

IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods

Sponsor

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Abstract: This recommended practice defines many common parameters for ac-dc and dc-dc electronic power distribution components and subsystems. This enables electronic system engineers, manufacturers, and researchers to speak with a common language and hence facilitates effective and efficient communications. Furthermore, implementation of a common specification language will allow the power electronics industry as well as the user communities, including government system developers, to acquire cost- and time-effective electronic power subsystems with significantly enhanced interchangeability.

Keywords: electronic power distribution, power subsystem, power supply, specification, specification language

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Introduction

(This introduction is not part of IEEE Std 1515-2000, IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods.)

Electronic power subsystems are integral parts of any electronic system. They perform the tasks of power processing, management, and distribution. Clear definition and precise understanding of the terms (or terminology) used in a specification are crucial to successful and cost-effective development programs.

This recommended practice attempts to define a parameter specification language for common parameters used to describe ac-dc and dc-dc electronic power distribution components and subsystems. This parameter specification language consists of test parameter definitions, test methods, and test conditions.

In the past two decades, the power electronics industry has experienced tremendous success and growth. For instance, switched-mode power supplies now occupy 95% of the market (compared to only 12% in the 1970s) and switched-mode motor devices are replacing traditional motor drives in virtually all applications. As with many other maturing technologies, unprecedented growth creates a problem that hinders further success and growth. That problem is the lack of a common parameter specification language.

Lack of a common parameter specification language creates confusion among industry manufacturers and systems developers. Different manufacturers and subsystem developers use similar terms to indicate different performance. This confusion not only hinders effective communication and the interchangeability among products, but also increases the cost and time for both development and procurement. This is particularly true for high-end customer designs, such as those intended for military and aerospace applications.

A common specification language will allow the power electronics industry and the government system developers to acquire cost- and time-effective electronic power subsystems with significantly enhanced interchangeability. This recommended practice was written with test methods that include test equipment characteristics rather than a requirement for specific test equipment. Implementation of this recommended practice will allow the subsystem designer to make performance comparisons among the contending electronic power distribution subsystem components that have been specified to the same criteria. Products will have been consistently specified and performance tested; thereby, minimizing buyer confidence testing.

The evaluation of competing products from different manufacturers for intra-operability will be a less expensive effort. The component developer who adheres to this recommended practice will ensure that customers can unambiguously understand their product specifications, increasing customer confidence and satisfaction.

This recommended practice collects, in a single document, most of the parameters used in specifying a power electronic product. As such, it will be useful both for systems engineers (who specify requirements for products) and for designers (who qualify their products to the specifications). This will also be useful for engineers and graduate students who are entering the field of power electronics, since many of the parameters are seldom discussed fully in university courses or in professional educational seminars.

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IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods

1. Overview

1.1 Scope

This recommended practice is written to provide a standard specification language for common parameters used to characterize the performance of electronic power distribution subsystem elements. Specifically, these are parameters relating to the integration of power supplies into electronic power distribution subsystems. The specification language consists of parameter definitions, test methods, and test conditions for the parameters. The specification language is meant to be used by both electronic power subsystem developers and designers and component manufacturers to insure unambiguous communication.

The specification language is intended to be applied to ac-dc and dc-dc electronic power distribution subsystems. The range of power subsystems includes single-phase and three-phase systems, with power levels from a fraction of a watt to 20 kW. The voltage range is from a few volts to 600 V, at a frequency or frequencies of dc –1 kHz. However, this recommended practice can be used outside the range.

1.2 Purpose

The purpose of this recommended practice is to standardize a specification language, not to specify or enforce “a standard specification.” A specification written in compliance with this language will ensure easy and precise understanding between manufacturers and users without, in any way, limiting manufacturers’ ability to present features that are special to their products.

Efforts have been made to include as many common parameters as possible, but this recommended practice is by no means meant to be all-inclusive.

1.3 Organization of the recommended practice

This recommended practice is organized into five clauses and two annexes. Clause 1 is an overview of the scope, purpose, and organization of the document. Clause 2 lists all the references that should be consulted when using this recommended practice. Clause 3 identifies the terms and acronyms that are used throughout the text of this recommended practice. Clause 4 presents parameters related to electrical performance of a power distribution subsystems, including parameter definitions, test methods, and test conditions. Each test method is the recommended method of testing a given parameter, and the test condition defines the range of values for test variables that are essential to the test.

Clause 5 collects common parameters related to reliability, maintainability, environmental parameters, and mechanical aspects of a power subsystem. Reliability and environmental parameters are crucial for a power subsystem to operate reliably, but they are out of the realm of electrical engineering. Hence, only definitions are given, together with relevant references to military standards. It is felt that this will be sufficient for circuit designs and will provide the necessary leads for further investigation. Mechanical parameters are given as a simple list of definitions for completeness.

Annex A is a list of additional readings that one may find helpful in understanding this recommended practice. Finally, Annex B provides a rather detailed discussion on “do’s and don’ts” when it comes to measuring data. Many people may find it helpful.

2. References

This recommended practice shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply.

ASTM E595-93 (1999), Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment.¹

IEC 60950:1999, Safety of Information and Technical Equipment Including Electrical Business Equipment.²

IEC 61000-3-2:1998, Electromagnetic compatibility (EMC)—Part 3-2—Limits for harmonic current emissions.

MIL-HBK-217, Reliability Prediction of Electrical Equipment, 1991.³

MIL-STD-139, Interface Standard for Shipboard Systems, Section 300A: Electric Power, Alternating Current (Metric), 1992.

MIL-STD 462D, Test Method Standard for Measurement of Electromagnetic Interference Characteristics, 1999.

MIL-STD-704E, Aircraft Electric Power Characteristics, 1991.

MIL-STD-810E, Environmental Engineering Considerations and Laboratory Tests, 1995.

¹ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

²IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

³MIL publications are available from Customer Service, Defense Printing Service, 700 Robbins Ave., Bldg. 4D, Philadelphia, PA 19111-5094.

MIL-STD-883E, Test Method Standard for Microcircuits, 1999.

MIL-STD-1540D, Test Requirements for Launch, Upper-Stage, and Space Vehicles, 1999.

RTCA DO-160D-1997, Environmental Conditions and Test Procedures for Airborne Equipment.⁴

UL 1950-1997, Information Technology Equipment Including Electrical Business Equipment.⁵

3. Definition of terms and acronyms

The terms defined here can be grouped into three categories—terms for test equipment characteristics, terms to be used in this document, and acronyms and abbreviations.

Definitions of the characteristics of the test equipment, which influence desired measurements, are solely included to convey the expectations of the test equipment for consistent measurements, without detailing the specific test equipment.

Terms collected here are not all inclusive of the terms used to describe an electronic power distribution subsystem. Additional terms can be found in Handbook of Standardized Terminology for Power Sources Industry published by the Power Sources Manufacturers Association (PSMA).

Acronyms and abbreviations frequently encountered are also included for easy reference.

3.1 ac signal: A time-varying signal whose polarity varies with a period of time T , and whose average value is zero.

3.2 active or real power: The average power consumed by a unit. For a two terminal device with current and voltage waveforms $i(t)$ and $v(t)$ which are periodic T , the real or active power P is

$$P = \frac{1}{T} \int_0^T v(t) i(t) dt$$

3.3 ambient temperature, T_a : Temperature of the ambient air immediately surrounding the unit under test (UUT).

3.4 BIT: The abbreviation for built-in-test.

3.5 composite signal: A signal that is composed of both ac and dc components.

3.6 current probe(s): A current probe is used to measure dc, ac, or composite currents. DC current probes should measure dc and composite currents to within $\pm 1\%$ with a probe calibrator and $\pm 3\%$ without the calibrator. AC current probes should measure ac currents to within $\pm 5\%$. This accuracy should be maintained up to the worst case expected peak current. Proper bandwidth should also be ensured.

3.7 dB: The abbreviation for decibels.

⁴RTCA standards are available from the Sales Department at 1140 Connecticut Ave., NW, Suite 1020, Washington, DC 20038, USA (<http://www.rtca.net/>).

⁵UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

3.8 crest factor (cf): The ratio of the peak value to the rms value of an ac waveform measured under steady-state conditions. It is unit-less, and the ratio for a pure sine wave is equal to $\sqrt{2}$.

$$cf = \frac{V_{in,pk}}{V_{in,rms}}$$

where

V_{in} is the voltage at the user input terminals.

3.9 dc signal: A signal whose polarity and amplitude do not vary with time.

3.10 digital multimeter (DMM): A DMM is used to measure electrical quantities such as dc or ac voltage, ac or dc current, resistance, etc. The input resistance/impedance should be at least 1000 times the resistance/impedance of the circuit being measured.

3.11 distortion (current or voltage): The rms value of the ac signal exclusive of the fundamental component. It may include various harmonic and inter-harmonic components. In a dc system, distortion is the rms value of the ac (ripple) component on the (fundamental) dc level.

Harmonics are sinusoidal distortion components that occur at integer multiples of the fundamental frequency. Inter-harmonics are distortion components that occur at non-integer multiples of the fundamental frequency.

3.12 distortion factor (current or voltage): The ratio of the rms value of an ac signal, exclusive of the fundamental, to the rms value of the fundamental component of the ac signal, expressed as a percent. For example, voltage distortion factor may be expressed as:

$$D_V = \sqrt{\left(\frac{V_2}{V_1}\right)^2 + \left(\frac{V_3}{V_1}\right)^2 + \dots + \left(\frac{V_n}{V_1}\right)^2}$$

with

$$f_1 < f_n \leq f_{max}$$

where

- D_V is voltage distortion factor in percent,
- V_1 is rms value of the fundamental frequency component,
- V_n is rms value of an individual non-fundamental frequency component,
- f_1 is the fundamental frequency,
- f_n is frequency of other individual waveform components, including harmonics and inter-harmonics (non-integral multiples of the fundamental),
- f_{max} is the maximum frequency of measurement.

3.13 EMI: The abbreviation for electromagnetic interference. EMI is any disturbance that interrupts, obstructs, or otherwise impairs the performance of electronic equipment.

3.14 EMC: The abbreviation for Electromagnetic Compatibility

3.15 external: Not associated with the equipment design.

3.16 fundamental frequency: The frequency of the primary power-producing component of a periodic waveform supplied by the generation system (component of order 1 of the waveform's Fourier series representation).

3.17 gain margin: The reciprocal of the gain of a control loop (expressed in dB) at the frequency for which there is 180° of phase shift around the control loop.

3.18 $I_{\max}$ output: The maximum allowable output load current over which the unit under test (UUT) output voltage is required to be maintained within the specified operational limits. $I_{\max}$ is also known as the rated current.

3.19 I_{avg} output: The average output load current at which to test the unit under test (UUT), $(I_{\min} + I_{\max})/2$.

3.20 $I_{\min}$ output: The minimum allowable output load current over which the unit under test (UUT) output voltage is required to be maintained within the specified operational limits.

3.21 I_{nom} output: The nominal load current for which the unit under test (UUT) output voltage is required to be maintained within the specified operational limits; the value should be between the minimum and maximum values.

3.22 line impedance stabilization network (LISN): A LISN is used to provide a standard connection from the power source to the unit under test (UUT) for EMI measurements. A LISN has input (power source), output (to UUT), signal output port, and a chassis ground connection. The signal output port must be terminated with a 50 ohm load when no measurement instrumentation is attached. The LISN schematic in Figure 1 is used in MIL-STD 462D. The LISN schematic in Figure 2 is used in RTCA DO-160D.

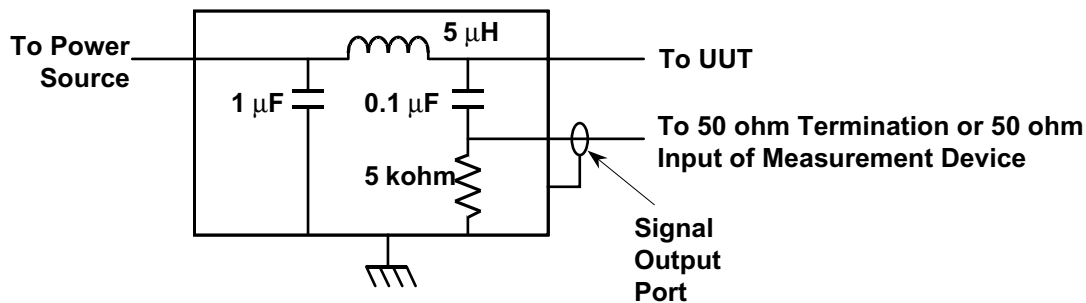


Figure 1—5 μH LISN schematic

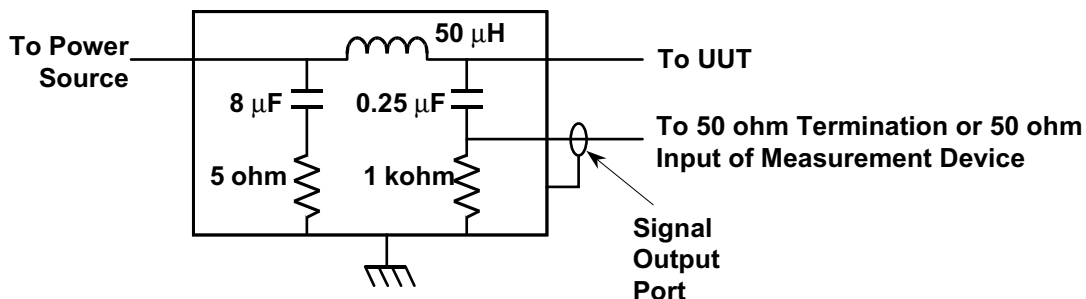


Figure 2—50 μH LISN schematic

3.23 load impedance: The load impedance begins at the equipment output termination (as shown in Figure 3) and ends at the equipment power return termination. Hence, all cabling is included in the load.

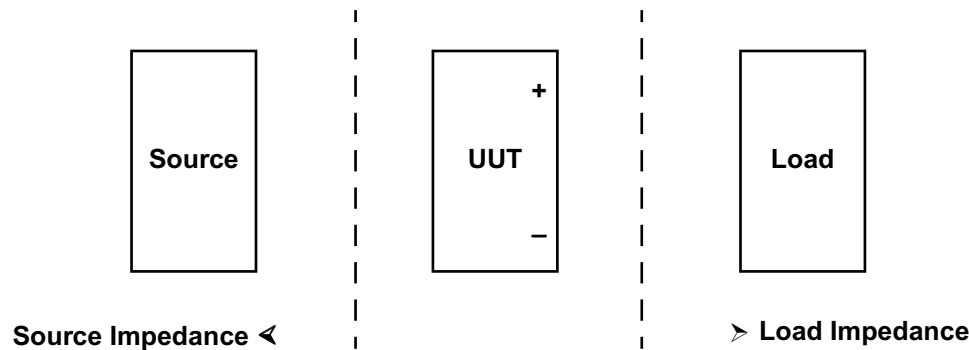


Figure 3—Electronic power distribution block diagram

3.24 loop stability: A term describing the stability of a control loop as measured against some criteria, e.g., phase margin and gain margin.

3.25 maximum frequency of interest: (1) For switching power supplies: 10 times the maximum power switch switching frequency. (2) For filter products: 10 times the 3 dB point.

3.26 operating temperature, T_{op} : The temperature a unit under test (UUT) operates at. It is often specified over a range and can have various definitions. Definitions include ambient temperature, baseplate temperature, inlet air temperature, etc.

3.27 oscilloscope: An instrument for measuring and displaying an electrical quantity (typically voltage) as a function of time. The bandwidth should be at least 10 times the maximum frequency of interest and include triggering capacity. *See also:* **maximum frequency of interest.**

3.28 overload: A condition in which the maximum current of the power supply is exceeded.

3.29 overtemperature protection: A feature in a power supply that senses and responds to an over-temperature condition.

3.30 PARD: The abbreviation for periodic and random deviation. PARD is the sum of all ripple and noise components measured over a specified bandwidth and stated, unless otherwise specified, in peak-to-peak values.

3.31 phase margin: The absolute value of loop phase angle subtracted from 180° found in a feedback system at the frequency for which its gain reaches unity. The margin from 180° represents a measure of dynamic stability.

3.32 point of regulation (POR): The location in the subsystem [unit under test (UUT)] where voltage is sensed for voltage regulation. The point of regulation can be remote or local to the voltage regulation equipment.

3.33 power factor (displacement): For user equipment, the displacement power factor is equal to the cosine of the angle, ϕ , between the input current and the input voltage at the fundamental frequency.

$$PF_{dp} = \cos \phi$$

This definition of power factor does not include the effect of distortion in the input current (and/or voltage) waveform.

3.34 power factor (distortion): The distortion power factor is defined as

$$PF_{dt} = \frac{1}{\sqrt{1 + THD^2}}$$

where

THD (Total Harmonic Distortion) is defined as in 3.42

This definition of power factor does not include effect of displacement.

3.35 power factor (true): For user equipment, the true power factor is the ratio of the active, or real, power (P) consumed in watts to the apparent power (S) drawn in volt-amperes, with

$$PF = P/S$$

and

$$S = \sqrt{P^2 + Q^2}$$

where

PF is power factor,
 P is active power in watts,
 Q is reactive power in vars,
 S is total power in volt-amperes.

This definition of power factor includes the effect of both displacement and distortion in the input current (and/or voltage) waveform.

Alternatively, if there are no inter-harmonics, the previous equation can be simplified to

$$PF = PF_{dp} \times PF_{dt}$$

3.36 reactive power: Reactive power (Q) is the vector difference between apparent and real power:

$$Q = \sqrt{S^2 - P^2}$$

3.37 remote on/off control: The control over the on/off operation of the unit under test (UUT) output power by means initiated externally or away from the UUT.

3.38 short circuit: The condition in which the output terminals of the power supply are directly connected together, resulting in near-zero output voltage.

3.39 source impedance: The source impedance is defined to begin at the power source termination (as shown in Figure 3) and end at the power source return termination. Hence, all cabling is included in the source impedance. The cables and interconnects used in the system should be used during test. Line impedance stabilization networks (LISNs) may be used in series with each input line to provide a uniform standard for source impedance. Different LISNs may be used for different test applications to test the UUT.

3.40 spectrum analyzer: A test instrument which measures and displays the measurements of amplitude versus frequency for a given signal. Its frequency range should be at least 100 Hz to 1500 MHz; resolution bandwidth should be at least 10 Hz to 3 MHz; the video bandwidth should be at least 1 Hz to 3 MHz, and amplitude range should be at least -135 to $+35$ dBm.

3.41 steady state: Steady state refers to the operating condition of a system wherein the observed variable has reached an equilibrium condition in response to an input or other stimulus in accordance with the definition of the system transfer function. This may involve a system output being at some constant voltage or current values in the case of power supplies. Referring to a subsystem operating parameter such as a thermal base-plate, it may refer to a temperature that has reached stability as a function of the system operating inputs, load, and ambient environment.

3.42 total harmonic distortion (THD): The ratio, expressed as a percent, of the rms value of the ac signal after the fundamental component is removed and inter-harmonic components are ignored, to the rms value of the fundamental. The formula defining total harmonic distortion is $PF = P/S$ and $S = \sqrt{P^2 + Q^2}$. The variables X_1 and x_n may represent either voltage or current, and may be expressed either as rms or peak values, so long as all are expressed in the same fashion.

$$THD_x = \frac{\sqrt{\sum_{n=2}^{\infty} x_n^2}}{X_1} \times 100\%$$

where

X_1 is fundamental value of current or voltage,
 x_n is n^{th} harmonic value of current or voltage.

3.43 total or apparent power: The total or apparent power (S) is the product of rms voltage and current (VA)

3.44 transient: Transient is a momentary departure of a characteristic from steady-state conditions and back to steady state conditions as a result of a system disturbance. Normal transients occur as a result of normal disturbances such as load or line changes. Abnormal transients result from abnormal disturbances such as a power interruption or wire fault.

3.45 UUT: The abbreviation for unit under test.

3.46 UVLO: The abbreviation for undervoltage lock-out.

3.47 V_{max} input: The maximum allowable input voltage rating at which the unit under test (UUT) can operate to specifications.

3.48 V_{min} input: The minimum allowable input voltage rating at which the unit under test (UUT) can operate to specifications.

3.49 V_{nom} input: The stated or objective value of the input voltage, which may not be the actual value measured. The value should be between the minimum and maximum input value.

3.50 voltage probe: A connecting device, usually consisting of a two-conductor shielded cable and frequency-compensating network, with a hand-held tip, for use with an oscilloscope to measure the amplitude and waveshape of a dc, ac, or composite signal. It should include a ground reference. The measurement

bandwidth should be at least 10 times greater than the frequency of interest. The impedance should be at least 50 times greater than the node impedance under measurement.

4. Electrical performance parameters

In general, if a single test result is to be provided for a given unit under test (UUT), it shall be the value measured over the most demanding combination of environmental stresses, input, and load characteristics. If a single number is to be provided as part of a *data-sheet* characterization of the product, a suitable margin shall be added to allow for production variations, test equipment accuracy, and aging. Any limiting conditions on the above shall be clearly identified. (See Annex B for general test practices.)

4.1 DC voltage

4.1.1 DC input voltage

4.1.1.1 Definition

DC voltage is the dc input voltage to a UUT excluding any ac or transient voltage within a specified range. For example, $22\text{ V} < V_{\text{in}} < 34\text{ V}$ is a typical voltage range of a 28 V bus.

4.1.1.2 Test method

Connect the test setup as shown in Figure 4. The measurement of the dc input voltage is performed with a digital multimeter directly across the UUT input terminals.

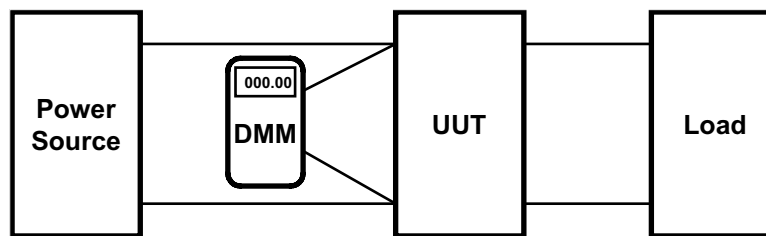


Figure 4—DC input voltage measurement test set up

4.2 AC voltage

4.2.1 RMS value (voltage)

4.2.1.1 Definition

The square root of the average of the square of the value of the function taken throughout the period. For instance, the rms voltage value for a sine wave may be computed as:

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^T v^2(t) dt} \quad (1)$$

where

T is waveform time period,

$v(t)$ is instantaneous voltage at time t ,
 V_{rms} is rms voltage value.

4.2.1.2 Test method

Details of this method are defined in the Handbook of Standardized Terminology for Power Sources Industry published by PSMA [B8].⁶

4.2.2 AC voltage (peak)

4.2.2.1 Definition

AC voltage (peak) is the maximum instantaneous value of a waveform reached during a particular cycle or waveform interval period. For a sine wave voltage the peak value is

$$V_{peak} = \sqrt{2} \times V_{rms} \quad (2)$$

For a voltage wave containing harmonics the peak value is

$$V_{peak} = V_{rms} \times cf \quad (3)$$

where

cf is the Crest Factor.

4.2.2.2 Test method

Connect the test setup as shown in Figure 5. Connect an oscilloscope to directly measure the peak value. Measurements can be taken phase-to-phase or phase-to-neutral for single- to multiple-phase systems.

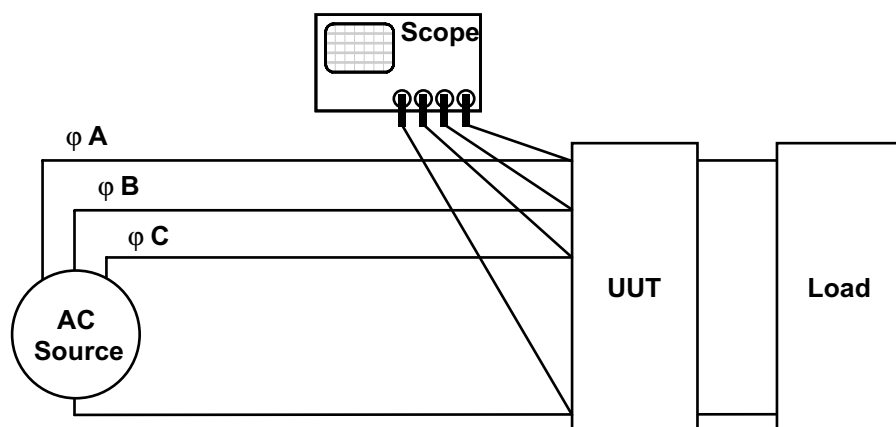


Figure 5—AC Voltage test setup for a wye-connected, 3-phase system

⁶The numbers in brackets correspond to those of the bibliography in Annex A.

4.2.3 AC voltage (steady state)

4.2.3.1 Definition

The value of any of the phase-to-neutral or phase-to-phase (in the absence of neutral) voltages supplied to single- or three-phase utilization equipment. All ac voltage values, unless otherwise specified, are root-mean-square (rms) values.

4.2.3.2 Test method

Connect the test setup as shown in Figure 6. Steady state AC voltage measurement test setup. Connect a rms meter as close to the UUT as possible to directly measure the value. Measurements can be taken phase-to-phase or phase-to-neutral for single- to multiple-phase systems.

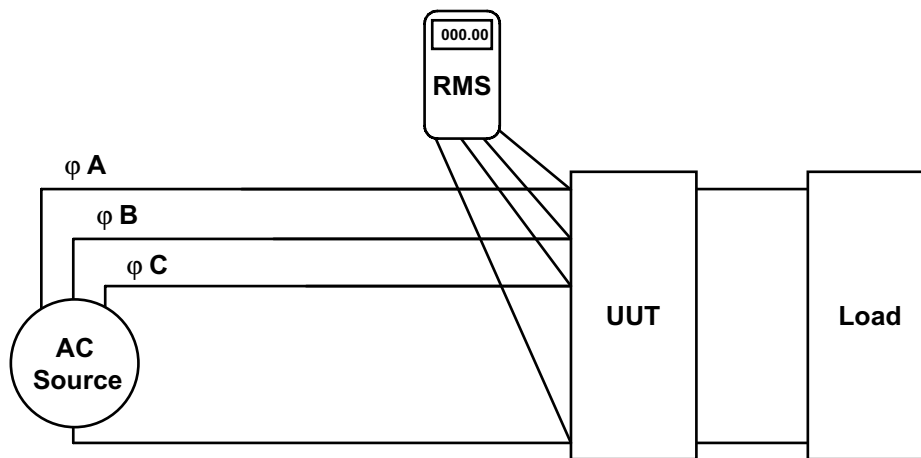


Figure 6—Steady state AC voltage measurement test setup

4.2.4 Voltage phase difference

4.2.4.1 Definition

Voltage phase difference is the difference in electrical degrees between the fundamental components of any two voltages taken at consecutive zero crossings traced in the negative to positive directions.

4.2.4.2 Test method

Connect the test setup as shown in Figure 5 using a three or more channel oscilloscope. The phase difference(s) may be read directly. Figure 7 illustrates a measure of voltage phase difference.

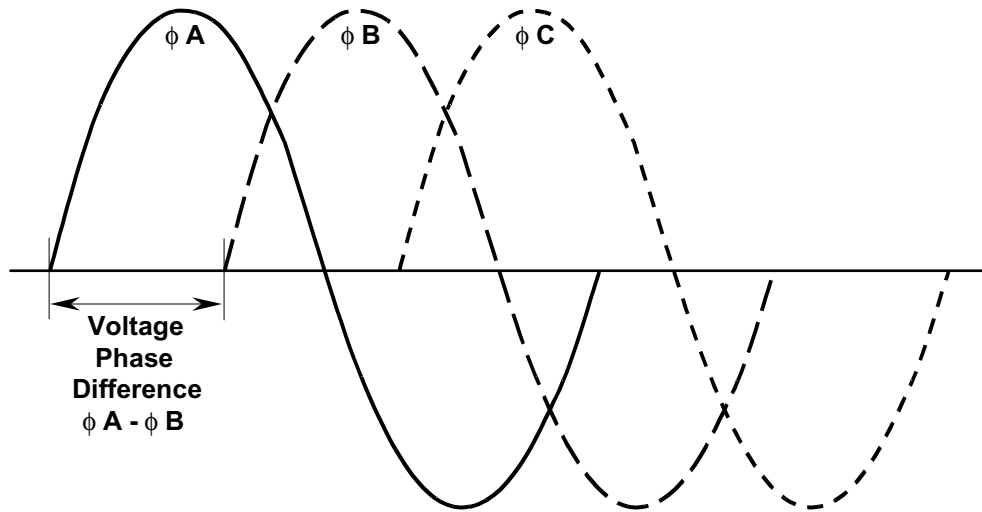


Figure 7—Three-phase voltage waveform

4.2.5 Voltage unbalance

4.2.5.1 Definition

Voltage unbalance is the maximum difference between rms phase-to-neutral or phase-to-phase voltage amplitudes at the UUT input terminals. For example, for a wye-connected, three-phase system

$$V_{UNB\%} = (\max[V_{AN}, V_{BN}, V_{CN}] - \min[V_{AN}, V_{BN}, V_{CN}]) \times 100 \quad (4)$$

where

V_{AN} , V_{BN} , V_{CN} are the phase voltage magnitudes,
 $V_{UNB\%}$ is maximum phase voltage unbalance.

Percent voltage unbalance is calculated by multiplying the maximum voltage unbalance (V_{UNB}) by 100, and then dividing the result by the average of the three phase voltages.

$$V_{UNB\%} = \frac{V_{UNB}}{\left(\frac{V_{AN} + V_{BN} + V_{CN}}{3}\right)} \times 100 \quad (5)$$

4.2.5.2 Test method

Connect the setup as shown in Figure 5. AC voltage test setup for a wye-connected, three-phase system. Measure each phase and take the difference between the largest and smallest reading.

4.2.6 Phase sequence

4.2.6.1 Definition

Phase sequence is the order in which the voltages in a polyphase system successively reach their positive maximum values.

4.2.6.2 Test method

Connect the setup as shown in Figure 5 and verify the time sequence of phases A, B, and C.

4.2.7 Input current unbalance

4.2.7.1 Definition

Input current unbalance is the ratio of loads on each phase of a three-phase, sinewave ac system.

4.2.7.2 Test method

Connect the setup as shown in Figure 8. One current probe is attached to each of the three input phases. (If a neutral wire is present, it should also be monitored with a current probe). A rms current meter is used for each measurement. This test is only applicable to three-phase, ac power sources. It is only performed on the input of the UUT. Source voltage (amplitude, phase, and source impedance) should be balanced. The rms current on each of the three input phases is measured and compared.

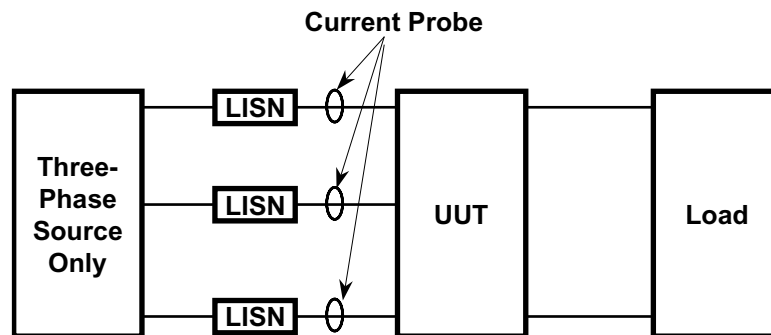


Figure 8—Input current unbalance test setup

4.2.7.3 Test condition

Test the UUT under conditions that produce the least favorable input current balance. This can be accomplished by changing the load and/or the mode of operation. Test the unit at 25 °C.

4.3 Efficiency

4.3.1 Efficiency

4.3.1.1 Definition

Efficiency is the ratio, expressed as a percentage, of the total real output power produced by a conversion process to the real power required to produce it using the following equation:

$$\eta = \frac{\sum_i P_{o,i}}{P_{in}} \times 100 \quad (6)$$

where $P_{o,i}$ is the output power of the i^{th} output. The input power includes all housekeeping and auxiliary circuits required for the converter to operate unless otherwise specified.

4.3.1.2 Test method

For a dc-to-dc converter, connect the test setup as shown in Figure 9. It is noted that the ratio defined in Equation (6) is zero at no-load and at short circuit. Therefore, it is desirable to define the UUT's efficiency curves as shown in Figure 10. The recommended curves would be plotted for the specified min., nom., and max. input voltages, with each curve consisting of 10 data points between no-load and max rated load.

To ensure valid measurements, input, and output power (and power factor where applicable) must be measured concurrently.

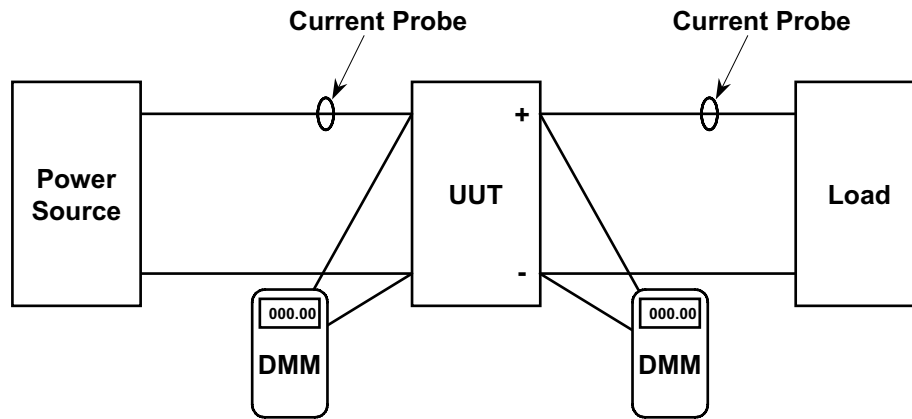


Figure 9—DC to DC converter efficiency and power dissipation measurement

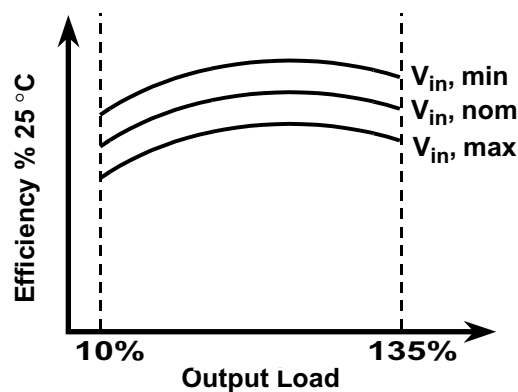


Figure 10—Efficiency vs. power curves

For an individual piece-part, a single useful value of UUT efficiency is obtained at the UUT's nominal input voltage and its maximum load. This is what is commonly referred to as a UUT maximum load efficiency.

4.3.1.3 Test condition

Adjust the input voltage and the output current from the minimum to the maximum specified limits. The operating temperature shall be minimum to maximum (stabilized after warm up).

Test conditions are as follows:

V_{in} = Min, nom, and max rated steady state input voltage
 Loads = All loads adjusted from minimum load to max rated load.
 Operating Temperature = Min, nom, and max (stabilized after warm up)

4.3.2 Electrical power dissipation

4.3.2.1 Definition

Electrical power dissipation is the difference between the electrical input power to the UUT and its electrical output power, expressed in watts.

$$P_{diss} = P_{in} - \sum_i P_{o,i} \quad (7)$$

Alternatively, power dissipation is expressed as:

$$P_{diss} = P_{in} - \sum_i P_{o,i} = (1 - \eta)P_{in} \quad (8)$$

4.3.2.2 Test method

Use the same test setup as shown in Figure 9 to measure power dissipation. Power dissipation is obtained from the efficiency measurements of the input and output power as functions of line, load, and temperature. This should be the worst case value.

4.3.2.3 Test condition

Adjust the input voltage and the output load current from the minimum to the maximum specified limits and record the results.

4.4 Regulation

4.4.1 Line regulation

4.4.1.1 Definition

Line regulation is the percentage variation of the specified steady state output voltage, V_o , while the input voltage varies over the range of specified input voltage, V_{in} , at specified output load values, with all other factors constant. Line regulation is expressed in percentage as:

$$\pm \frac{V_{o,max} - V_{o,min}}{V_{o,max} - V_{o,min}} \times 100 \quad (9)$$

where

$V_{o,max}$ is the maximum measured output voltage,
 $V_{o,min}$ is the minimum measured output voltage.

4.4.1.2 Test method

For line regulation tests, use the test setup shown in Figure 11. Output load and operating temperature are held constant. Measure V_o as close as possible between the plus and minus output connections of the UUT.

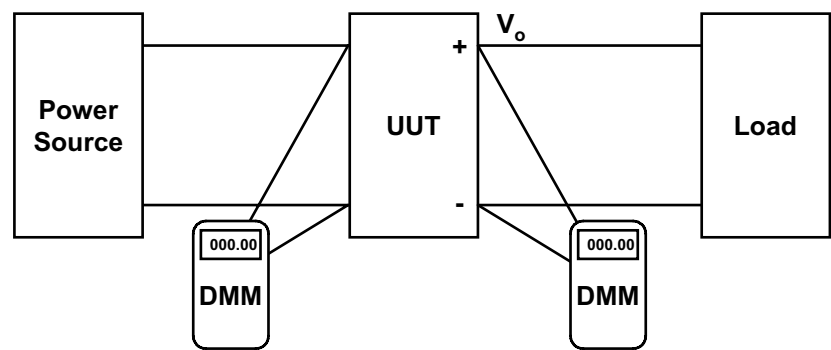


Figure 11—Line regulation test setup

4.4.1.3 Test conditions

Test for line regulation from minimum to maximum specified input voltage, holding the load and operating temperature constant, typically, at nominal values.

4.4.2 Load voltage regulation

4.4.2.1 Definition

The percentage variation of an output voltage, V_o , while that output's load is changed over the specified range, with all other factors held constant as specified. Figure 12 depicts the relationship between output voltage and load current. Load voltage regulation is expressed in percentage as:

$$\pm \frac{V_{o,max} - V_{o,min}}{V_{o,max} + V_{o,min}} \times 100$$

(10)

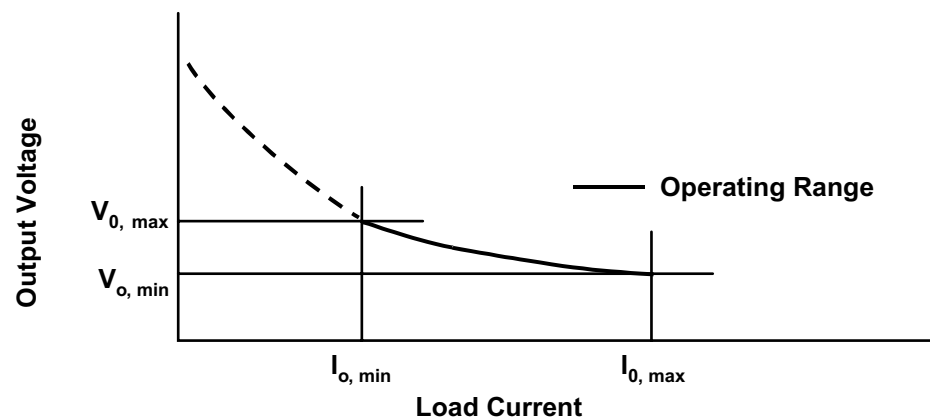


Figure 12—Load voltage regulation

4.4.2.2 Test method

Connect the test setup as shown in Figure 13. Measure the output voltage, V_o with a digital multimeter at the plus and minus outputs of UUT and as close as possible to the output connections.

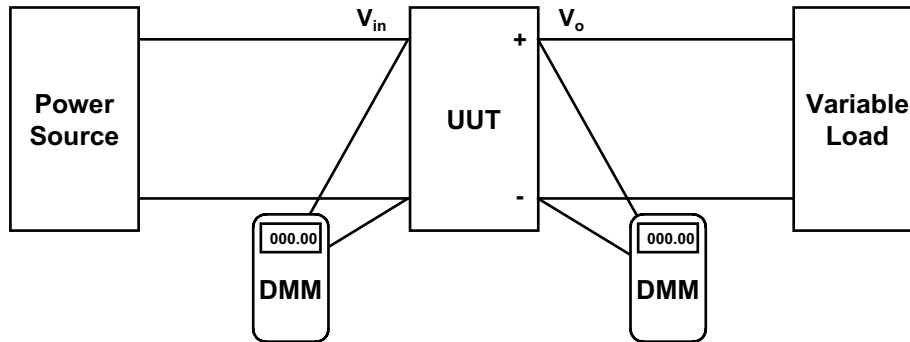


Figure 13—Load voltage regulation test setup

4.4.2.3 Test conditions

V_{in} shall be adjusted to the full operating range of input voltage, the output load shall be resistive and adjusted from I_{min} to I_{max} , and over the full operating temperature range, unless otherwise specified.

4.4.3 Temperature regulation

4.4.3.1 Definition

Temperature regulation is the change in the unit output due to a change in temperature with all other parameters held constant. As a power supply output specification, it is the percent positive and negative deviation around an average value, derived by the following formula:

$$\pm \frac{V_{o, max} - V_{o, min}}{V_{o, max} + V_{o, min}} \times 100 \quad (11)$$

If the change is approximately linear with temperature, an acceptable alternative or supplement is to provide the highest value of the change of temperature within the specified range, expressed in units of $^{\circ}\text{C}$.

$$\frac{\Delta V_o}{\Delta V_{o, min}} \times 100 \quad (12)$$

4.4.3.2 Test method

Connect the UUT to a power source and the specified nominal load as shown in Figure 13. Measure the output voltage with a digital multimeter.

4.4.3.3 Test condition

Adjust the unit input voltage and the load current to nominal. Slowly increase the ambient temperature to maximum, allowing it to settle and maintain constant at specific points, and measure the output voltage.

4.4.4 Cross regulation

4.4.4.1 Definition

In a multiple output power supply, cross regulation is the percent voltage change at output m caused by the load change in output n . It is expressed in percentage as:

$$CR_{m/n} = \pm \frac{V_{o,m,max} - V_{o,m,min}}{V_{o,m,max} + V_{o,m,min}} \times 100 \bigg|_{I_{o,n,min}}^{I_{o,n,max}} \quad (13)$$

where

- m is the m^{th} output voltage,
- n is currents in n^{th} output and $m \neq n$.

4.4.4.2 Test method

Use the test setup shown in Figure 14. The loads are adjusted to rated current levels as indicated on the ammeters. The output voltages are measured as close as possible to the plus and minus connections of the UUT with a digital multimeter.

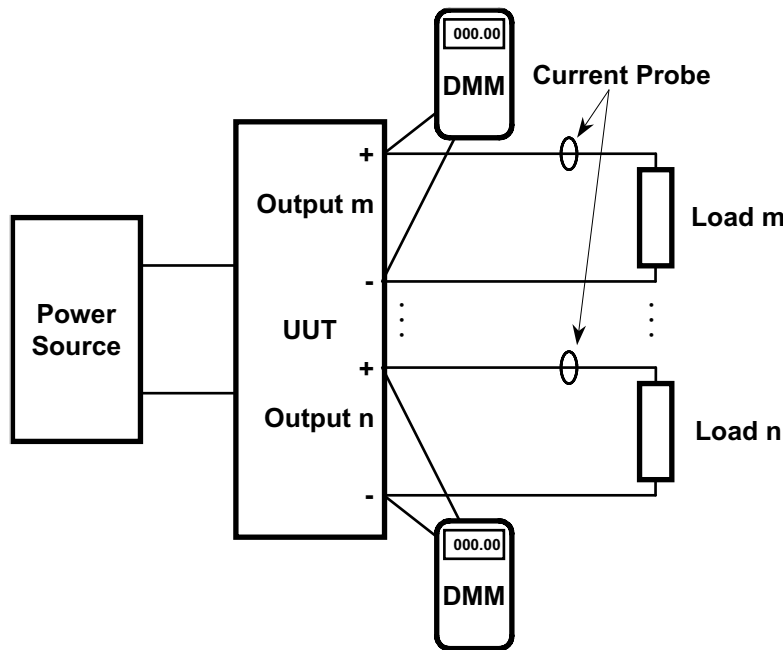


Figure 14—Cross regulation test setup

4.4.4.3 Test condition

Conduct over the full range of input voltage and output load (resistive). The temperature shall be held constant. Set the UUT output m to $I_{m,max}$, and sweep the n^{th} output from $I_{n,max}$ to $I_{n,min}$, and measure the output voltages. Set the output m to $I_{m,min}$ and sweep the n^{th} output from $I_{n,min}$ to $I_{n,max}$, and measure the output voltages.

4.4.5 System dynamics

4.4.5.1 Definition

System dynamics is defined as the desired performance characteristics of a system of any order may be specified in terms of the transient response to a step-function input. The dynamics of a system may be evaluated in terms of the following quantities, as shown in Figure 15:

- Maximum overshoot, c_p , is the magnitude of the first overshoot of the target value. This may be also expressed in percent of the target or final value.
- Time to maximum overshoot, t_p , is the time required to reach maximum overshoot.
- Time to first zero error, t_0 , is the time required to reach the final value the first time. It is sometimes referred to as the duplicating time.
- Settling time, t_s , is the time required for the output response first to reach and thereafter remain within a prescribed percentage of the final value. This percentage must be specified in the individual case applied to the envelope that yields t_s . The settling time, t_p , may be smaller than t_s .

In cases where the oscillating frequencies are of interest, measurement should be taken.

The time response differs for each set of initial conditions. Therefore, to compare the time response of various systems it is necessary to start with standard initial conditions. The most practical standard is to start with the system at rest or at a nominal standard value. Then the response characteristics, such as maximum overshoot and settling time, can be compared significantly.

For some systems, these specifications are also applied for a ramp input. In such cases, the plot of error with time is used with the definitions. For systems subject to shock inputs, the response due to an impulse is used as a criterion of performance.

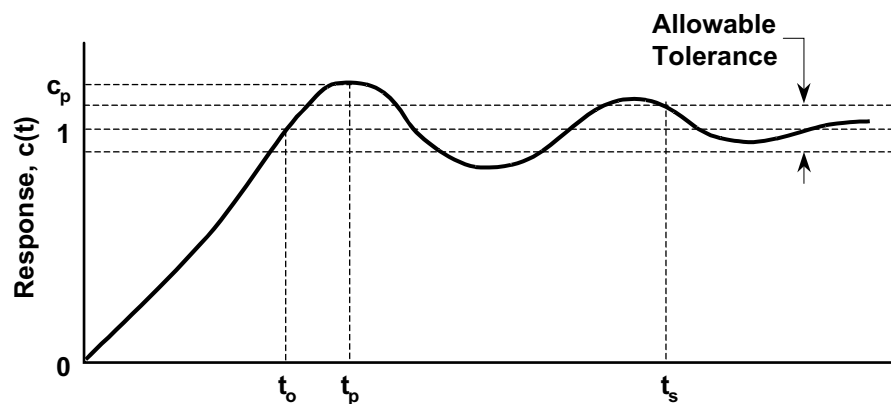


Figure 15—Typical underdamped response to a step function

4.4.6 Dynamic line regulation

4.4.6.1 Definition

Dynamic line regulation is the transient response of the output voltage of an electronic power distribution subsystem element to a step change in the input voltage.