diagram and be substantially equivalent in the following respects to be grouped as one type for approval tests:

(1) Rated volts per turn
(2) Length, cross section, and shape of magnetic circuit
(3) Characteristics of the core material
(4) Arrangement of the coils with respect to the magnetic circuit
(5) Relation of resistance of the windings to the rated voltage

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APPENDIX F
(Informative)
Historical Background

F.1 Preface to the First Edition (1910)

In undertaking 2 years ago to formulate a meter code, it was the ambition of the Meter Committee of the Association of Edison Illuminating Companies (AEIC) to produce a reliable and up-to-date manual covering the many phases of electric meter practice as encountered by all companies, both large and small. It was the Committee's belief that such a Code, if intelligently prepared, would prove of great value not just to those actually engaged in operating meters, but also to those interested in the practices of metering from other standpoints, namely, official, legal, etc. There was also felt an urgent need of a closer agreement between the manufacturers and the operating companies as to reasonable and satisfactory specifications covering both operation and design.

The development of such a Code with the collecting of the very large amount of necessary data was placed in the hands of the Electrical Testing Laboratories of New York, and at the Briarcliff Convention of 1909 there was presented the first issue of the Code, covering four sections and representing the first year's work. As a means of increasing the strength and support of the work, and at the same time avoiding duplication of effort along similar lines, it was arranged with the consent of the Executive Committee of both Associations to join hands with the Meter Committee of the National Electric Light Association (NELA) for the further development of the Code. The second year's work, therefore, represents the combined efforts of the Meter Committees of the two Associations.

The Code to date as here presented includes with minor revisions and corrections those sections which have been presented in the reports at the 1909 Edison Convention and the 1910 NELA Convention, and also two entirely new sections. It is hoped that it may find its place among reliable books of reference in the hands of those responsible for, and interested in, the purchase, installation, and operation of electric meters.

A considerable amount of ground still remains to be covered, and it is only to be expected that, with changes and improvements in the art, revisions must from time to time become necessary, but it is the intention of the Committees to continue the work to its logical conclusion.

While the Code is naturally based upon scientific and technical principles, the commercial side of metering has been constantly kept in mind as of very great importance, and it is believed that due consideration has been given to this phase of the problem.

Although the work has been directed very closely by the two Committees, the burden of the undertaking has been carried by the Electrical Testing Laboratories, to which full credit should be given.

The Committees are indebted to Clayton H. Sharp for his personal interest and cooperation in the conduct of the work and to W.W. Crawford, also of the Laboratories, for the zeal and discrimination which he has displayed in preparing the drafts of the Code for the Committee's consideration.

The Committees would also acknowledge most gratefully the hearty and valuable cooperation of the manufacturing companies and particularly that of F.P. Cox and L.T. Robinson of the General Electric Company, and William Bradshaw of the Westinghouse Electric and Manufacturing Company. It is the earnest desire of the Committees that the Code may prove its value to all of those interested in the precise commercial measurement of electrical energy and may contribute to the advancement of the art.

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Committee personnel

AEIC	NELA
J. W. Cowles, Chairman	G. A. Sawing, Chairman
O. J. Bushnell	W. H. Fellows
George Ross Green	W.E. McCoy
J. T. Hutchings	
S. G. Rhodes	

F.2 Preface to the Second Edition (1922)

This edition of the Code for Electricity Meters is a revised and complete compilation of the sections issued separately during the past 5 years. The revision and arrangement here have been under the supervision of the Meter Committees of the Association of Edison Illuminating Companies and the National Electric Light Association.

Advantage was taken of the printing of the Code in complete form to make such revisions in the text and to add such new matter as appeared desirable. The Electrical Testing Laboratories joined with the Committees in this revision and compilation as they did in the original preparation of the various sections of the Code, and this revised edition has their approval.

The Code for Electricity Meters has been generally accepted as a standard of reference for meter practice. Its revision, completion, and appearance in one volume enhance its value for this purpose.

Committee personnel

AEIC	NELA
S. G. Rhodes, Chairman	O. J. Bushnell, Chairman
O. J. Bushnell	W. H. Fellows
J. W. Cowles	W. E. McCoy
George Ross Green	F. A. Vaughn
J. T. Hutchings	W. L. Wadsworth
G. A. Sawin	

F.3 Preface to the Third Edition (1928)

This edition of the Code for Electricity Meters is a completely revised and rearranged compilation of the Second Edition, issued in 1912, and the section on demand meters, issued in 1920. The 1912-20 edition of the Code was approved as an American Standard by the American Engineering Standards Committee in July 1922 (C12-1922). The present revision has been made under the joint sponsorship of the Association of Edison Illuminating Companies, the National Electric Light Association, and the US National Bureau of Standards by a Sectional Committee representing all interested organizations, in accordance with the procedure established by the American Engineering Standards Committee for the revision of American Standards.

The sponsors hereby express their appreciation to the members of the Sectional Committee and their associates for the painstaking and careful manner in which the revision was carried out.

A preliminary draft was presented at a meeting of the Sectional Committee on April 1, 1926. This draft was approved in general outline, and referred to an editorial committee consisting of Messrs Brooks, Currier, Doyle, Fellows, Hill, Koenig, Meyer, and Pratt. This committee carefully reviewed the draft, agreed upon a standard form and arrangement, and appointed H. Koenig, the Secretary of the Sectional Committee, to prepare the final draft for the printer. A considerable amount of material appearing in the Second Edition has been omitted, particularly the circuit diagrams in Section VII, all of Section IX, and

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the maintenance paragraphs of Section X. The sections of chapters have been renumbered. The omitted material is fully covered in the Handbook for Electrical Metermen, where it now properly belongs.

This Code, as revised, was submitted in galley-proof form to all the members of the Sectional Committee for final approval by letter ballot, and it was then formally approved by each of the sponsors. The sponsors, acting jointly, presented the Code to the American Engineering Standards Committee for approval as American Standard, and it was so approved February 20, 1928.

Committee personnel

W. M. Bradshaw	F. Holmes	J. Franklin Meyer
O. J. Bushnell	F. A. Kartak	A. L. Pierce
F. P. Cox	H. Koenig	G. A. Sawin
Burleigh Currier	R. C. Lanphier	C. H. Sharp
E. D. Doyle	F. V. Magalhaes	C. R. Vanneman
R. W. Easton	Alexander Maxwell	W. L. Wadsworth

The Sectional Committee was formally organized March 14, 1924; J. Franklin Meyer, Chairman; E. D. Doyle, Secretary, later succeeded by H. Koenig.

The actual revision of the Code was done by four technical subcommittees, as authorized by the Section Committee. These subcommittees were:

(1) Acceptance Specifications: F. V. Magalhaes, Chairman; A. J. Allen, W. M. Bradshaw, H. B. Brooks, O.J. Bushnell, C.J. Clarke, C. I. Hall, F. C. Holtz, C. H. Ingalls, A. E. Knowlton, W. H. Pratt

(2) Installation and Maintenance Methods: B. Currier, Chairman; A. S. Albright, A. J. Allen, W. H. Fellows, R. C. Fryer, E. E. Hill, C. H. Ingalls, A. G. Turnbull, W. L. Wadsworth

(3) Standards: E. d. Doyle, Chairman; A. S. Albright, C. J. Clarke, H. G. Hamann, E. E. Hill

(4) Definitions: J. F. Meyer, Chairman; W. H. Fellows, F. C. Holtz, F. A. Kartak, C. H. Sharp

F.4 Preface to the Fourth Edition (1941)

This fourth edition of the Code for Electricity Meters was prepared by Sectional Committee C12 of the American Standards Association. The sponsors were the National Bureau of Standards, and the American Standards Association — Electric Light and power Group (the Association of Edison Illuminating Companies and the Edison Electric Institute).

The sectional Committee C12 which prepared the revision was as follows:

J. Franklin Meyer, Chairman
H. C. Koenig, Secretary

A. J. Allen	O. K. Coleman	R. E. Johnson
R. B. Bennet	Stanley S. Green	N. S. Meyers
W. M. Bradshaw	C. B. Hayden	R. H. Nexsen
H. B. Brooks	E. E. Hill	W. H. Pratt
J. O'R. Coleman	F. C. Holtz	

The work of revision was divided into six major sections and was done by the following six subcommittees:

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(1) Definitions: R. D. Bennett, Chairman; H. B. Brooks, P. G. Elliott, W. H. Fellows, R. E. Johnson, E. E. Kline, W. H. Pratt

(2) Standards and Metering: H. B. Brooks, Chairman; A. s. Albright, W. M. Bradshaw, F. E. Davis, Jr., F. C. Holtz, H. C. Koenig, G. R. Sturtevant

(3) Specifications for Acceptance of Types of Electricity Meters and Auxiliary Devices: W. C. Wagner, Chairman; W. M. Bradshaw, H. B. Brooks, A. B. Craig, W. R. Frampton, E. E. Hill, H. C. Koenig, R. H. Nexsen, W. H. Pratt

(4) Installation Methods and Watthour Meter Test Methods: O.K. Coleman, Chairman; A. P. Good, Stanley S. Green, C. B. Hayden, N. S. Meyers, L. D. Price

(5) Laboratory and Service Tests: P. L. Holland, Chairman; J. S. Cruikshank, P. G. Elliott, J. H. Goss, E. E. Hill, J. C. Langdell, F. L. Pavey

(6) Demand Meters: A. J. Allen, Chairman; F. C. Holtz, R. E. Johnson, E. A. LeFever, R. H. Nexsen, A. R. Rutter, W. C. Wagner, W. H. Witherow

F.5 Preface to the Fifth Edition (1965)

Following the issuance of the Fourth Edition of the Code for Electricity meters in 1941, a modification of periodic test schedules (Paragraph 827 – changing the test period to 96 months for ac meters rated to 12 kVA) was issued as an American War Standard on November 5, 1942. This change was approved by ASA as an American Standard in 1947. In 1957, American Standard Code for Electricity Meters, C12-1947, and American Standard Revisions to the Code for Electricity Meters, C12a-1947, were reaffirmed.

Many improvements and innovations in meters and their auxiliary equipment, and in metering practices, have taken place since the Fourth Edition of the Code was issued. These developments were taken into account in preparing the present edition. For the first time, the Code recognizes that statistical methods may be applied to in-service testing of meters to reveal where testing and maintenance effort should be directed; and guidance is offered toward the selection of sound statistical procedures. The other sections of the Code have also been broadened and largely rewritten to cover other phases of electricity metering in line with the present state of the art.

Finally, it should be noted that the name of this standard has been changed to American Standard Code for Electricity Metering, as the committee believed that this title more accurately described the content of the standard.

This edition of the American Standard Code for Electricity Metering was prepared by Sectional Committee C12 of the American Standards Association. The sponsors are the National Bureau of Standards and the Edison Electric institute.

The personnel of Sectional Committee C12 that prepared this revision of the Code were as follows:

F. K. Harris, Chairman
A. T. Higgins, Secretary

J. Anderson
T. D. Barnes
D. T. Canfield
W. C. Downing, Jr.
J. W. Dye
P. W. Hale
H. H. Hunter
H. W. Kelley
J. D. McKechnie
W. J. Piper
R. E. Purucker
A. W. Rauth
R. A. Road
G. B. M. Robertson
F. H. Rogers
R. S. Smith
L. O. Steger
G. P. Steinmetz
G. J. Yanda

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Liaison Members: L. V. Hung
J. M. Vanderleck

The work of revision was done by a number of task forces, and was reviewed by the Sectional Committee. These task forces and their assignments were as follows:

(1) Definitions: W. J. Piper
(2) Measurement of Power and Energy: D. T. Canfield
(3) Standards: F. K. Harris, Chairman; E. F. Blair
(4) Acceptance of New Types of Meters: G. B. M. Robertson, Chairman; T. D. Barnes, E. F. Blair, J.D. McKechnie, R. A. Road, R. S. Smith
(5) Watthour meter Test Methods: P. W. Hale, Chairman; J. Anderson, T. D. Barnes, W. C. Downing, Jr., H. W. Kelley, J. D. McKechnie, E. C. Nuesse, R. A. Road, F. H. Rogers
(6) Installation Requirements: H. w. Kelley, Chairman; E. B. Hicks, H. H. Hunter, L. H. Keever, R. E. Purucker, A. W. Rauth, L. O. Steger
(7) Instrument Transformers and Auxiliary Devices: J. W. Dye, Chairman; E. F. Blair, F. R. D'Entremont, B. L. Dunfee, W. H. Farrington, H. W. Kelley
(8) In-Service Tests of Watthour Meters: H. H. Hunter, Chairman; F. K. Harris, A. L. Hobson, C. L. Lucal, J. D. McKechnie, C. V. Morey, R. E. Purucker, F. H. Rogers, L. O. Steger, G. Wey
(9) Demand Meters (Acceptance, Test Methods, In-Service Tests); G. J. Yanda, Chairman; R. V. Adams, W. C. Downing, Jr., P. W. Hale, F. M. Hoppe, W. J. Piper, R. A. Road, R. J. Stowel
(10) Editorial: G. B. M. Robertson, Chairman; J. Anderson, P. W. Hale, F. K. Harris, A. T. Higgins, H. H. Hunter, H. W. Kelley, F. H. Rogers, G. J. Yanda

F.6 Preface to the Sixth Edition (1975)

A number of significant advances have been made in the design of watthour meters, in the verification of their accuracy, and in demand metering, since the Fifth Edition of this Code was issued in 1965. Improvements in bearings and mechanical construction, and new sealing techniques that exclude dust have made modern meters remarkably stable, as well as accurate. Sampling methods of in-service testing sanctioned by the 1965 Code have been shown to be economical and effective.

A new form of auxiliary device, known as a pulse recorder, has come into general use during the past 10 years. It records, on magnetic or paper tape, pulses received from pulse initiators installed on watthour or other integrating meters. The tapes are processed by automated equipment using computer techniques, thus reducing human errors and speeding up accounting and data-interpretation processes for both customer billing and survey installations.

These developments as well as others have been taken into account in this edition of the Code. Recommended periodic test intervals for modern meters have been lengthened, and sampling methods have been extended to additional kinds of meters. In addition, performance requirements have been incorporated for the new types of pulse devices and for the standard watthour meters used as references to maintain the kilowatthour or to test other meters. Many other changes have been made.

This standard is a revision of American National standard Code for Electricity Metering. C12-1965. The secretariat of American National Standards Committee C12 is held by the Edison Electric institute and the National Bureau of Standards.

This standard was processed and approved for submittal to ANSI by the American National Standards Committee on Code for Electricity metering, C12. Committee approval of the Standard does not necessarily imply that all committee members voted for its approval. At the time it approved this standard, The C12 Committee had the following members:

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F. L. Hermach, Chairman
A. T. Higgins, Secretary

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D. B. Berry	F. G. Kuhn	R. A. Road
E. F. Blair	F. J. Levitsky	E. W. Schwarz
H. L. Colbeth	D. McAuliff	L. O. Steger§
C. R. Collinsworth	W. E. Osborn	J. M. Vanderleck

*Replaced Mr. Holdaway in September, 1974
+Deceased, July, 1974
§Until retirement in April, 1973.

The work of revision was done by a number of subcommittees, and was reviewed by the C12 Standards Committee. The assignments of these subcommittees were as follows:

(1) Definitions, and (2) Measurement of Power and Energy: E. F. Blair, Chairman; R. S. Turgel, J. M. Vanderleck, A. Yenkelun
(3) Standards and Standardizing Equipment: F. L. Hermach, Chairman; M. F. Borleis, W. E. Osborn, J. Roth, E. W. Schwarz, D. M. Smith
(4) Acceptance of New Types of Watthour Meters: A. Fini, Chairman; J. Anderson, D. B. Berry, E. F. Blair, M. F. Borleis, C.R. Colinsworth, F. G. Kuhn, D. McAuliff, G. F. Walsh
(5) Watthour meter Test Methods: F. J. Levitsky, Chairman; J. Anderson, E. F. Blair, T. J. Pearson
(6) Installation Requirements: B. E. Kibbe, Chairman; D. Berry, A. Browne, M. A. Frederickson, L. M. Holdaway, H. W. Redecker
(7) Instrument transformers and Auxiliary Devices: T. J. Pearson, Chairman; B. L. Dunfee, F. A. Fragola, J. Landry, R. Stetson
(8) In-Service Tests of Watthour Meters: H. L. Colbeth, Chairman; E. L. Barker, M. A. Frederickson, J. Keever, J. C. Liewehr, B. Renz, C. F. Riederer, J. Suridis
(9) Demand Meter and Pulse Devices: C. R. Collinsworth, Chairman, E. C. Benbow, H. A. Duckworth, R. Hopkins, S.C. McColum, C. F. Riederer, C. Ringold, R. J. Stowell, G. F. Walsh
(10) Editorial: R. A. Road, Chairman; J. Anderson, F. L. Hermach, A. T. Higgins, F. J. Levitsky, W. E. Osborn, C. F. Riederer

F.7 Foreword to the Seventh Edition (1982)

(This Foreword is not a part of ANSI C12.1-1982, American National Standard Code for Electricity Metering.)

This standard has been enlarged to include performance specifications for a new class of self-contained watthour meters with increased load range. The specifications for a new class of self-contained watthour meters with increased load range. The specifications for other meters have been retained from the previous edition without major changes, but the presentation of some of the data has been rearranged to improve clarity. The section on standard watthour meters has also been revised to take account of the types of meters which have come into more widespread use during the last few years. Numerous other revisions are mainly editorial to correct errors and to bring the text into agreement with current standard terminology.

Since 1976, the C12 Committee has assumed responsibility for developing additional standards related to the Code for Electricity Metering, some of which were formerly issued by other organizations. By providing mechanical and other specifications, generally not directly related to performance, these

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standards complement the Code for Electricity Metering. The Code, which until this edition has been known as C12, has now been redesignated C12.1. The other standards issued by the C12 Committee are listed below.

C12.4-1978, *American National Standard for Mechanical Demand Registers.*
C12.5-1978, *American National Standard for Thermal Demand Meters.*
C12.6-1978, *American National Standard for Marking and Arrangement of Terminal for Phase-Shifting Devices Used in Metering.*
C12.7-1982, *American National Standard for Test Switches for Transformer-Rated Meters.*
C12.10-1978, *American National Standard for Watthour Meters.*
C12.11-1978, *American National Standard for Instrument Transformers for Metering Purposes, 15 kV and Less.*
C12.14-1982, *American National Standard for Magnetic Tape Pulse Recorders for Electricity Meters.*

This standard was developed by the American National Standards Committee on Electricity Metering, C12, for full consensus approval as an American National Standard. Suggestions for improving this standard are welcome. They should be sent to the American National Standards Institute, 1430 Broadway, New York, NY 10018.

The Secretariat of the American National Standards Committee C12 on Electricity Metering is held by the Institute of Electrical and Electronics Engineers and the National Bureau of Standards. At the time this standard was processed and approved, the C12 Committee has the following members:

R. S. Turgel, Chairman
V. Condello, Secretary

J. Anderson
J. C. Arnold, Jr.
D. B. Berry
W. C. Bush
C. R. Collinsworth
T. C. Drew
M. Faser
R. Fowler
F. J. Levitsky
J. C. Liewehr
A. Loika
D. McAuliff
C. F. Mueller
C. F. Fiederer
C. Six
G. F. Walsh
V. J. Yanakieff

The following Subcommittees of ANSI C12 were actively involved in the revision of this standard. The assignments of these subcommittees were as follows:

(3) Standards and Standardizing Equipment: R.S. Turgel, Chairman; W. C. Busch, P. Cunningham, R.E. Koll, F J. Levitsky, R. H. Stevens

(4) Acceptance of New Types of Watthour Meters: A. Fini, Chairman; J. Anderson, A. G. Ashenbeck, Jr., D. F. Becker, C. R. Collinsworth

(10) Editorial: F. J. Levitsky, Chairman; C. F. Mueller, A. Loika, R. S. Turgel

F.8 Foreword to Eight Edition

Foreword

(This Foreword is not part of ANSI C12.1-1988, American National Standard Code for Electricity Metering.)

This standard was developed by the Accredited Standards Committee on Electricity Metering, C12, for full consensus approval as an American National Standard. This revised edition supersedes ANSI C12.1-1982. Suggestions for improving this standard are welcome. They should be sent to the American National Standards Institute, 1430 Broadway, New York, NY 10018.

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The technical content of this standard has been brought up to date, and the changes affect nearly all chapters. In addition, following IEEE editorial policy aimed at avoiding duplication of similar or identical requirements in their standards, those sections of text from other IEEE standards that had been incorporated in the previous edition of C12.1 were replaced by appropriate references to those standards.

The other related standards that the C12 Committee has issued, and is continuing to issue, are listed below:[3]

C12.4-1984, *American National Standard for Mechanical Demand Registers.*

C12.5-1978, *American National Standard for Thermal Demand (R1978) Meters.*

C12.6-1987, *American National Standard for Marking and Arrangement of Terminals for Phase-Shifting Devices Used in Metering.*

C12.7-1987, *American National Standard Requirements for Watthour Meter Sockets.*

C12.8-1981, *American National Standard for Test Blocks and Cabinets for Installation of Self-Contained "A" Base Watthour Meters.*

C12.9-1987, *American National Standard for Test Switches for Transformer-Rated Meters.*

C12.10-1988, *American National Standard for Watthour Meters.*

C12.11-1987, *American National Standard for Instrument Transformers for Revenue Metering, 10 kV BIL Through 350 kV BIL (0.6 kV NSV Through 69 kV NSV).*

C12.13-1985, *American National Standard Time-of-Use Registers for Electromechanical Watthour Meters.*

C12.14-1982, *American National Standard for Magnetic Tape Pulse Recorders for Electricity Meters.*

The Secretariat of the Accredited Standards Committee on Electricity Metering, C12, is held by the Institute of Electrical and Electronics Engineers and the National Institute of Standards and Technology. At the time this standard was processed and approved, the C12 Committee had the following members:

R. S. Turgel, Chairman
F. Huber, Jr, Secretary

Organization Represented	Name of Representative
Institute of Electrical and Electronics Engineers	F.J. Levitsky R. Hopkins
National Institute of Standards and Technology	R. S. Turgel
National Electrical Manufacturers Association	T. C. Drew L. Struchtemeyer D. D. Elmore

[3] These publications are available from the Service Center, Institute of Electrical and Electronic Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, or from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

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	J. W. Hogg (Alt.)

The following subcommittees of C12 were actively involved in the revision of this standard:

Subcommittee 3 — Standards and Standardizing Equipment	R. S. Turgel, Chairman
	W. C. Busch
	P. Cunningham
	H. L. Friend
	F. J. Levitsky
	R. H. Stevens
Subcommittee 4 — Acceptance of New Types of Watthour Meters	
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Subcommittee 5 — Watthour Meter Test Method	F. J. Levitsky, Chairman
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Subcommittee 8 — In-Service Test of Watthour Meters	W. C. Busch, Chairman
Subcommittee 10 — Editorial	F. J. Levitsky, Chairman D. Dassman D. D. Elmore D. Scott R. S. Turgel

In addition to the Committees listed above, C12 also has the following subcommittees:

Subcommittee	Chairman
Subcommittee 1 — Definitions	(vacant)
Subcommittee 2 — Measurement of Power and Energy	(vacant)
Subcommittee 6 — Installation Requirements	(vacant)
Subcommittee 9 — Demand Meters	(vacant)
Subcommittee 11 — Safety Requirements	F. J. Levitsky
Subcommittee 12 — Solid-State Meters	D. Dassman
Subcommittee 13 — Time-of-Day Metering	T. C. Drew
Subcommittee 14 — Pulse Recorders	T. C. Drew
Subcommittee 15 — Watthour Meter Sockets and Test Blocks	F. A. Marta
Subcommittee 16 — Solid-State Watthour Meters	D. Dassman

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