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DEPARTMENT OF DEFENSE INTERFACE STANDARD

SECTION 300, PART 1

LOW VOLTAGE ELECTRIC POWER, ALTERNATING CURRENT

AMSC N/A

FSC 1990

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FOREWORD

1. Preamble. This standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Purpose. This section defines the standard interface requirements for and the constraints on the design of shipboard user equipment that will utilize shipboard alternating current (AC) low voltage electric power.

3. Nature of the interface. In any system involving power source, distribution network, and load (user equipment), the characteristics at the system and user equipment interface are mutually dependent on the design and operation of both. In order for the electric power system to perform within the established tolerances, it is necessary to place constraints on the power source, the distribution system, and the user equipment. This interface standard defines the electric power system characteristics. User equipment constraints are also established.

4. Structure. The technical content first delineates the characteristics of the shipboard electric power system at the interface in terms of voltage, frequency, continuity, and voltage waveform. Constraints on user equipment design and installation, which are necessary to achieve shipboard compatibility with and to assure these characteristics, are then established. Finally, test requirements are specified to verify conformance of user equipment to this standard.

5. Invoking the standard. Naval Sea Systems Command (NAVSEA) will consider the mission requirement of the user equipment being developed or acquisitioned. NAVSEA will then select those conditions under which the user equipment is to operate and those conditions, which the user equipment will withstand without failure, but not necessarily, operate normally. NAVSEA will also specify those tests commensurate with the equipment's mission, which will ensure the user equipment's satisfactory operation, the user equipment's compatibility with the shipboard electric power system and other equipment, and the equipment's survival.

6. NATO coordination and standardization. The standard characteristics of AC electric power supplied for U.S. Navy ships have been coordinated with North Atlantic Treaty Organization (NATO) standardization documentation, where applicable. In particular, the standard characteristics of Type I and Type II power conform to corresponding power types specified in STANAG 1008 (Edition 9).

7. Numerical quantities. Numerical quantities are expressed in metric (SI) units.

8. Contact information. Comments, suggestions, or questions on this document should be addressed to Commander, Naval Sea Systems Command, ATTN: SEA 05S, 1333 Isaac Hull Avenue, SE, Stop 5160, Washington Navy Yard, DC 20376-5160 or emailed to CommandStandards@navy.mil, with the subject line "Document Comment". Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla mil.

CONTENTS

CONTENTS

CONTENTS

PARAGRAPH PAGE

CONTENTS

PARAGRAPH PAGE

CONTENTS

PARAGRAPH PAGE

CONTENTS

FIGURES PAGE

CONTENTS

1. SCOPE

1.1 Scope. This military standard section establishes electrical interface characteristics for shipboard equipment utilizing AC low voltage electric power to ensure compatibility between user equipment and the electric power system. MIL-STD-1399-300-2 describes Navy or industrial medium voltage systems. Characteristics of the electric power system are defined and tolerances are established, as well as requirements and test methods for ensuring compatibility of shipboard user equipment with the power system. The policies and procedures established by MIL-STD-1399 are mandatory. This section and the basic standard are to be viewed as an integral single document for use in the design and testing of electric power systems and user equipment.

1.2 Classification. Types of shipboard low voltage electric power to be supplied from the electric power system are classified as follows:

Type I - Type I power is 440 or 115 volts root mean square (V_{rms}), 60 hertz (Hz) and is the standard AC shipboard electric power source. 440-V_{rms} interfaces are either three-phase or single-phase and are either ungrounded or high-resistance grounded. 115-V_{rms} interfaces are either three-phase or single-phase and are either ungrounded or solidly-grounded. Type I power is used unless a deviation is granted (see 4.4).

Type II - Type II power is 440 or 115 V_{rms}, 400 Hz ungrounded and has only limited application. Use of Type II power requires the submittal and approval of a deviation request (see 4.4).

Type III - Type III power is 440 or 115 V_{rms}, 400 Hz ungrounded having tighter tolerances as compared to Type II. Type III power has restricted use and its use requires the submittal and approval of a deviation request (see 4.4).

1.2.1 Special power classifications at the load interface.

a. For servicing aircraft in hangars and on flight decks, avionic shops, and hotel services:

Type I - Type I power is 115/200 V_{rms}, 60 Hz, three-phase, four-wire wye, grounded neutral.

b. For servicing aircraft in hangars and on flight decks, avionic shops, and Landing Craft Air Cushion (LCAC) systems:

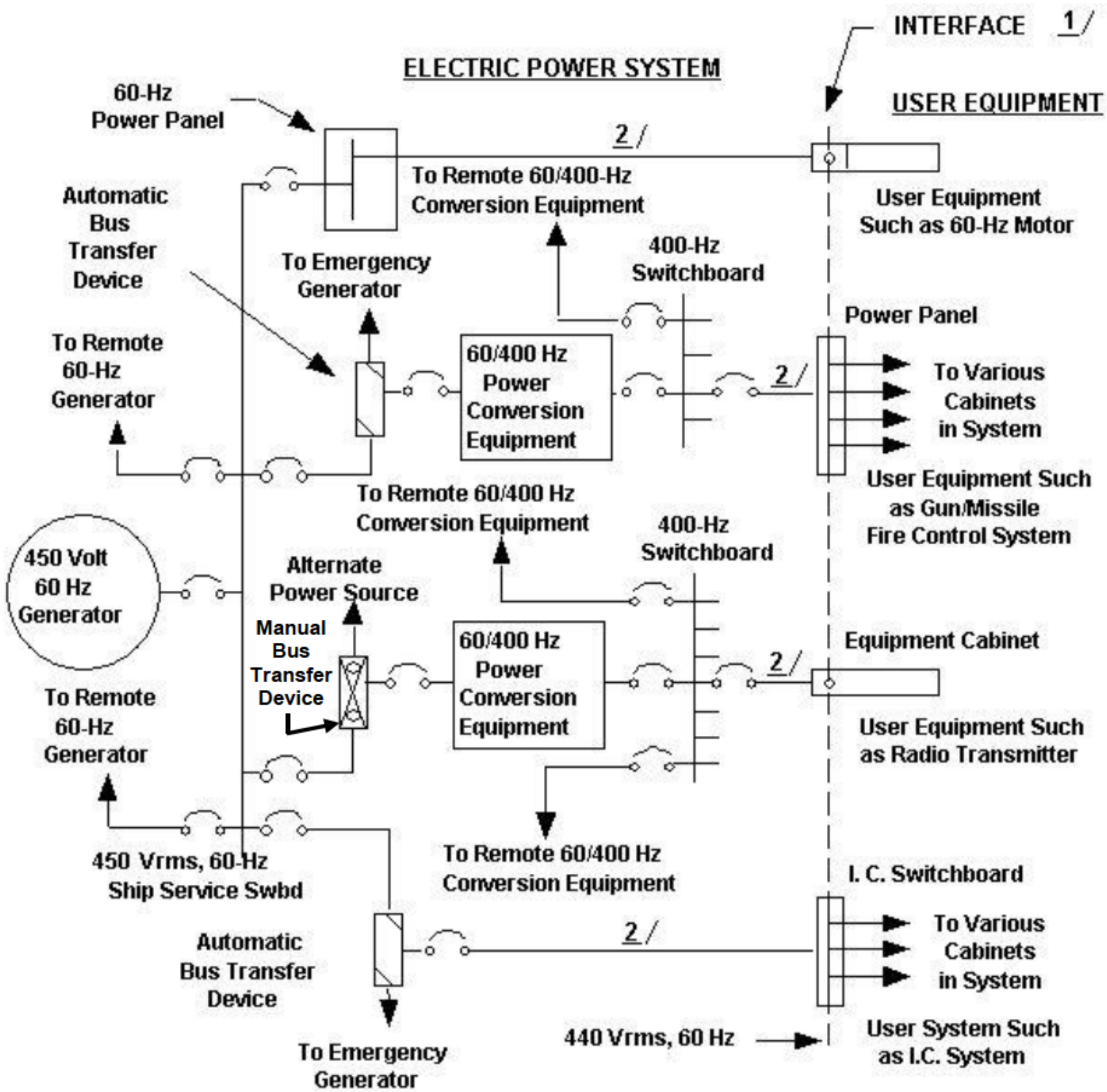
Type III - Type III power is 115/200 V_{rms}, 400 Hz, three-phase, four-wire wye, grounded neutral.

c. For NATO load equipment:

Type I - Type I power is 230 V_{rms}, 60 Hz, three-phase ungrounded or 230 V_{rms}, 60 Hz, single-phase grounded or ungrounded. Its tolerances are the same as for Type I power as described in table II except that the spike voltage will be at 1400-V peak.

1.2.2 Special non-standard power. For types of shipboard electric power supplied for specific industrial equipment such as washers, dryers, etc., see NAVSEA Drawing 302-7512881 for 120/208-V_{rms} rated loads and NAVSEA Drawing 302-7598285 for 240/120-V_{rms} rated loads. Non-standard power should comply with Type I tolerances. Perform the tests in 5.3 at the input terminals to the transformer receiving ship's power from the shipboard distribution power panel or the load center switchboard.

1.3 Electric power at the interface. The ship service generation sources supply electric power to the interface (see 3.2) which feeds the user equipment as shown on figure 1. At this location, cable designations change from power or lighting designations, such as P, EP, PP, L, EL, or SF, to other or no designation change at the user equipment electric power input terminals.



NOTES:

1. Typical Power System Characteristics: Voltage, Frequency, and Emergency Conditions.
2. Typical User Equipment Constraints: Type of Power, Power Factor, Power Interruption, Grounding, Load Unbalance, Pulsed Loads, Input Current Waveform, and Surge/Inrush Current.

FOOTNOTES:

1/ Refer to 1.3 for a description of the interface.

2/ Cables with power/lighting designations.

FIGURE 1. Typical interface of electric power system and user equipment.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3, 4, or 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3, 4, or 5 of this standard, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-917 - Electric Power Equipment, Basic Requirements for

MIL-DTL-24765 - Power Supply, Uninterruptible, Static (Naval Shipboard)

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-461 - Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

MIL-STD-1399 - Interface Standard for Shipboard Systems

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-2036 - Preparation of Electronic Equipment Specifications

(Copies of these documents are available online at https://quicksearch.dla.mil.)

2.2.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

NAVAL SEA SYSTEMS COMMAND (NAVSEA) DRAWINGS

302-7512881 - Non-Standard Power Distribution System 120/208 V_{rms}, with Grounded Neutral

302-7598285 - Non-Standard Power Distribution System 240/120 V_{rms}

802-7094558 - CVN 78 Class Aircraft Carrier Electrical Interface Characteristics

(Copies of these documents are available from the applicable repositories listed in S0005-AE-PRO-010/EDM, which can be obtained online via Technical Data Management Information System (TDMIS) at https://mercury.tdmis.navy.mil. Copies of these documents may also be obtained from the Naval Ships Engineering Drawing Repository (NSEDR) online at https://199.208.213.105/webjedmics/index.jsp. To request an NSEDR account for drawing access, send an email to NNSY_JEDMICS_NSEDR_HELP_DESK@navy.mil.)

NAVAL SEA SYSTEMS COMMAND (NAVSEA) PUBLICATIONS

S9086-KC-STM-010/300 - Electric Plant - General

(Copies of this document are available online via Technical Data Management Information System (TDMIS) at https://mercury.tdmis.navy.mil by searching for the document number without the suffix. Refer questions, inquiries, or problems to: DSN 296-0669, Commercial (805) 228-0669. This document is available for ordering (hard copy) via the Naval Logistics Library at https://nll.ahf.nmci.navy.mil. For questions regarding the NLL, contact the NLL Customer Service at nllhelpdesk@navy.mil, (866) 817-3130, or (215) 697-2626/DSN 442-2626.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

IEEE

IEEE 45.1 - IEEE Recommended Practice for Electrical Installations on Shipboard - Design

IEEE 45.3 - IEEE Recommended Practice for Shipboard Electrical Installations - Systems Engineering

(Copies of these documents are available online at www.ieee.org.)

JOHNS HOPKINS UNIVERSITY TECHNICAL PAPER

Power-Specification Frequency-Domain Test and Analysis Methodology for Large Dynamic Loads

(Copies of this document are available online at http://www.jhuapl.edu/DFTProcedure.pdf.)

2.4 Order of precedence. Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Electric power system. The electric power system is the electric power generation and distribution system (excluding electric propulsion systems) including generation, cables, switchboards, switches, protective devices, converters, transformers, and regulators up to the user equipment interface.

3.2 Electrical interface. The electrical interface is the boundary between the electric power system and the user equipment where the electric power system characteristics (see 5.1) and the user equipment compatibility requirements (see 5.2) apply. Figure 1 illustrates the interface.

3.3 Electric power system ground. Ground is a plane or surface used by the electric power system as a common reference to establish zero potential. Usually, this surface is the metallic hull of the ship. On a nonmetallic hull ship, a special ground system is installed for this purpose.

3.3.1 Ungrounded electric power system. An ungrounded electric power system is a system that is intentionally not connected to the metal structure or the grounding system of the ship, except for test purposes. Although intentionally not system grounded, there exists an impedance to ground from each power line due to the always present parasitic capacitance to ground. An ungrounded electric power system can continue to perform normally if one line conductor becomes solidly grounded. However, an ungrounded system may be subject to over-voltages greater than five times nominal voltage as a result of an inductive arcing ground between one line and ground. Tolerance of a single line ground fault is managed by limiting the AC line-to-ground impedance (capacitance) such that the single fault ground current will be tolerated by the electric plant.

3.3.2 High-resistance grounded electric power system. A high-resistance grounded electric power system is a system that employs an intentional high resistance between the electric system neutral and ground. High-resistance grounding provides the same advantages of ungrounded systems (i.e., the system can continue to perform normally with one line grounded) yet limits the severe transitory over-voltages associated with ungrounded systems.

3.3.3 Solidly grounded electric power system. A solidly grounded electric power system is a system in which at least one conductor or point (usually the neutral point of the transformer or generator winding) is intentionally and effectively connected to system ground. A single ground fault from one line to ground will produce high fault current that should cause selective tripping of protective circuit breakers interrupting power service continuity.

3.4 Frequency. Units are in Hertz (Hz). It is denoted by the symbol “f”.

3.4.1 Nominal frequency. Nominal frequency ($f_{nominal}$) is the designated frequency in Hz in accordance with the Type Power Classification.

3.4.2 Frequency modulation. Frequency modulation is the periodic variation in frequency during normal operation, calculated by equation 1 and shown on figure 2; the permitted modulation is provided in table II, Item 2. The periodicity of frequency modulation should be considered as greater than one cycle, but not exceeding 10 seconds.

$$\text{Frequency modulation (percent)} = \left(\frac{f_{maximum} - f_{minimum}}{2 \times f_{nominal}}\right) \times 100$$

EQUATION 1

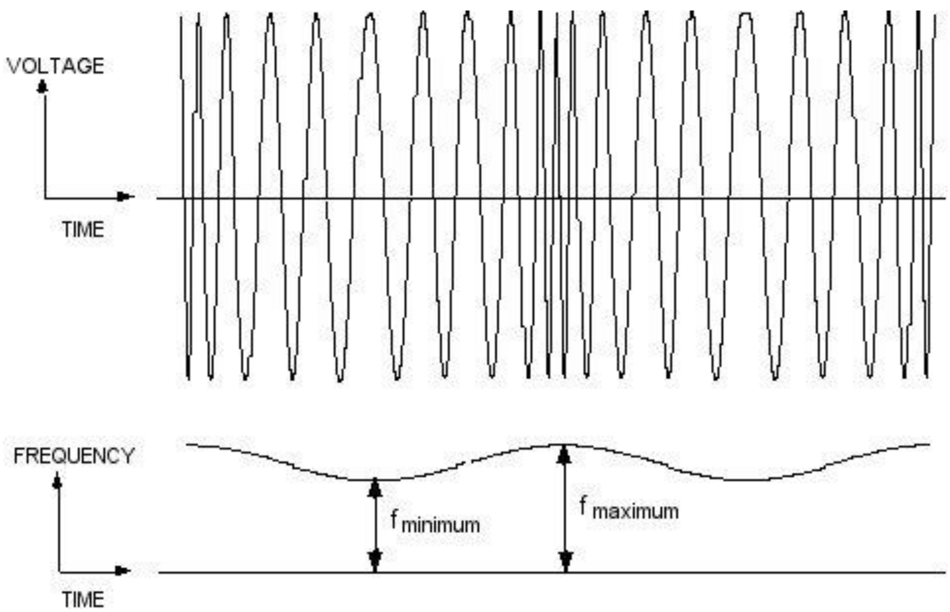


FIGURE 2. Frequency modulation.

3.4.3 Frequency tolerance. Frequency tolerance is the allowed variation from nominal frequency expressed as a percent of the nominal frequency; the permitted tolerance is provided in table II, Item 3. This tolerance is the maximum permitted value during normal operation including variations caused by small load changes, environmental effects (temperature, humidity, vibration, and inclination), and drift, excluding modulation and transients. The frequency tolerance may be calculated using equation 2.

$$\text{Frequency tolerance (percent)} = \left(\frac{f_{measured} - f_{nominal}}{f_{nominal}}\right) \times 100$$

Where:

$f_{measured}$ is the measured frequency and $f_{nominal}$ is the nominal frequency provided in table II, Item 1.

EQUATION 2

3.4.4 Frequency transients. A frequency transient is a sudden change in frequency that goes outside the frequency tolerance limits and returns to and remains within these limits within a specified recovery time (longer than 1 millisecond) after the initiation of the disturbance such as large load changes.

3.4.4.1 Frequency transient tolerance. Frequency transient tolerance is the allowed variation from nominal frequency expressed as a percent of the nominal frequency during transient conditions; the permitted tolerance is provided in table II, Item 4. The frequency transient tolerance may be calculated using equation 3.

$$\text{Frequency transient tolerance (percent)} = \left(\frac{f_{transient} - f_{nominal}}{f_{nominal}}\right) \times 100$$

Where:

$f_{transient}$ is the measured frequency transient and $f_{nominal}$ is the nominal frequency provided in table II, Item 1.

EQUATION 3

3.4.4.2 Frequency transient recovery time. Frequency transient recovery time is the time elapsed from the instant the frequency first goes outside the frequency tolerance limits until the instant the frequency recovers and remains within the frequency tolerance limits.

3.4.5 Worst case frequency steady-state and transient excursion. The worst case frequency excursion is the allowed excursion resulting from a combination of steady-state characteristics (modulation, tolerance) and transient characteristics with no individual characteristic exceeding its limits in table II; the permitted excursion is provided in table II, Item 5. This does not include emergency conditions.

3.5 Voltage. Units are in Volts (V). Unless specified as peak or DC quantities, voltages in this standard are root-mean-square (rms) values. Tolerances are expressed in percent of the nominal user voltage. It is denoted by the symbol "V".

3.5.1 Nominal user voltage. Nominal user voltage ($V_{nominal}$) is the designated voltage at the interface. As shown on figure 1, the generated or transformed source voltage is normally 450, 208, or 120 V_{rms}, and taking into consideration cable impedance voltage drop, the interface voltage should be set to 440, 200, or 115 V_{rms} by adjusting the source voltage.

3.5.2 Voltage unbalance (line-to-line). The line-to-line voltage unbalance is the difference of the maximum and minimum line-to-line voltages divided by the nominal line-to-line voltage; the permitted unbalance is provided in table II, Item 8. Voltages are either all rms or all peak (sinusoidal crest) values as shown in equation 4.

$$\text{Line-to-line voltage unbalance (percent)} = \left(\frac{V_{maximum} - V_{minimum}}{V_{nominal}}\right) \times 100$$

Where:

$V_{maximum}$ is the maximum line-to-line voltage,

$V_{minimum}$ is the minimum line-to-line voltage, and

$V_{nominal}$ is the nominal line-to-line voltage provided in table II, Item 7.

EQUATION 4

3.5.3 Voltage modulation (amplitude). Voltage modulation is the periodic voltage variation (peak-to-valley) of a single line-to-line user voltage, calculated by equation 5 and shown on figure 3; the permitted modulation is provided in table II, Item 9. The periodicity of voltage modulation should be considered to be longer than one cycle time at nominal frequency and less than 10 seconds. Voltages used in the following equation are either all rms or all peak (sinusoidal crest) values. $V_{nominal}$ is provided in table II, Item 7.

$$\text{Voltage modulation (percent)} = \left(\frac{V_{maximum} - V_{minimum}}{2 \times V_{nominal}}\right) \times 100$$

Where:

$V_{maximum}$ is the maximum line-to-line voltage,

$V_{minimum}$ is the minimum line-to-line voltage, and

$V_{nominal}$ is the nominal line-to-line voltage provided in table II, Item 7.

EQUATION 5

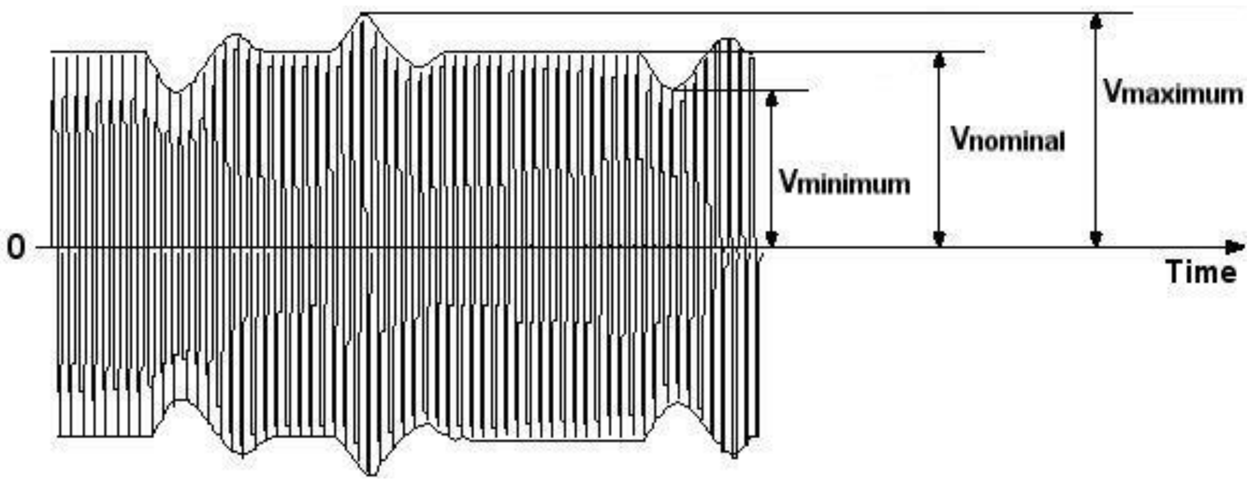


FIGURE 3. Voltage amplitude modulation.

3.5.4 Average line-to-line voltage tolerance. The average line-to-line user voltage tolerance is the allowed departure of the average of the line-to-line voltages from the nominal voltage as a percent of the nominal voltage. This average line-to-line voltage tolerance is the maximum permitted value (provided in table II, Item 10) during normal operation including variations caused by small load changes, environmental effects (temperature, humidity, vibration, and inclination), and drift, excluding voltage unbalance, modulation, and transients. The average line-to-line voltage tolerance is calculated in equation 6. Voltages are either all rms or all peak (sinusoidal crest) values.

$$\text{Average line-to-line voltage tolerance (percent)} = \left(\frac{V_{average} - V_{nominal}}{V_{nominal}}\right) \times 100$$

Where:

$V_{average}$ is the sum of the line-to-line voltages divided by the number of line-to-line voltages and $V_{nominal}$ is the nominal user voltage provided in table II, Item 7.

EQUATION 6

3.5.5 Single line-to-line voltage tolerance. The single line-to-line user voltage tolerance is the allowed departure of any single line-to-line voltage from nominal user voltage expressed as a percent of the nominal voltage. This line-to-line voltage tolerance is the maximum permitted value (provided in table II, Item 11) during normal operation including variations caused by small load changes, environmental effects (temperature, humidity, vibration, and inclination), and drift, excluding voltage unbalance, modulation, and transients. The line-to-line voltage tolerance is calculated in equation 7. Voltages are either all rms or all peak (sinusoidal crest) values.

$$\text{Single line-to-line voltage tolerance (percent)} = \left(\frac{V_{LL} - V_{nominal}}{V_{nominal}}\right) \times 100$$

Where:

V_{LL} is each line-to-line voltage and $V_{nominal}$ is the nominal user voltage provided in table II, Item 7.

EQUATION 7

3.5.6 Maximum voltage steady-state departure. The maximum voltage departure is the allowed departure resulting from a combination of steady-state characteristics (unbalance, modulation, and tolerance) with no individual characteristic exceeding its limits in table II; the permitted maximum steady-state voltage departure is provided in table II, Item 12.

3.5.7 Voltage transients. A voltage transient (excluding voltage spikes [see 3.5.9]) is a sudden change in voltage (longer than 1 millisecond) that exceeds, positively or negatively, the user voltage tolerance limits and returns to and remains within these limits within a specified recovery time after the initiation of the disturbance such as large load changes.

3.5.7.1 Voltage transient tolerance. Voltage transient tolerance is the allowed variation from nominal voltage expressed as a percent of the nominal voltage during transient conditions; the permitted voltage transient tolerance is provided in table II, Item 13. The voltage transient tolerance may be calculated using equation 8. Voltages are either all rms or all peak (sinusoidal crest) values.

$$\text{Voltage transient tolerance (percent)} = \left(\frac{V_{transient} - V_{nominal}}{V_{nominal}}\right) \times 100$$

Where:

$V_{transient}$ is the measured momentary line-to-line transient voltage and $V_{nominal}$ is the nominal user voltage provided in table II, Item 7.

EQUATION 8

3.5.7.2 Voltage transient recovery time. Voltage transient recovery time is the time elapsed from the instant the voltage first goes outside the user voltage tolerance limit until the instant when the voltage recovers and remains within the user voltage tolerance limit. A typical low level transient voltage is shown on figure 4.

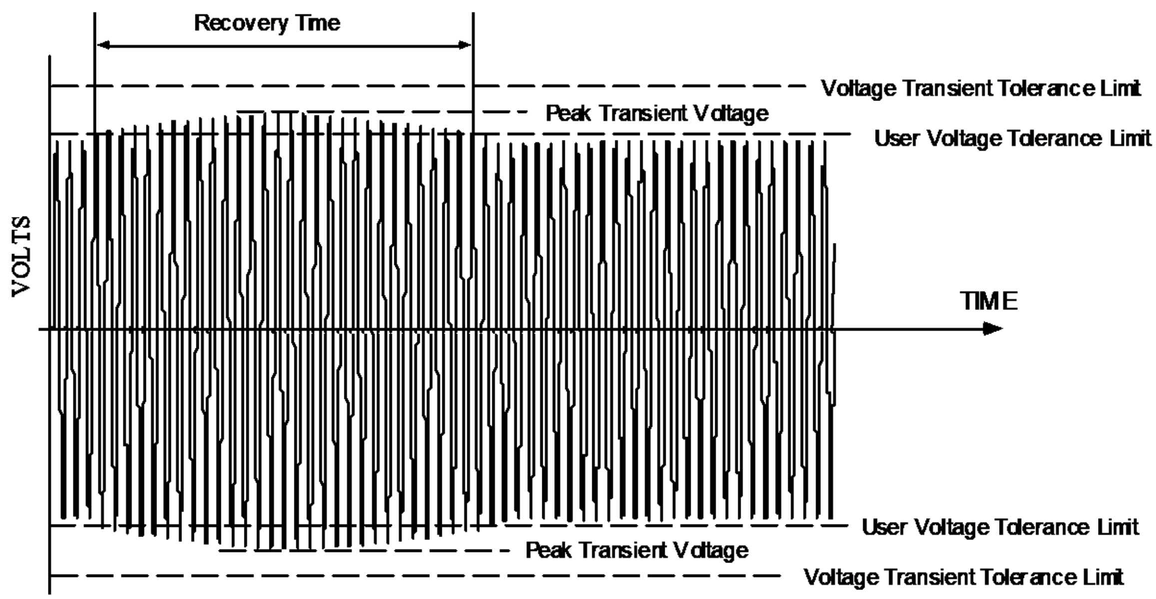


FIGURE 4. Voltage transient tolerance.

3.5.8 Worst case voltage steady-state and transient excursion. The worst case voltage excursion is the allowed excursion resulting from a combination of steady-state characteristics (unbalance, modulation, and tolerance) and transient characteristics with no individual characteristic exceeding its limits in table II; the permitted worst case voltage excursion is provided in table II, Item 14. This does not include emergency conditions.

3.5.9 Voltage spike. A voltage spike is a voltage change or impulse of very short duration (less than 1 millisecond) represented on figure 5. Voltage spikes in shipboard power systems are generally of an oscillatory nature and not unidirectional as those often used in testing. The impulse waveform shown on figure 6 is the characteristic voltage spike used for test purposes. The spike magnitude is measured in peak voltage (V_p).

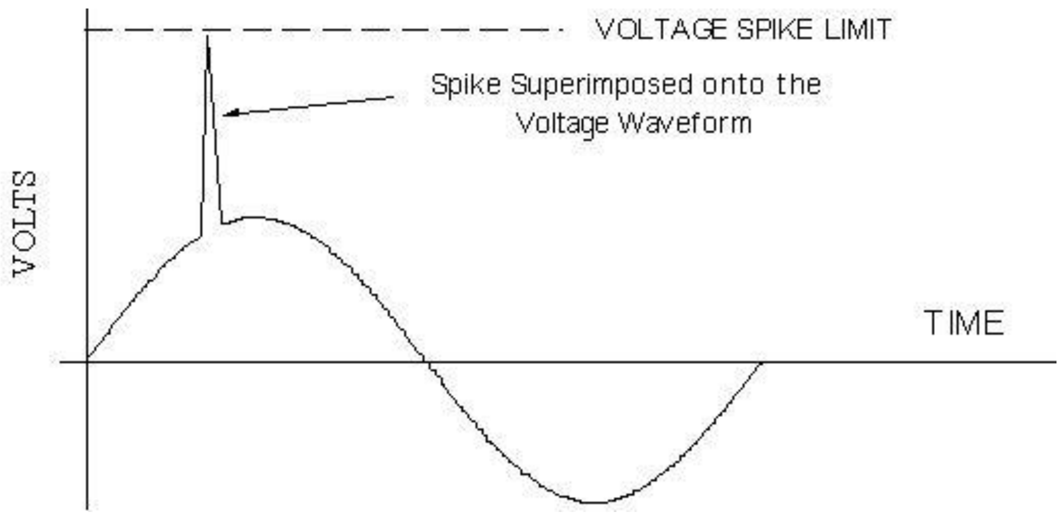
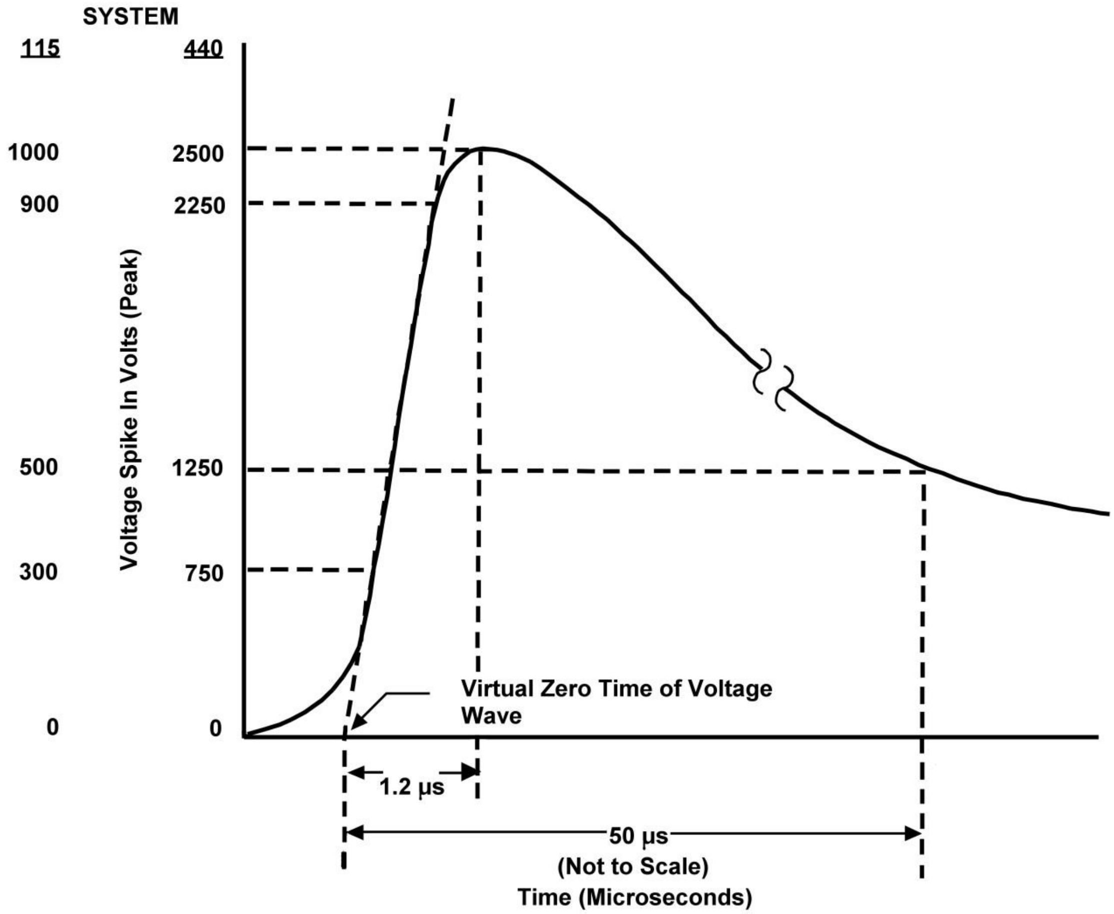


FIGURE 5. Voltage spike.



(NOTE: 2500-V peak and 1000-V peak spikes ride on the fundamental AC voltage waveform.)

FIGURE 6. Voltage spike impulse wave shape.

3.5.10 Voltage waveform. The voltage waveform is a voltage vs. time function.

3.5.10.1 Voltage single harmonic. A voltage single harmonic is a sinusoidal component of the voltage's periodic waveform having a frequency that is an integral multiple of the fundamental frequency.

3.5.10.2 Voltage single harmonic content. The voltage single harmonic content of a voltage wave is the ratio, in percentage, of the rms value of that harmonic to the rms value of the fundamental.

3.5.10.3 Voltage total harmonic distortion (THD). The THD of a voltage wave is the ratio in percentage of the rms value of the residue (after elimination of the fundamental) to the rms value of the fundamental, calculated by equation 9.

$$\text{Voltage THD (percent)} = 100 \times \sqrt{\sum_{h\geq 2}\left(\frac{V_h}{V_{fundamental}}\right)^2}$$

Where:

V_h is the rms voltage of individual harmonics

$h \geq 2$

$V_{fundamental}$ is the rms voltage at the fundamental frequency

EQUATION 9

3.5.10.4 Voltage deviation factor. The voltage deviation factor of the voltage waveform is the ratio (a/b) where "a" is the maximum deviation between corresponding ordinates of the waveform and of the equivalent sine wave and "b" is the maximum ordinate of the equivalent sine wave when the waveforms are superimposed in such a way that they make the maximum difference as small as possible. This is calculated by equation 10 and shown on figure 7. NOTE: The equivalent sine wave is defined as having the same frequency and the same rms voltage as the waveform being tested.

$$\text{Voltage deviation factor (percent)} = \left(\frac{\text{Maximum deviation}}{\text{Maximum ordinate of the equivalent sine wave}}\right) \times 100$$

EQUATION 10

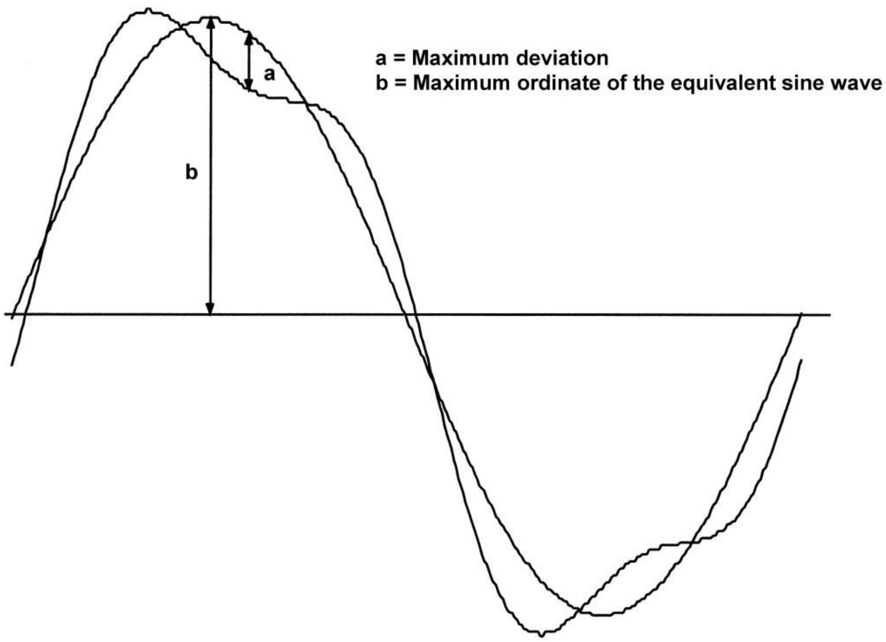


FIGURE 7. Voltage deviation factor variables.

3.6 Current. Units are in Amperes (A). Unless specified as peak or DC quantities, currents in this standard are rms values. It is denoted by the symbol "I".

3.6.1 Current unbalance. Current unbalance for three-phase loads is the ratio of the maximum line current magnitude minus the minimum line current magnitude to the average of the three line current magnitudes in amperes, shown in equation 11. Currents used in the following equation are rms values.

$$\text{Current unbalance (percent)} = \left(\frac{I_{linemax} - I_{linemin}}{(I_A + I_B + I_C)/3} \right) \times 100$$

EQUATION 11

3.6.2 Current waveform. The current waveform is a current vs. time function.

3.6.2.1 Current single harmonic. A current single harmonic is a sinusoidal component of the current's periodic waveform having a frequency that is an integer multiple of the fundamental frequency. There may exist currents at individual frequencies that are not harmonics and may be produced by switching frequencies internal to equipment.

3.6.2.2 Current single harmonic content. The current single harmonic content of a current waveform is the ratio, in percentage, of the rms value of that harmonic to the rms value of the fundamental.

3.6.3 Surge/inrush current. Surge/inrush current is a sudden change in line current to a user equipment that occurs during start-up or after a power interruption or as a result of a change to the operating mode. Typically, the surge current will rise to a maximum value in a few milliseconds and decay to rated value in several milliseconds to several seconds. The limit in 5.2.11 is evaluated as the ratio of the highest peak surge/inrush current to the peak of the rated current of the equipment.

3.6.4 Leakage current. Leakage current is energized circuit current from a conductor to another conductor or ground through parasitic capacitance and insulation resistance.

3.6.5 Line-to-ground current. Line-to-ground current is current from the line conductor through an impedance due to filter components-to-ground or leakage current.

3.6.6 Ground current. Ground current is current through a grounding conductor to ground, equal to the phasor summation of all the line-to-ground currents and is ideally equal to zero. This current only appears when there is an imbalance in the phases of the line-to-ground circuit and has a path to return to a similar circuit on the same distribution system.

3.6.7 Ground current from the simulated human body impedance ground current test. This is ground current due to unbalanced leakage and/or filter current that passes through a simulated human body circuit impedance magnitude of 1986 ohms and an angle of -5.37 degrees at 60 Hz using the metering circuit on figure 36. This current may appear when the load equipment becomes ungrounded and is measured through the simulated human body impedance.

3.6.8 Hull current. Hull current is the phasor summation of ground current through the hull of the ship.

3.7 Power factor (pf). The pf is the ratio of the real power in watts to the product of the rms voltage and rms current. For voltage waveforms with distortion, pf can be approximated as the product of the displacement pf (dpf) (see 3.7.1) and the distortion (μ) (see 3.7.2). This is shown in equation 12.

$$pf = \frac{P\ (watts)}{V_{rms}\ I_{rms}} \approx \mu\ dpf$$

EQUATION 12

3.7.1 Displacement power factor (dpf). The dpf is defined as the cosine of the angle difference between the fundamental frequency component of the input voltage and the fundamental frequency component of the current, shown in equation 13. The dpf is the same as the pf in linear circuits with sinusoidal voltages and currents. The angle determines whether the pf is leading or lagging. A positive value of the angle means that the current lags the voltage (lagging pf, inductive load). A negative value of the angle means that the current leads the voltage (leading pf, capacitive load).

$$dpf = \cos\left(\phi_V - \phi_I\right)$$

Where:

φ_V is the angle of the fundamental frequency component of the input voltage

φ_I is the angle of the fundamental frequency component of the current

EQUATION 13

3.7.2 Distortion component (μ) of pf. The distortion component (μ) of pf is the ratio of the rms magnitudes of the fundamental frequency current to the total current, shown in equation 14.

$$\mu = \frac{I_{fundamental}}{I_{total}}$$

Where:

$I_{fundamental}$ is the rms value of the fundamental frequency current

I_{total} is the rms value of the total current, which is the square root of the sum of the squares of the fundamental and harmonic currents

EQUATION 14

3.8 Power. Quantity that consists of real, reactive, and apparent power.

3.8.1 Real power. Real power is the average of the product of the current and voltage over time. As shown in equation 12, it is also the product of the rms voltage and rms current multiplied by the pf. The unit of real power is the watt. Real power provides work over time. It is denoted by the symbol “P”.

3.8.2 Reactive power. Reactive power is defined as the product of the rms voltage and rms current multiplied by a reactive factor. Reactive power can be calculated as the square root of the difference between the square of the apparent power and the square of the real power. The unit of reactive power is volt-ampere reactive (VAR). Reactive power provides no net energy transfer over time; the average instantaneous reactive power over a fundamental cycle period is 0. It is denoted by the symbol "Q".

3.8.3 Apparent power. Apparent power is defined as the product of the rms voltage and the rms current. The unit of apparent power is volt-ampere (VA). Apparent power can be calculated as the square root of the sum of the squares of real and reactive power. It is denoted by the symbol "S".

3.9 Pulse. A pulse is a brief excursion of power lasting longer than one cycle at nominal frequency and less than 10 seconds.

3.10 Pulsed load. A pulsed load is user equipment that demands infrequent or repetitive power input that could be supplemented by energy storage. Infrequent events are defined as events occurring no more than once every 120 seconds. A repetitive power input creates a dynamic waveform. An example of a pulsed load is sonar or radar user equipment. Pulsed loading may result in unwanted modulation in the system voltage amplitude and frequency and needs to be constrained to enable acceptable responses of the voltage regulation and prime mover speed governor systems.

3.10.1 Peak-to-peak pulsed real power. For a given window of observation, the peak-to-peak pulsed real power is the difference between the maximum instantaneous value and the minimum instantaneous value as shown on figure 8.

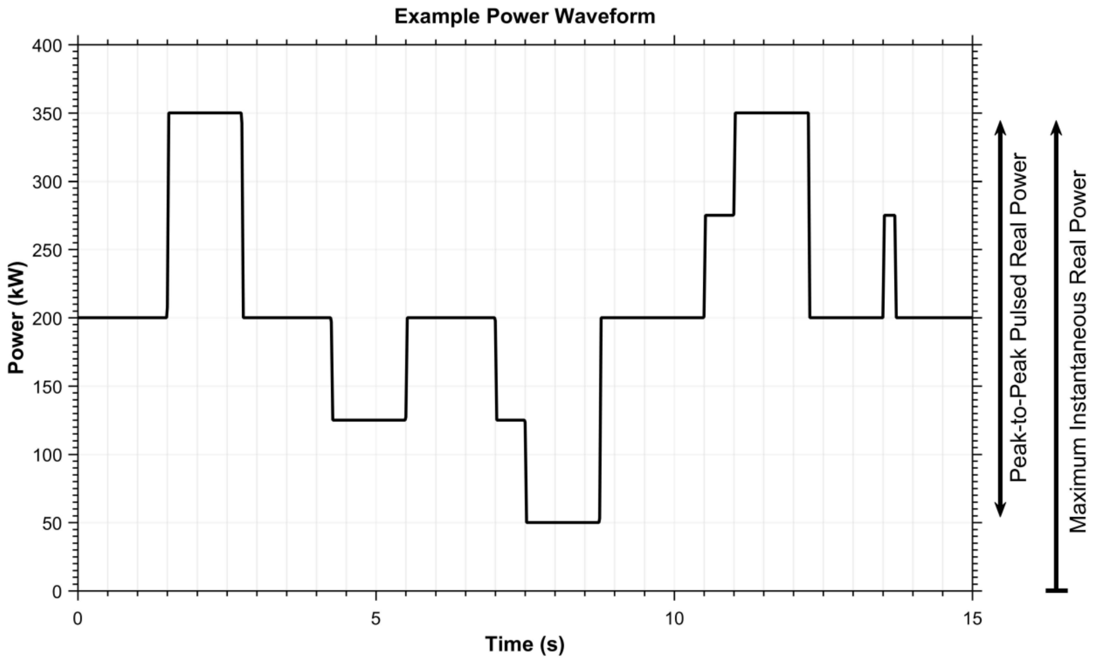


FIGURE 8. Peak-to-peak pulsed real power defined.

3.11 Ramp load. A ramp load is user equipment that is applied to the electrical system causing a smooth rise in power or small increasing step increments of the total load.

3.12 Power total signal distortion (TSD). The TSD of a real-power waveform is the ratio in percentage of the value of the square root of the sum of squares of the power magnitudes at their individual frequencies to the square root of 2 times the average power magnitude, calculated by equation 15 in its generic form. When performing a DFT on the power signal, which is an estimate of the frequency content, the noise characteristics of the DFT are affected by windowing and zero padding. This effect is captured in a term called equivalent noise bandwidth (ENBW), which requires a modification to equation 15, shown in A.2 Step 11. Further information can be found in The Johns Hopkins University Applied Physics Laboratory technical paper entitled Power-Specification Frequency-Domain Test and Analysis Methodology for Large Dynamic Loads.

$$\text{Power TSD (percent)} = 100 \times \sqrt{\sum_{s}\left(\frac{P_s}{\sqrt{2}}\cdot\frac{1}{P_{av}}\right)^2}$$

Where:

P_s is the zero-to-peak real power amplitude at individual signal frequency s

1 Hz ≤ s ≤ 2 kHz

P_{av} is the average real power over a specified time period determined by the application

EQUATION 15

3.13 User equipment. User equipment is any system or equipment that uses electric power from the shipboard electric power system.

3.14 Emergency conditions. Emergency conditions are unexpected occurrences of a serious nature that may result in electrical power system deviations. Emergency conditions include, but are not limited to, battle damage and malfunction or failure of equipment. Conditions may include power interruptions, voltage and frequency excursions, and decays. Emergency conditions characteristics are provided in table II, Items 20 through 23.

3.15 Mission critical equipment (MCE). MCE is equipment designated by NAVSEA to remain operational during emergency conditions.

3.16 Power interruption. A power interruption is a condition where the ship service power is not being supplied for a period of time. Power interruptions are evaluated with respect to two time periods, reconfiguration time (t_r) and generator start time (t_s).

3.16.1 Reconfiguration time (t_r). t_r is the maximum duration of a power interruption that an interface (user equipment) will experience due to source transfer, typically up to 5 seconds. t_r consists of the detection (of non-compliant user power) latency interval, the bus transfer interval, and the transient recovery interval (to compliant user power). The detection latency interval is the period of time from when the bus voltage and frequency deviates from compliant power to the time at which this deviation has been detected. The bus transfer interval is the period of time from when the adverse bus conditions are detected requiring initiation of a transfer up to the completion of the transfer. The transient recovery interval is the period of time from the completion of transfer to compliant power. User equipment including MCE (see 3.15) will be exposed to power interruption during this time period; MCE is required to provide the needed internal energy storage for continued operation. t_r does not take into account bringing on additional generation capacity. Reconfiguration time is identified in IEEE 45.3.

3.16.2 Generator start time (t_s). t_s is the maximum duration of a power interruption that an interface (user equipment) will experience due to the time needed to add generation capacity, including system protection coordination time, typically up to 5 minutes. User equipment including MCE will be exposed to power interruption during this time period; MCE needs to restart on its own or a no-break source (see 3.19) may be used for continued operation. Generator start time is identified in IEEE 45.3.

3.17 Independent power sources. Two power sources are independent if a single fault cannot result in a power interruption on both power sources at the same time.

3.18 Limited-break power source. A limited-break power source consists of a switching device supplied by two or more independent, isolated power sources. A limited-break power source incorporates an automatic means for detecting failure of a power source and for transferring the user equipment load to another power source within a specified time period. Two examples of a limited-break power source are an electromechanical automatic bus transfer (ABT) switch and a solid-state automatic bus transfer (SABT) switch. The limited-break source provides power continuity at the load interface during a loss of power during time t_r by switching between normal and alternate power feeds. The limited-break transfer time is considered part of the t_r power interruption seen by the user equipment.

3.19 No-break power source. A no-break power source is a device which maintains a continuous supply of electric power to connected equipment by supplying power from a separate source when normal power is not available. A no-break power source may be an uninterruptible power supply (UPS) which is supplied by independent power sources with a practically instantaneous transfer between sources; one power source may be derived from energy storage. The no-break supply characteristics are continuously held within specified limits to produce power in accordance with this standard's requirements. The no-break power source can supply compliant power to user equipment through the t_r or t_s time period, as required.

4. GENERAL REQUIREMENTS

4.1 Interface requirements. The specific interface requirements and constraints established herein are mandatory and shall be adhered to regarding any aspect of shipboard electrical power systems or user equipment designs to which these requirements and constraints apply, including systems and equipment design, production, and installation (see MIL-STD-1399). MIL-HDBK-2036 may be used as a guide for tailoring of requirements.

4.2 Conformance test requirements. Requirements and tests (see table I and 5.3) to ensure conformance of equipment to the interface requirements and constraints incorporated in this standard shall be included in the electric power system and user equipment specifications. Conformance of requirements (see 5.3) shall be verified by test. Formal testing shall not commence without approval of the test procedures by the Command or agency concerned. If necessary, the approval authority for testing shall be as specified (see 6.2). Table I lists the requirement and its corresponding compliance test.

TABLE I. Requirements and compliance tests.

Requirement	Requirement	Compliance
Grounding	5.2.4	5.3.1
Power Profile: Type of Power	5.1.1	5.3.2.a
Power Profile: Number of Phases	5.2.2	5.3.2.b
Power Profile: Operating Frequency	5.1.8.1	5.3.2.c
Power Profile: Operating Voltage	5.2.2	5.3.2.d
Power Profile: Line Current Magnitude	Informational	5.3.2.e
Power Profile: Power	5.2.2	5.3.2 f
Power Profile: Power Factor	5.2.7	5.3.2.g
Power Profile: Duty Cycle	Informational	5.3.2.h
Power Profile: Surge/Inrush Current	5.2.11	5.3.2.i
Power Profile: Current (Load) Unbalance	5.2.6	5.3.2.j
Power Profile: Pulsed Loading	5.2.8	5.3.2.k
Power Profile: Ramp Loading	5.2.9	5.3.2.l
Power Profile: Spike Generation	5.1.8.2.3	5.3.2 m
Power Profile: Line-to-Ground Capacitance	5.2.4	5.3.2.n
Power Profile: Line-to-Ground Current	5.2.4	5.3.2.o

TABLE I. Requirements and compliance tests - Continued.

Requirement	Requirement	Compliance
Voltage & Frequency Tolerance	Table II: #3, #10	5.3.3
Voltage & Frequency Transient Tolerance	Table II: #4, #11	5.3.4
Voltage Spike	5.2.15	5.3.5
Emergency Conditions: t_r Power Interruption	5.1.3, 5.2.3.1	5.3.6.2.1
Emergency Conditions: t_s Power Interruption	5.1.3, 5.2.3.1	5.3.6.2.2
Emergency Conditions: Power Source Decay	5.1.4	5.3.6.2.3
Emergency Conditions: Positive Excursion	5.1.4	5.3.6.2.4
Current Waveform	5.2.10	5.3.7
Voltage & Frequency Modulation	5.1.8.3	5.3.8
Simulated Human Body Ground Current	5.2.5	5.3.9
Equipment Voltage Withstand Test	5.2.12, 5.2.13, 5.2.14	5.3.10

4.3 User equipment. User equipment shall operate from a power system having the characteristics of table II and shall be designed within these constraints in order to reduce adverse effects of the user equipment on the electric power system. Test methods are included for verification of compatibility. User equipment to be installed on ships built to superseded versions of this standard shall meet the most stringent demands of the applicable version.

4.4 Deviations, waivers, and tailoring. The power interfaces in this standard are based on knowledge of typical shipboard AC electric power systems. To meet the intent of this interface standard for specific applications, a deviation or waiver of requirements will be considered. The deviation provisions in MIL-STD-1399 shall be adhered to, for deviation or waiver requests, during the early development stage of user equipment, as specified (see 6.2 and 6.4). For large loads (see 5.2.8.1.2.1 and 5.2.8.1.2.2) and loads known to be challenged by specific requirements, the tailoring of requirements may be necessary. Tailoring is done with analysis of the intended system and tradeoffs between the requirements and the equipment designs needed to ensure compliance. The recommended tailoring shall be approved by NAVSEA (see 6.2 and 6.4).

5. DETAILED REQUIREMENTS

5.1 Electric power system characteristics. The shipboard electric power system serves a variety of user equipment such as aircraft elevators, air conditioners, communication equipment, weapon systems, and computers. Electric power is centrally generated and distributed throughout the ship from the switchboard to power panels and finally to the user equipment served. Ship design requires that conversion equipment be minimized and that most equipment served be designed to operate from the Type I, 60-Hz power system. Performance of the ship can best be served by minimizing the requirement for Types II or III, 400-Hz power. Characteristics of shipboard electric power systems at the interface shall be as specified in table II. The characteristics for the CVN 78 class are derived from NAVSEA Drawing 802-7094558. The designated nominal frequency and voltage at the interface as shown on figure 1 is given in table II, Items 1 and 7, for the different power types. These designated nominal values are the basis for the characteristics which are presented in the compliance tests of 5.3 to equipment that is to be installed aboard ship. These compliance tests are representative of actual possible shipboard conditions. Equipment to be installed aboard ship is tested to these characteristics and those that pass these tests are electrically qualified to be installed aboard ship for utilization. The generated voltages are also identified in IEEE 45.1. For 115/200-V, four-wire grounded systems as specified in 5.1.8.2.c and 5.1.8.2.d, the characteristics apply to line-to-neutral power unless the parameter is inappropriate; for example, line balance would not apply. Type II or III power is provided by deviation only (see 4.4 and 6.4). Type I, 60-Hz power shall be used for new user equipment development unless a deviation is granted. Frequency does not decrease to 0 (minus 100 percent) without a decrease in voltage. Figure 9, 5.1.4.1, and 5.1.4.2 shall apply.

TABLE II. Characteristics of shipboard electric power systems.

Characteristics	Type I	Type II	Type III
Frequency			
1. Nominal Frequency	60 Hz	400 Hz	400 Hz
2. Frequency Modulation	0.5%	0.5%	0.5%
3. Frequency Tolerance	±3% (Submarines: ±5%)	±5%	±0.5%
4. Frequency Transient Tolerance	±4%	±4%	±1%
5. Worst Case Frequency Steady-State and Transient Excursion	±5.5%	±6.5%	±1.5%
6. Recovery Time from Item 4 or 5	2 seconds	2 seconds	0.25 second
Voltage			
7. Designated Nominal User Voltage	440, 115, 115/200 V_{rms}	440, 115 V_{rms}	440, 115, 115/200 V_{rms}
8. Line-to-Line Voltage Unbalance	3% (Submarines: 0.5% for 440 V_{rms}; 1% for 115 V_{rms})	3%	2%
9. Voltage Modulation	2%	2%	1%
10. Average Line-to-Line Voltage from Nominal Tolerance	±5%	±5%	±2%
11. Single Line-to-Line Voltage from Nominal Tolerance	±7% (CVN 78 class: ±10%)	±7%	±3%
12. Maximum Voltage Steady-State Departure	±8% (CVN 78 class: ±10%)	±8%	±4%
13. Voltage Transient Tolerance	±16%	±16%	±5%
14. Worst Case Voltage Steady-State and Transient Excursion	±20%	±20%	±5.5%
15. Recovery Time from Item 13 or 14	2 seconds	2 seconds	0.25 second
16. Voltage Spike (± Peak Value)	2.5 kV_p (440 V_{rms} sys) 1.0 kV_p (115 V_{rms} sys)	2.5 kV_p (440 V_{rms} sys) 1.0 kV_p (115 V_{rms} sys)	2.5 kV_p (440 V_{rms} sys) 1.0 kV_p (115 V_{rms} sys)
Waveform (Voltage)			
17. Maximum THD	5%	5%	3%
18. Maximum Single Harmonic	3%	3%	2%
19. Maximum Deviation Factor	5% (Submarines: 3%)	5%	5%
Emergency Conditions			
20. Frequency Excursion	-100% to +12%	-100% to +12%	-100% to +12%
21. Duration of Frequency Excursion	2 minutes	2 minutes	2 minutes
22. Voltage Excursion	-100% to +35%	-100% to +35%	-100% to +35%
23. Duration of Voltage Excursion:			
a. Upper Limit (+35%)	2 minutes	0.17 second	0.17 second
b. Lower Limit (-100%)	2 minutes	2 minutes	2 minutes
NOTE: Characteristics are defined in Section 3.			

5.1.1 Types of power. Types of power are as follows:

5.1.1.1 Type I, 60-Hz power. The ship service electrical power distribution system supplied by the ship's electric power source is 440 V_{rms}, 60 Hz, three-phase, ungrounded or high-resistance grounded. Power for the ship's lighting distribution system and other user equipment such as electronic equipment, supplied from the ship service power distribution system through transformers, is 115 V_{rms}, 60 Hz, three-phase ungrounded. Single-phase power is available from both the 440-V_{rms} and the 115-V_{rms} systems. The ship service power and lighting distribution systems are labeled as Type I. Type I, 230-V_{rms}, 60-Hz, single- or three-phase, ungrounded or solidly-grounded power can be made available for NATO load equipment upon special request. See 1.2.1 and 1.2.2 for special power types.

5.1.1.2 Types II and III, 400-Hz power. The ship service power supplied by 400-Hz motor/generator (M/G) sets or solid-state converters is 440 V_{rms}, three-phase, 400 Hz ungrounded with 115 V_{rms} delivered by transformer. The 400-Hz power is of two kinds, designated as Types II and III. Subject to the approval of a deviation request, the use of Type II is preferred over Type III, but if more precise characteristics are required, Type III power may be supplied. Type III, 115/200-V_{rms}, 400-Hz, three-phase, four-wire grounded wye power is available for avionics shops and for aircraft servicing.

5.1.2 System grounding. Electric power systems supplying 440-V_{rms} power shall be ungrounded or high-resistance grounded. 115-V_{rms} power shall be ungrounded or solidly-grounded. Other interfaces are as specified in 5.1.8.2.c and 5.1.8.2.d and 5.2.4. Momentary intentional grounding is permitted for the operation of ground detection equipment. Line-to-ground current of up to 20 A may exist in an electric power system as a result of capacitive coupling of cables and equipment filters connected to ground.

5.1.2.1 Ungrounded system. Under ungrounded system conditions, an ungrounded electric power system shall continue to perform normally if one line conductor becomes solidly grounded.

5.1.2.2 Grounded system. A single ground fault from one line to ground will produce high fault current that shall trip protective circuit breakers, isolating the fault. Only one ground connection point is allowed for each grounded power system.

5.1.2.3 High-resistance grounded system. This system employs an intentional resistance between the electric system neutral and ground. The resistance shunts the system capacitance-to-ground, reducing possible over-voltages-to-ground. The resistance reduces line-to-ground fault current so the electric power system shall continue to perform normally if one line conductor becomes solidly grounded; the ground is indicated by the reduced fault current.

5.1.3 Electric plant power interruption. A power interruption experienced by user equipment can occur as a result of normal operations, an equipment casualty, training exercise, or operator error. The length of a power interruption can be specified as t_r or t_s as defined in 3.16. t_r and t_s shall be based on the loss of a single electrical power system component causing the power interruption. Different interfaces may have different values for t_r and t_s during the diverse operating conditions such as anchor, cruising, functional, and emergency conditions. t_r will be affected by the electric plant configuration. For a split plant configuration, t_r will consist of the system protection (detection) coordination time and will include bus transfer and recovery time. For a parallel plant configuration, t_r will consist of the system protection (detection) coordination time and may include bus transfer and recovery time. t_s will consist of the system protection coordination time, but will also include the time needed to add generation capacity. The worst case maximum duration t_r and t_s values shall be determined for use in 5.2.3.1 by the electric plant design agent. The electrical power system design may employ the following sources to control the duration of power interruptions at the interface.

5.1.3.1 Using a limited-break power source. As described in 3.18, in order to maintain reliability and continuity during diverse operating conditions and electric plant configurations, some loads are provided with a limited-break power source where possible. The extent to which this can be done will vary with the ship design, electric plant capacity, and the specific user equipment. In some instances, user equipment with a need to control the power-up cycle after the interruption should not use a limited-break power source. In other instances, the capacity of the ship service or emergency generators may limit the use of limited-break sources, whereby manual transfer switches shall be provided. Limited-break equipment such as an ABT or SABT is normally used to switch power to an interface during an operator-initiated transfer or during a loss of power, with the transfer time contributing to time t_r. The value of t_r can vary depending on the type and configuration of the ABT or SABT as well as the other connected loads. Traditional mechanical ABTs can contribute 70 milliseconds to 5 seconds to the value of t_r. SABTs can contribute 8 milliseconds (with random transfer mode selected) or greater (with in-phase transfer mode selected) to the value of t_r. In addition, the ABT or SABT transfer time may also contain a time delay from the loss of the normal power source to the switch to the alternate power source to avoid excessive transient currents caused by residual voltage. Therefore, in establishing the value of t_r at an interface, including the detection latency time, the impact of the switch transfer time, transformer inrush and saturation and current limiting of power electronic sources shall be considered, if applicable. MCE is required to provide the needed internal energy storage for continued operation through t_r. The limited-break power source should be used unless otherwise determined that a no-break supply may be required.

5.1.3.2 Using a no-break power source. As described in 3.19, the no-break power source is normally used to provide power continuity at the interface for MCE during a loss of power during time t_s although, depending on viability, may be used during a loss of power during time t_r. If a no-break power supply is required and it is not provided by the shipboard electric power system, it shall be provided as part of the user equipment, but shall be subject to specific functional requirements established by NAVSEA in MIL-DTL-24765.

5.1.4 Frequency and voltage excursions and decay. Frequency and voltage excursions and decay can occur on the following electric power systems during normal operations including training exercises, mechanical or electric power system tests, or during emergency conditions when malfunction or damage has occurred.

5.1.4.1 Type I electric power system. An electric power frequency and voltage excursion and decay can occur on the Type I, 60-Hz electric power system as a result of the loss of prime mover, equipment failures, or by the operation of switching equipment and protective devices. Figure 9 illustrates the voltage and frequency decay characteristics of a steam driven generator set on loss of prime mover. The voltage may start to decay when the frequency decays to about 40 Hz in approximately 5 to 20 seconds and may not reduce to 0 Hz for several minutes, depending on the initial load and the inertia of the generator set. The output voltage and frequency of generators driven by gas turbine and diesel prime movers will fall off faster than that of the steam prime mover. The output voltage and frequency of solid state sources may be interrupted by protective devices within 2 milliseconds of the start of the voltage and frequency decay.

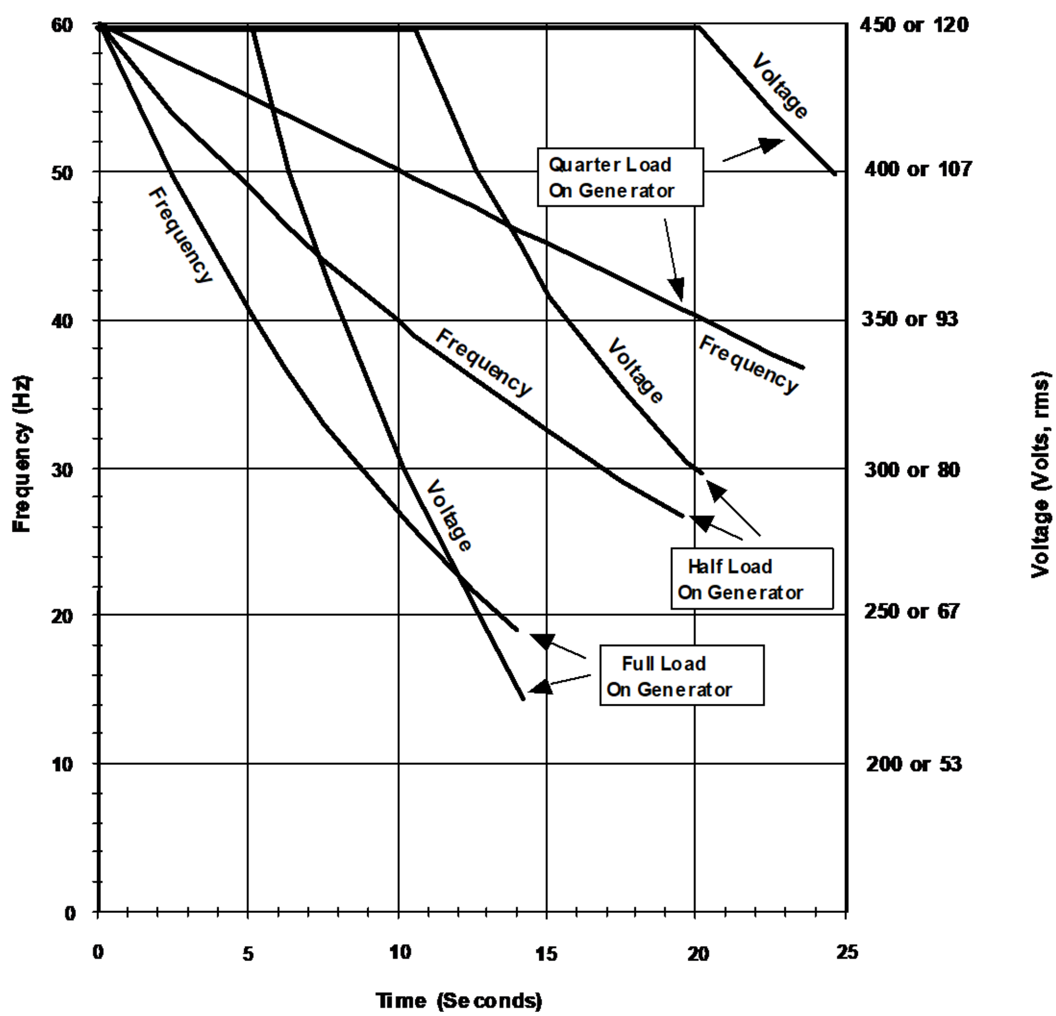


FIGURE 9. Voltage and frequency decay characteristics on loss of prime mover for typical steam turbine driven generator set, Type I, 60-Hz electric power system.

5.1.4.2 Types II and III electric power systems. A frequency and voltage excursion can occur on the Types II and III electric power systems as a result of equipment failures or by the operation of switching equipment and protective devices. Loss of input power to 60/400-Hz M/G sets will activate control circuits provided with M/G sets which trip the M/G output circuit breaker. This interrupts power to 400-Hz loads in a few milliseconds. Upon loss of 60-Hz power to solid-state frequency changers (SSFCs), the 400-Hz power is interrupted within 2 milliseconds by controls in the SSFC. Switchboard voltage and frequency monitors trip the 400-Hz output circuit breaker when the output voltage or frequency reaches those values specified in 5.1.7.2 or 5.1.7.3, as applicable to the type of power provided.

5.1.5 Phase sequence. Standard phase sequence for three-phase AC systems in the U.S. Navy is in the following order: AB, BC, and CA. For grounded systems, the phase sequence is AN, BN, CN.

5.1.6 Phase angular relations. The ungrounded three-phase source shall have an angular relationship of 120 degrees between phases under balanced load conditions. If the source is a grounded or high resistance-grounded, four-wire system (with neutral), the angular displacement between phases shall be 120 degrees ±1 degree under balanced load conditions.

5.1.7 Electric power system protection. Protection is provided for the electric power system, but not for user equipment.

5.1.7.1 Type I, 60-Hz electric power system protection. The electric power system protection shall be a circuit breaker with possible fuse that is sized to provide overcurrent and fault current protection in accordance with the cable rating. 115-V_{rms} solidly-grounded circuits may be protected by a ground fault circuit interrupter.

5.1.7.2 Type II, 400-Hz electric power system protection. For the 400-Hz electric power system, protective devices (separate from protection devices that may be provided to integral conversion equipment) are provided to interrupt the Type II electric power system within 100 to 170 milliseconds if the voltage or frequency excursions exceed the limits set forth below:

a. Overvoltage: 120 to 130 percent of nominal voltage in any phase measured line-to-line.

b. Undervoltage: 70 to 80 percent of nominal voltage in any phase measured line-to-line.

c. Overfrequency: 425 to 435 Hz.

d. Underfrequency: 365 to 375 Hz.

5.1.7.3 Type III, 400-Hz electric power system protection. For the 400-Hz electric power system, protective devices (separate from protection devices that may be provided to integral conversion equipment) are provided to interrupt the Type III electric power system within 100 to 170 milliseconds if the voltage or frequency excursions exceed the limits set forth below:

a. Overvoltage: 110 to 120 percent of nominal voltage in any phase measured line-to-line and on 115/200-V_{rms} wye-connected systems, measure line-to-neutral.

b. Undervoltage: 84 to 90 percent of nominal voltage in any phase measured line-to-line and on 115/200-V_{rms} wye-connected systems, measure line-to-neutral.

c. Overfrequency: Above 415 to 425 Hz.

d. Underfrequency: Below 375 to 385 Hz (surface ships).

5.1.7.4 Conditions not protected against. The electric power system protection shall not interrupt the electric power to the user equipment under the following conditions:

a. High voltage excursions of very short duration (voltage spike) (see figures 5 and 6).

b. The momentary interruption and restoration of power of less than 100 milliseconds.

c. 500-V direct current (DC) insulation resistance tests performed using megohmmeters (surface ships).

d. Active ground detector (AGD) tests where 500 VDC is applied from line-to-ground in a 440-V_{rms} line-to-line circuit and 150 VDC is applied from line-to-ground in a 115-V_{rms} line-to-line circuit.

5.1.8 Electric power system parameters. Power system parameters shall be as specified in 5.1.8.1 through 5.1.8.5 and figures 10 through 15 where the time axes are on a logarithmic scale.

5.1.8.1 Nominal frequency. The nominal frequency is either 60 Hz or 400 Hz. Where there are overriding design features demanding a different frequency, deviations from this requirement are subject to the requirements of 4.4 and 6.4. Characteristics of the frequency are the tolerance and the transient tolerance. The equation for the tolerance is provided in 3.4.3 and the equation for the transient tolerance is provided in 3.4.4.1.

5.1.8.1.1 Type I, 60-Hz frequency tolerance and transient tolerance. Figure 10 illustrates the Type I, 60-Hz frequency tolerance and transient tolerance envelope limits specified in table II. The time to reach the transient minimum or maximum varies from 0.1 to 1.0 second after initiation of the disturbance. The frequency shall recover to the frequency tolerance band within 2 seconds.

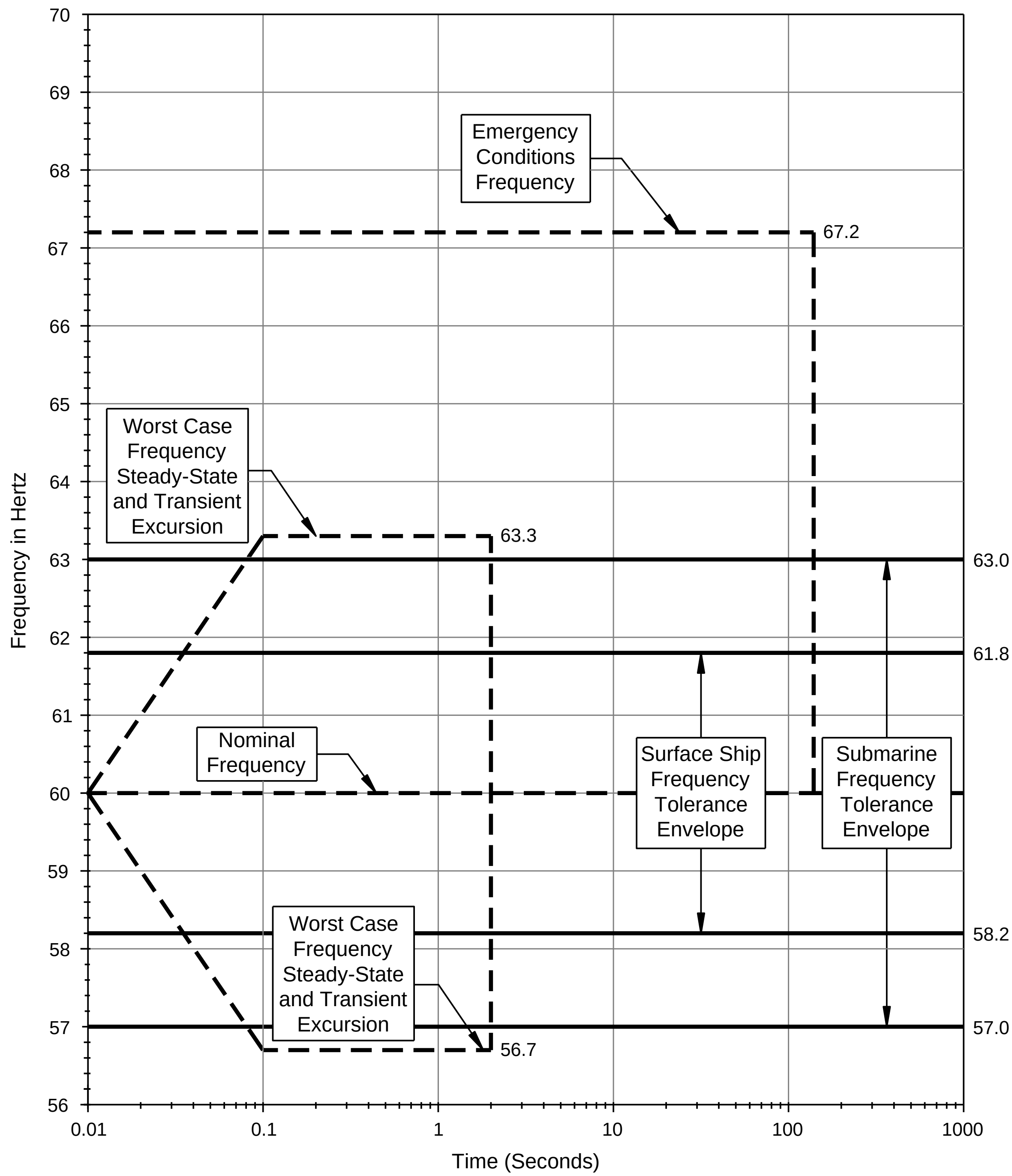


FIGURE 10. Type I frequency tolerance and transient tolerance envelopes.

5.1.8.1.2 Type II, 400-Hz frequency tolerance and transient tolerance. Figure 11 illustrates the Type II, 400-Hz frequency tolerance and transient tolerance envelope limits specified in table II. The time to reach the transient minimum or maximum varies from 0.05 to 0.1 second after initiation of the disturbance. The frequency shall recover to the frequency tolerance band within 2 seconds.

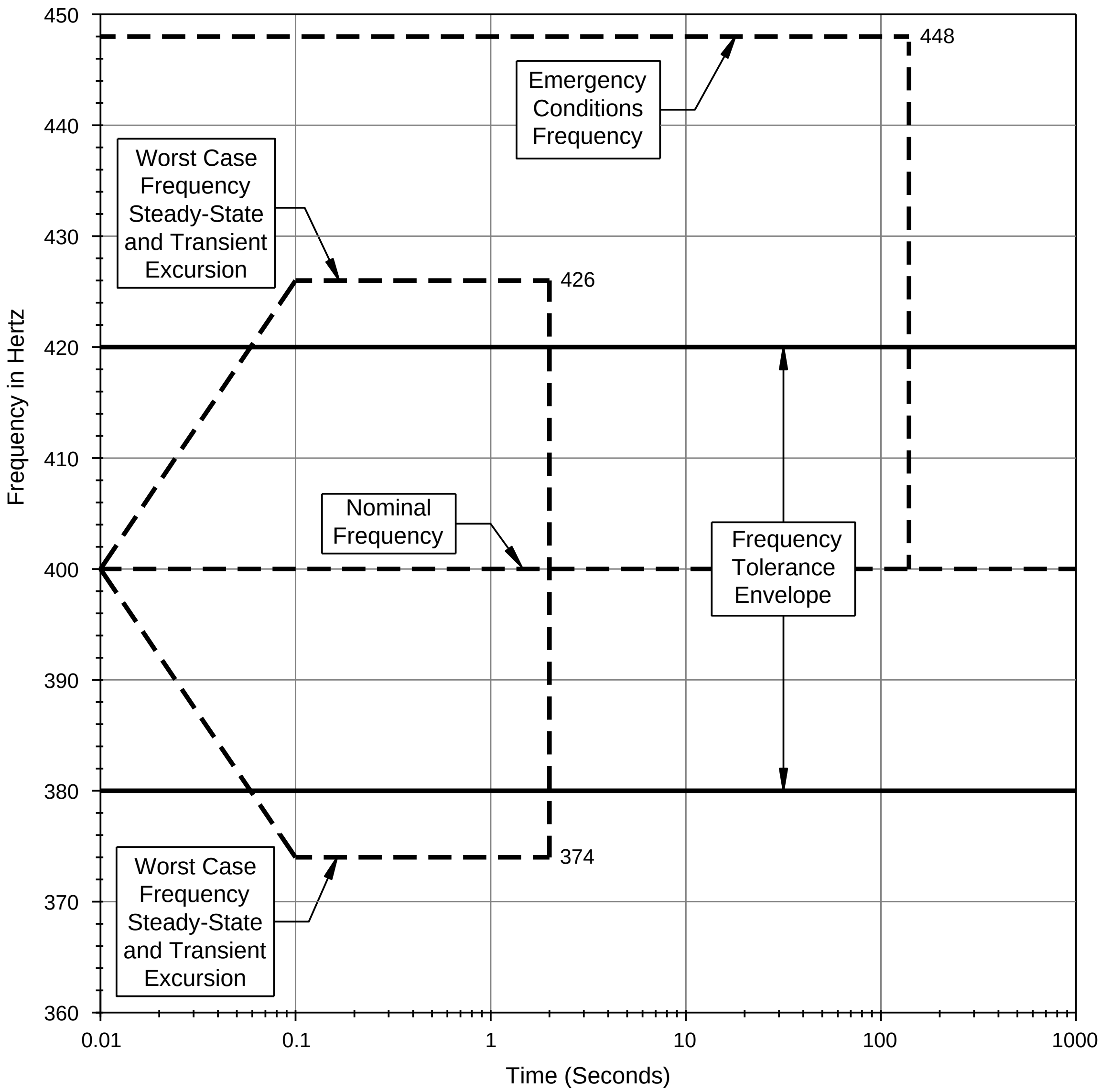


FIGURE 11. Type II frequency tolerance and transient tolerance envelopes.

5.1.8.1.3 Type III, 400-Hz frequency tolerance and transient tolerance. Figure 12 illustrates the Type III, 400-Hz frequency tolerance and transient tolerance envelope limits specified in table II. The time to reach the transient minimum or maximum varies from 0.05 to 0.1 second after initiation of the disturbance. The frequency shall recover to the frequency tolerance band within 0.25 second.

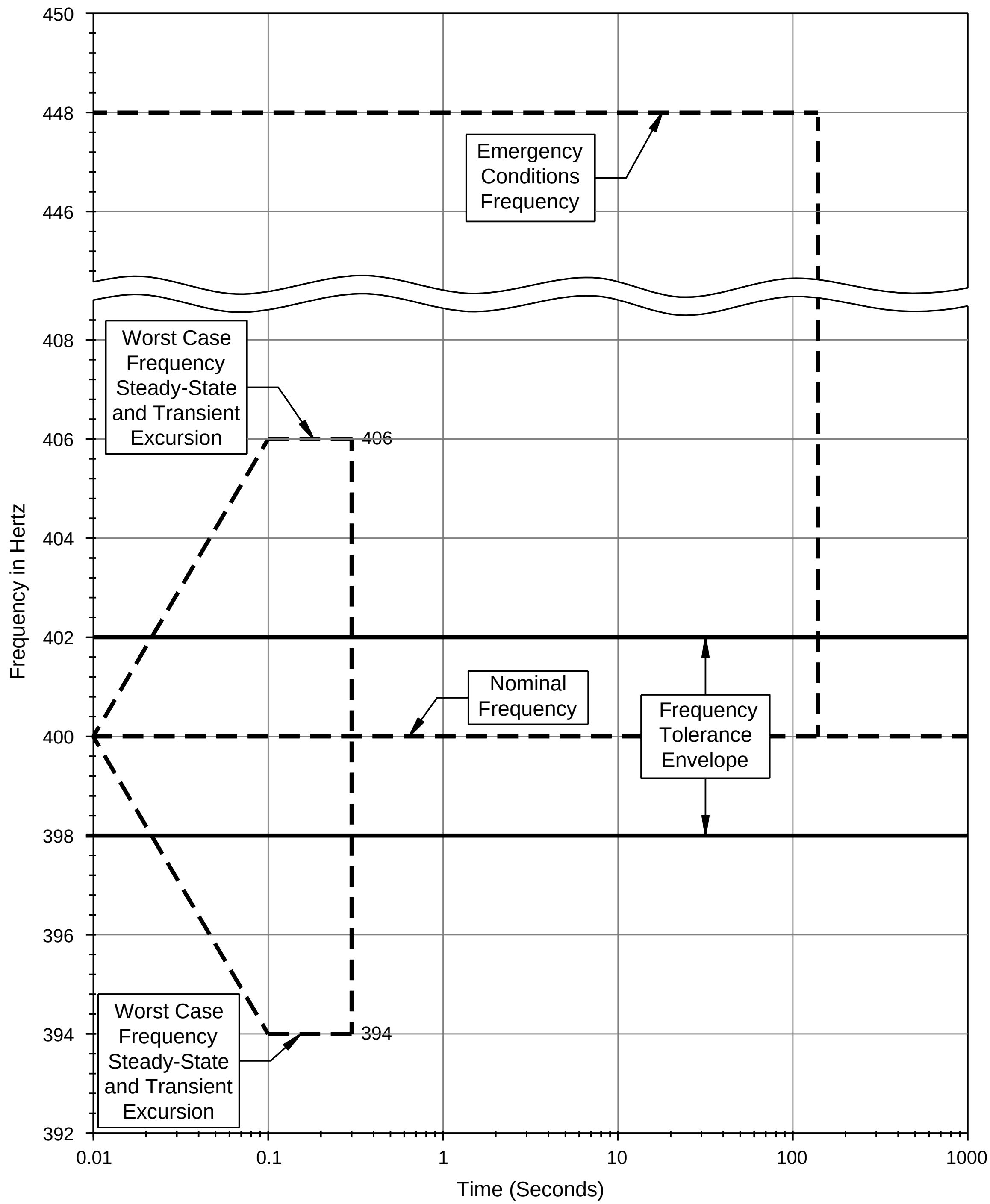


FIGURE 12. Type III frequency tolerance and transient tolerance envelopes.

5.1.8.2 Nominal user voltage. The nominal user (equipment) voltage is a line-to-line voltage present at the interface to the equipment. User voltages are as follows (see 5.2.2):

a. 440 V_{rms}, three-phase or single-phase, ungrounded or high-resistance grounded.

b. 115 V_{rms}, three-phase or single-phase, ungrounded or solidly-grounded.

c. Special service, 115/200 V_{rms}, three-phase, four-wire, grounded neutral, 400-Hz power is provided for servicing aircraft in hangars and on flight decks, to avionics shops, and LCAC systems.

d. Special service, 115/200 V_{rms}, three-phase, four-wire, grounded neutral, 60-Hz power is provided for avionic shops and hotel services.

e. Special service, 230 V_{rms}, 60 Hz, three-phase, ungrounded or 230 V_{rms}, 60 Hz, single-phase, grounded or ungrounded. This power is provided upon request only for NATO load equipment.

f. Special service, 120/208 V_{rms}, 60 Hz, three-phase, four-wire, grounded neutral or 240/120 V_{rms}, 60 Hz, single-phase, grounded neutral. These special distribution user voltages shall be in accordance with NAVSEA Drawing 302-7512881 and NAVSEA Drawing 302-7598285, respectively.

Characteristics of the voltage are the tolerance and the transient tolerance. The equation for the tolerance is provided in 3.5.5 and the equation for the transient tolerance is provided in 3.5.7.1.

5.1.8.2.1 Type I, 60-Hz and Type II, 400-Hz power voltage tolerance and transient tolerance. Figure 13 illustrates the 440-V_{rms} Type I, 60-Hz and Type II, 400-Hz user voltage tolerance and transient tolerance envelope limits specified in table II. Figure 14 illustrates the 115-V_{rms}, Type I, 60-Hz and Type II, 400-Hz, user voltage tolerance and transient tolerance envelope limits specified in table II (CVN 78 class unique values of table II are not depicted on figure 13). The time to reach the transient voltage limits may vary depending on the rating of the generator and the type of regulator and excitation system employed. The sudden removal of a user equipment from the Type I or Type II electric power system may cause the voltage to increase to the transient voltage limit within 0.001 to 0.1 second. The voltage may then decrease to a minimum value that is below the nominal voltage by an amount equal to ⅓ to ⅔ of the maximum transient voltage rise at a rate equal to 20 to 75 percent of the nominal voltage per second. Recovery to within the user voltage tolerance envelope will occur within 2 seconds. The sudden application of user equipment to the Type I or Type II electric power system may cause the voltage to decrease to the transient voltage minimum value within 0.001 to 0.1 second. The voltage may then increase to a maximum value that is above the nominal voltage by an amount equal to ⅓ to ⅔ of the minimum transient voltage drop at a rate equal to 20 to 75 percent of the nominal voltage per second. Recovery to within the user voltage tolerance envelope shall occur within 2 seconds.

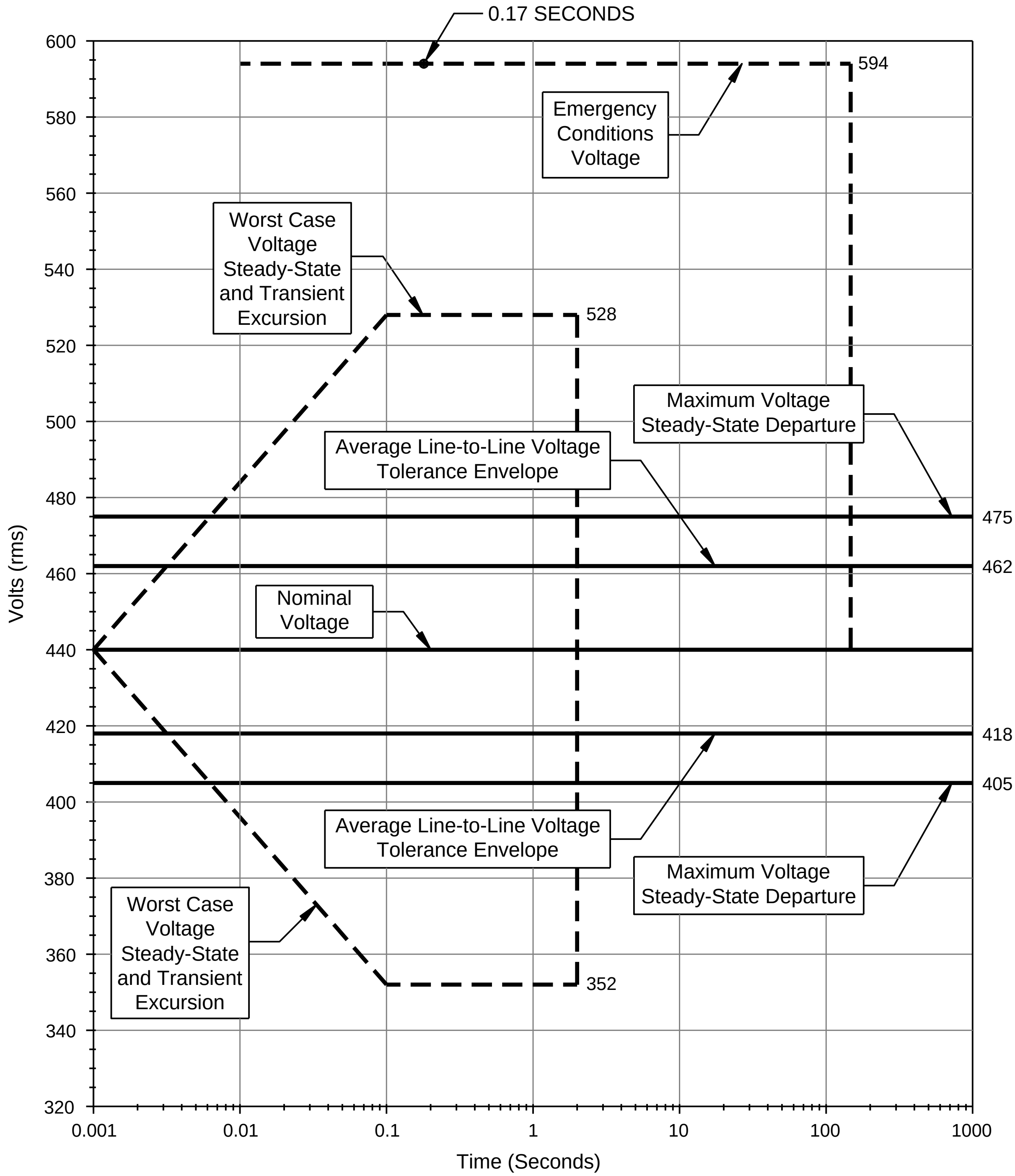


FIGURE 13. Types I and II, 440-V_{rms} power user voltage tolerance and transient tolerance envelopes.

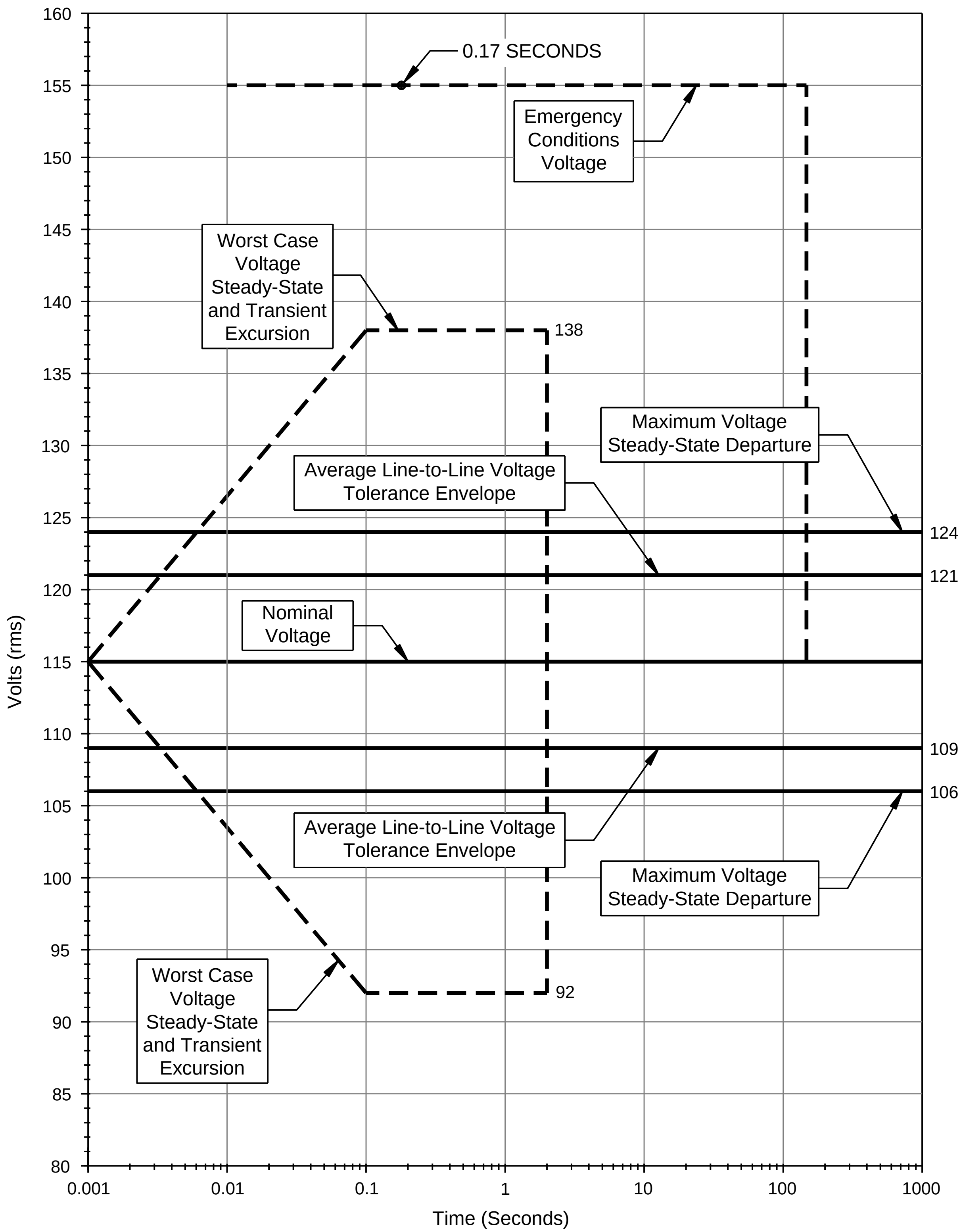


FIGURE 14. Types I and II, 115-V_{rms} power user voltage tolerance and transient tolerance envelopes.

5.1.8.2.2 Type III, 400-Hz power voltage tolerance and transient tolerance. Figure 15 illustrates the 440-V_{rms}, Type III, 400-Hz user voltage tolerance and transient tolerance envelope limits specified in table II. Figure 16 illustrates the 115-V_{rms}, Type III, 400-Hz, user voltage tolerance and transient tolerance envelope limits as specified in table II. The time to reach the transient voltage limits may vary depending on the rating of the generator and the type of regulator and excitation system employed. The sudden removal of a user equipment from the Type III electric power system may cause the voltage to increase to the transient voltage limit within 0.001 to 0.1 second. The voltage may then decrease to a minimum value that is below the nominal voltage by an amount equal to ⅓ to ⅔ of the maximum transient voltage rise at a rate equal to 50 to 100 percent of the nominal voltage per second. Recovery to within the user voltage tolerance envelope will occur within 0.25 second. The sudden application of user equipment to the Type III electric power system may cause the voltage to decrease to the transient voltage minimum value within 0.001 to 0.1 second. The voltage may then increase to a maximum value that is above the nominal voltage by an amount equal to ⅓ to ⅔ of the minimum transient voltage drop at a rate equal to 50 to 100 percent of the nominal voltage per second. Recovery to within the user voltage tolerance envelope will occur within 0.25 second.

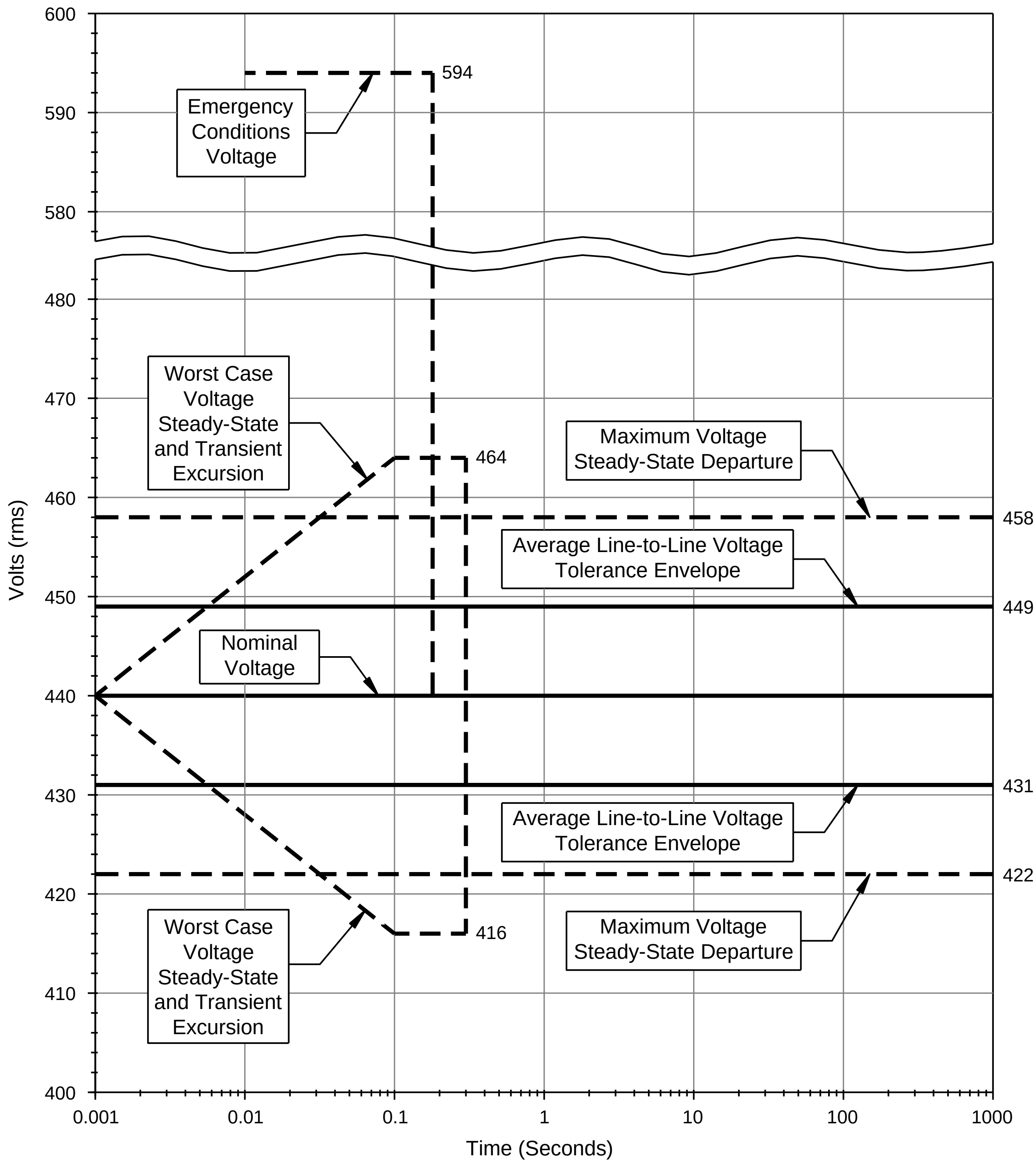


FIGURE 15. Type III, 440-V_{rms}, 400-Hz power user voltage tolerance and transient tolerance envelopes.

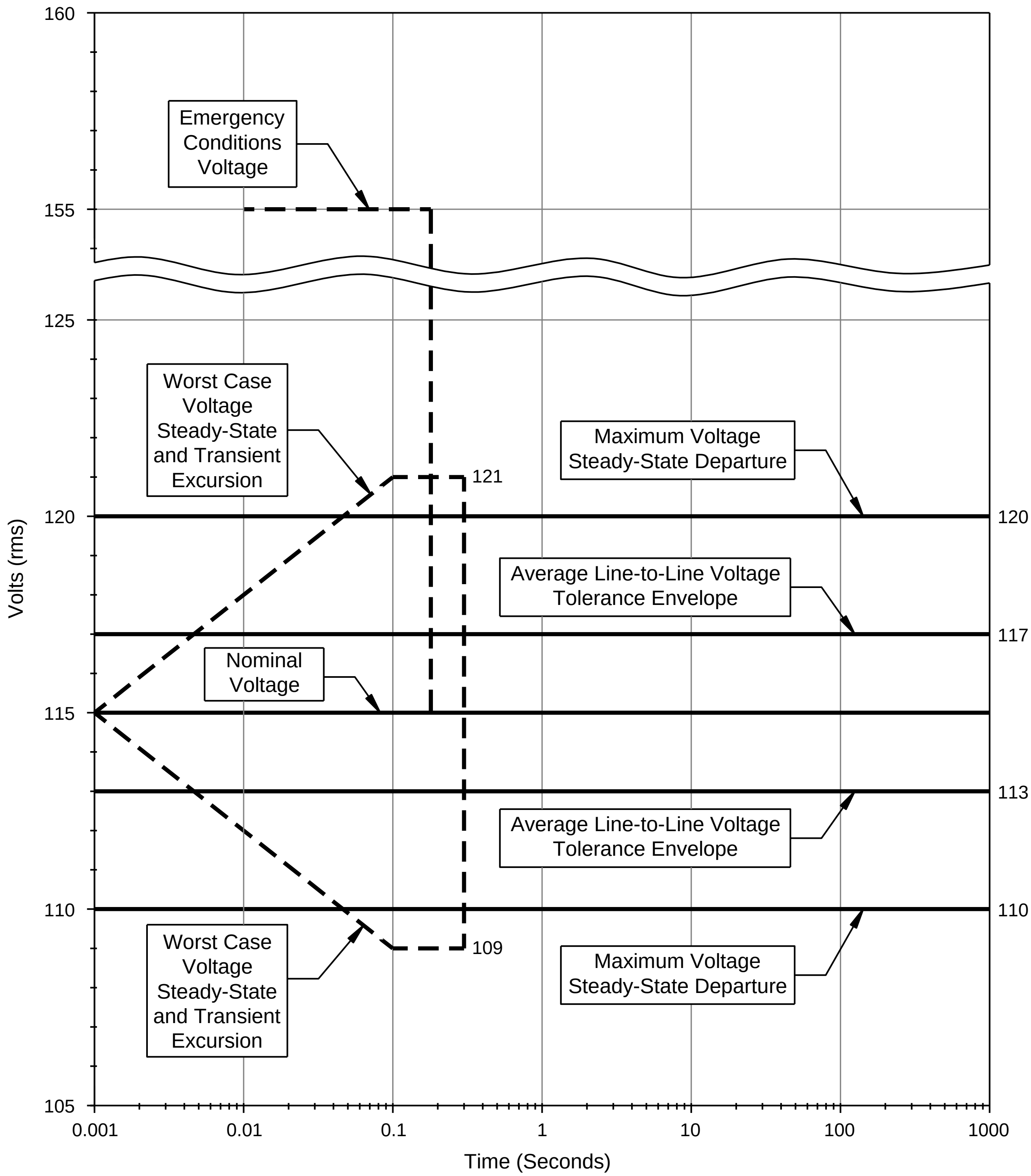


FIGURE 16. Type III, 115-V_{rms}, 400-Hz power user voltage tolerance and transient tolerance envelopes.

5.1.8.2.3 Voltage spike characteristics. Voltage spikes of 2500-V peak on 440-V_{rms} systems, 1400-V peak on 230-V_{rms} systems (special power classification), and 1000-V peak on 115-V_{rms} systems may be present on the electrical power system between line-to-line and between line-to-ground (or neutral). Approximately 50 spikes per week occur on the power system. The amplitude and waveform of a voltage spike will vary depending on system parameters, but it may be compared to the description in 3.5.9.

5.1.8.3 Voltage and frequency modulation. Shipboard electric power may contain voltage modulation up to 2 percent and frequency modulation up to 0.5 percent. For voltage modulation of 2 percent, the nominal voltage rms value of 440 may vary within a range bounded from 431.2 to 448.8 V_{rms} over periods from 17 milliseconds to 10 seconds. For frequency modulation of 0.5 percent, the nominal frequency of 60 Hz may vary within a range bounded from 59.7 to 60.3 Hz also over periods from 17 milliseconds to 10 seconds. These modulations shall be limited as they may cause torque and speed ripples that can generate vibration, noise, and mechanical stress in the bearings, couplings, and supports of induction motors. The equation for voltage modulation is provided in 3.5.3 and the equation for frequency modulation is provided in 3.4.2.

5.1.8.4 Voltage unbalance. For surface ships, the voltage provided to user equipment is required to be balanced within 3 percent; for submarines, the voltage is required to be balanced within 0.5 percent for 440-V_{rms} systems and within 1 percent for 115-V_{rms} systems. The major unwelcome effect of voltage unbalance is additional heating and losses in three-phase motors. Voltage balance shall be assisted by maintaining the current unbalance restriction for individual three-phase loads and by ensuring single-phase loads are distributed as evenly as possible across the three phases during installation on the shipboard electrical power distribution system. The equation for voltage unbalance is provided in 3.5.2.

5.1.8.5 Voltage waveform. The line-to-line voltage waveform supplied by ship's power shall not contain single voltage harmonics or voltages at any frequency greater than 3 percent of the fundamental voltage. The THD shall be not greater than 5 percent and the voltage deviation factor shall be not greater than 5 percent (3 percent for submarines). These characteristics are specified in table II and defined in 3.5.10.

5.2 User equipment interface requirements. User equipment shall meet the requirements specified in 5.2.1 through 5.2.14 to ensure compatibility with the electrical power system characteristics specified in table II.

5.2.1 Compatibility. The construction of user equipment utilizing electric power shall be compatible with the electric power system characteristics as specified in 5.1.

5.2.2 User equipment voltage. Voltage preference shall be as follows (see 5.1.8.2):

a. User equipment operated above 5 kilovolt amperes (kVA) shall use 440-V_{rms}, three-phase input power.

b. User equipment operated at 5 kVA or less shall use 440-V_{rms}, three-phase input power. Where such an input is not practical, the following shall be the order of preference:

(1) 115 V_{rms}, three-phase

(2) 115 V_{rms}, single-phase

(3) 440 V_{rms}, single-phase

c. Special equipment, 115/200 V_{rms}, three-phase, four-wire wye, grounded neutral, 60-Hz power shall be provided for servicing aircraft in hangars and on flight decks, avionic shops, and hotel services.

d. Special equipment, 115/200 V_{rms}, three-phase, four-wire wye, grounded neutral, 400-Hz power shall be provided for servicing aircraft in hangars and on flight decks, avionic shops, and LCAC systems.

e. Special equipment, 230 V_{rms}, 60 Hz, three-phase, ungrounded or 230 V_{rms}, 60 Hz, single-phase, grounded or ungrounded. This power is provided upon request only for NATO load equipment.

f. Special equipment, 115 V_{rms}, 60 Hz, single-phase, grounded neutral or 230 V_{rms}, 60 Hz, single-phase, grounded neutral. 115-V_{rms} and 230-V_{rms}, 60-Hz, single-phase, grounded neutral loads shall be limited to 5 kVA. Equipment utilizing these special distribution user voltages shall be in accordance with NAVSEA Drawing 302-7512881 and NAVSEA Drawing 302-7598285, respectively, and shall be held to the power quality requirements in this standard.

5.2.3 Emergency conditions. User equipment shall withstand and not be damaged by emergency conditions described as power interruptions, decay, and excursions.

5.2.3.1 Power interruptions. User equipment shall not be damaged due to power interruptions from 5.1.3 and may require a manual restart. User equipment designated as MCE shall operate through power interruptions of duration t_r without interruption, not suffer any loss of data, or require a restart or reboot. MCE, not on a no-break power source, after an extended power interruption of t_s, shall be capable of restarting upon restoration of power without operator intervention. NAVSEA (see 6.4) will determine if the MCE needs a no-break power source to cover power interruptions of duration t_s or, if viable, duration t_r. To gain knowledge of the interruption time to attempt to maintain power continuity for MCE, t_r and t_s are two characteristics of the power system that shall be specified in 6.2 in the acquisition documentation for the vendor for each power interface which feeds the affected user equipment. This will determine the MCE's energy storage needs to operate through t_r or t_s. Longer time periods may result in larger and more expensive stored energy sources for MCE. If t_r is unknown, 70 milliseconds will be the t_r power interruption time period. If t_s is unknown, 2 minutes will be the t_s power interruption time period.

5.2.3.2 Power source decay. User equipment is not required to sustain operation after the voltage and frequency pass below the voltage and frequency tolerance envelopes as defined on figures 10 through 16. However, the equipment shall be capable of returning to normal operation after power within the bounds of table II is suddenly reapplied at the end of the decay transient. Equipment designated as MCE, not on a no-break power source, shall sustain operation for duration t_r, then shall be capable of restarting without operator assistance upon the reapplication of power within the bounds of table II.

5.2.3.3 Voltage and frequency excursions. User equipment shall not be damaged due to voltage and frequency excursions specified in table II, Items 20 through 23, and shall be capable of returning to normal operation when power is restored within the user tolerance envelope. User equipment designated as MCE shall operate without interruption, not suffer any loss of data, or require a restart or reboot through excursions specified in table II, Items 20 through 23.

5.2.4 Grounding. User equipment, except for equipment on special voltage (grounded system, see 5.2.2(c) and (d)), shall be ungrounded as related to the electric power system ground. Where power line filters are required in the user equipment, a line-to-line configuration is preferred. If a line-to-ground configuration is used for filtering, then the value of the filter capacitance shall not exceed 0.1 microfarad per line-to-ground for 60-Hz equipment and 0.02 microfarad per line-to-ground for 400-Hz equipment for all nominal user voltages. Filters shall use balanced capacitance per line-to-ground with a tolerance value not exceeding 10 percent. Line-to-ground fundamental frequency current due to filters, etc., shall not exceed 30 milliamperes per line-to-ground. If performance or operational needs of user equipment require an electrical ground either solidly or by means of capacitors which exceed the values stated above or if the line-to-ground current exceeds 30 milliamperes per line-to-ground, then that equipment shall be electrically isolated from the power system. The neutral connection to user equipment on special voltage systems shall not be grounded at the user equipment.

5.2.5 Human body ground current limits for personnel safety. In order to evaluate user equipment for potential shock hazards, a test using an impedance network simulating human body impedance shall be conducted on all equipment that requires a dedicated ground conductor or connection path to the ship's hull. The test simulates the worst case current path through the human body to a neutral point ground if the equipment ground connection is opened. The hull neutral potential ground is created by the many line-to-ground capacitors contained in the typical equipment electromagnetic interference (EMI) filter assemblies. Simulated human body ground current shall be measured from single-phase user equipment connected across one single-phase (line-to-line of a delta source or line-to-neutral of a wye source) of a three-phase transformer aboard ship, from single-phase equipment connected across two phases (line-to-line of a wye source) of a three-phase transformer aboard ship and from three-phase user equipment, using the tests in 5.3.9. Human body ground current test limits are defined for two frequency ranges.

5.2.5.1 Low frequency human body ground current limits for personnel safety. Low frequencies include the input power fundamental and harmonics up to 700 Hz. The current limit through the impedance network simulating the human body for the test in 5.3.9 for the low frequency range is 5 milliamperes.

5.2.5.2 High frequency human body ground current limits for personnel safety. High frequencies include those greater than 700 Hz and less than 100 kHz. The requirement to conduct a high frequency test shall be determined from an evaluation of the conversion technology (switching frequency) included in the equipment design. Any power-switching converter operating at a switching frequency above 1 kHz shall be tested. The current limit through the impedance network simulating the human body for the test in 5.3.9 for the high frequency range is 70 milliamperes.

5.2.6 Current (load) unbalance. User equipment that is three-phase or comprised of a combination of single-phase and three-phase loads shall have a resulting input three-phase line current unbalance not exceeding 5 percent (submarines 3 percent) using normal operating current under normal operating conditions during normal operating modes. This current shall be measured at nominal voltage in all operating modes with a voltage source having a line voltage unbalance less than 1 percent. Three-phase current unbalance shall be calculated as defined in 3.6.1. This requirement does not apply to aircraft servicing systems that are designed for a maximum current unbalance of 15 percent of the user equipment rating.

5.2.7 User equipment pf. User equipment shall operate within the user frequency and voltage tolerance envelope of figures 10 through 16 as applicable with a pf within the range of 0.8 lagging to 0.95 leading for 60 Hz and 0.8 lagging to 0.9 leading for 400 Hz under normal steady state operating conditions, excluding start-ups and pulsing loads. There is no pf requirement for loads operating less than 1 kVA.

5.2.8 Pulsed load requirements. The following pulsed load requirements apply to Type I, II, and III powers.

5.2.8.1 Pulsed load requirement for type I power by category. A pulsed load may be categorized as infrequent or repetitive load changes, which result in a dynamic waveform.

5.2.8.1.1 Infrequent pulsed load requirements. An infrequent pulsed load shall be limited by the inrush current (see 5.2.11) and the ramp load requirements (see 5.2.9). As stated in 3.10, infrequent events are defined as events occurring no more than once every 120 seconds.

5.2.8.1.2 Repetitive pulsed load requirements. The repetitive pulsed load requirements shall meet the pulsed power deviation limit in the time domain, the pulsed power magnitude/frequency limits in the frequency domain, and the power total signal distortion limit, all covered in the following paragraphs. The limits on the repetitive pulsed power waveform maintain this standard's modulation requirements as well as an acceptable response of the prime mover/generator (see 3.10). Further information can be found in The Johns Hopkins University Applied Physics Laboratory technical paper entitled Power-Specification Frequency-Domain Test and Analysis Methodology for Large Dynamic Loads. The repetitive pulsed load requirements are always invoked except during infrequent events as defined in 5.2.8.1.1.

5.2.8.1.2.1 Pulsed power deviation limit (time domain). The user equipment shall limit the instantaneous three-phase pulsed real power deviation from the average real power level to be less than ±50 kilowatt (kW) over a 1-second integration interval centered on the event. This requirement applies for loads with a maximum instantaneous real power greater than or equal to 100 kW and less than or equal to 2 megawatt (MW) as seen by the ship's electric plant. For loads with a maximum instantaneous real power greater than 2 MW, substitute requirements are needed that address the relevant power system's source impedance and response characteristics of the intended platform for all operating modes. The substitute requirements will be specified in the acquisition documents (see 6.2) and shall have NAVSEA approval (see 6.4). An example showing the ±50 kW pulsed power deviation limit is shown on figure 17; in this example, the maximum instantaneous real power is 350 kW and the peak-to-peak pulsed real power is 300 kW. The average real power level is determined over a 1-second integration interval centered on the event. This 1-second centered rolling-average power level is calculated on the entire power waveform and is given by the middle dotted line in the graph. The ±50 kW limits are shown by the two bounded dotted lines. Violations of the ±50 kW limits are highlighted in gray.

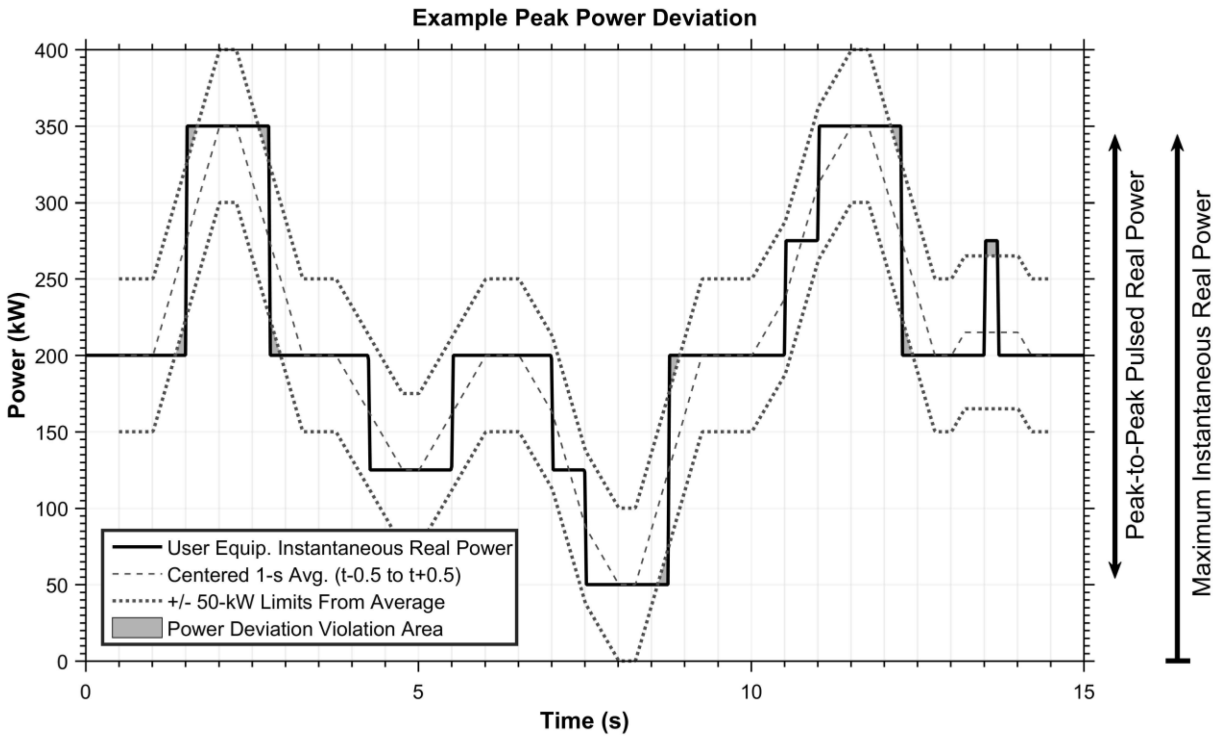


FIGURE 17. Pulsed power waveform and deviation example.

5.2.8.1.2.2 Pulsed power magnitude/frequency limits (frequency domain). The user equipment shall limit the magnitude and frequency of the instantaneous three-phase pulsed real power by the following constraints:

a. This requirement applies to loads with a maximum instantaneous real power level greater than or equal to 100 kW. An absolute limit is also imposed in that the load's allowed peak-to-peak real pulsed power as defined in 3.10.1 shall be less than or equal to 25 percent of the minimum prime mover real power rating. The window of observation for this limit is over a 100-second window. Pulsed loads with peak-to-peak real pulsed power greater than 25 percent of the minimum prime mover real power rating or greater than 2 MW shall be separately addressed as specified (see 6.2 and 6.4).

b. The repetitive pulsed power magnitude/frequency limits are provided on figure 18. The plot presents the acceptable zero-to-peak real power magnitude in watts at a given frequency as a percent of the average real power in watts (e.g., at 1 Hz the allowed zero-to-peak real power magnitude is 3 percent of the average load). The zero-to-peak real power magnitude is determined with the average power component removed from the instantaneous power waveform. The average real power is calculated from the instantaneous real power waveform integrated over a 100-second averaging window. To use figure 18, the instantaneous real power pulsed waveform shall be decomposed into its frequency components after the average real power component has been removed. This is accomplished by using the Discrete Fourier Transform (DFT), incorporating a long window DFT for frequencies below 1 Hz and a short sliding window DFT for frequencies 1 Hz and above. The corresponding recommended procedure for performing the DFT is found in Appendix A. If the algorithm used to perform the DFT differs from Appendix A, a listing of the modified algorithm shall be as specified (see 6.2).

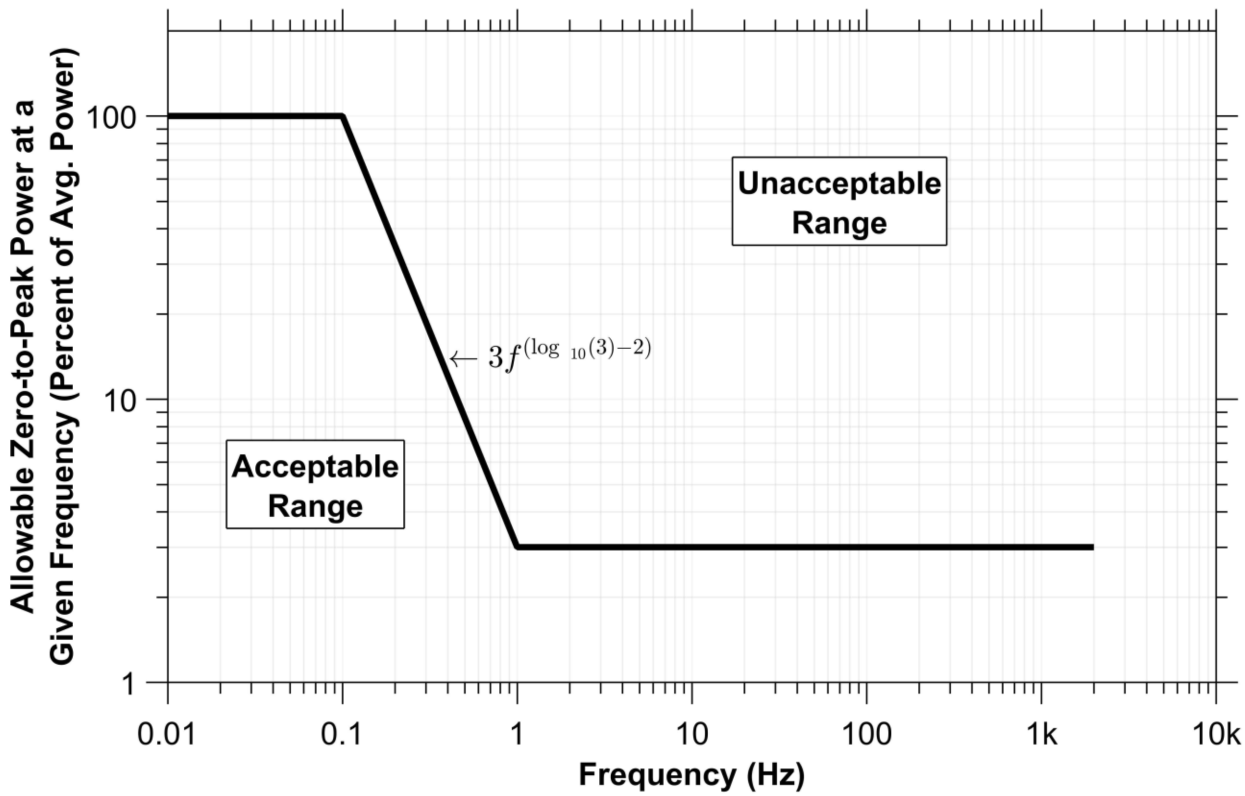


FIGURE 18. Type I pulsed power vs. frequency.

c. The time for the long window is 100 seconds and the time for the short sliding window is 4 seconds. Each 4-second sliding window shall have a 3-second overlap with the preceding 4-second window. This process is shown on figure 19.

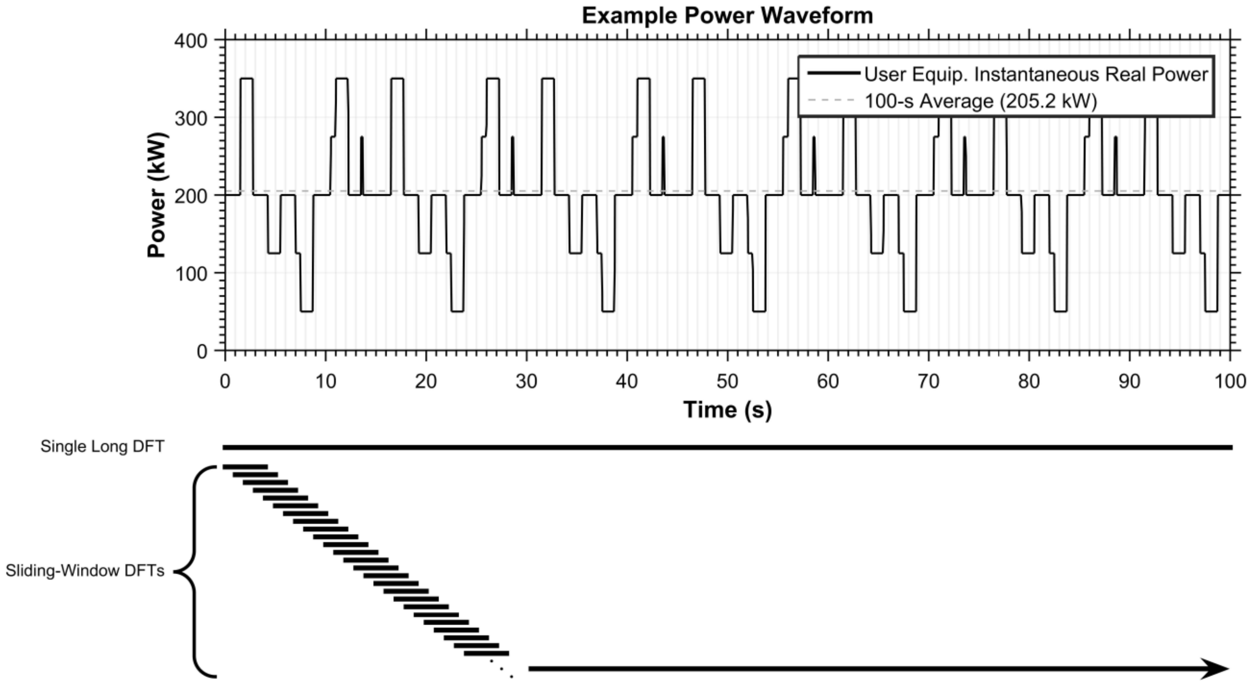


FIGURE 19. Sliding averaging window example.

d. The DFT decomposition of the real power pulsed waveform shall be restricted at any single frequency to the limits shown in the plot on figure 18. The corresponding recommended procedure for performing the DFT is found in Appendix A.

5.2.8.1.2.3 Power total signal distortion (TSD) limit (frequency domain). For Type I power, the load shall limit the calculated power TSD defined in 3.12 to less than 5 percent for frequencies from 1 Hz to 2 kHz where the average power shall be calculated over a 100-second window. As defined in Appendix A, a TSD calculation on each separate 4-second rolling window DFT is performed. The maximum TSD of all 4-second rolling window DFTs is to be the reported TSD value to be compared against the 5 percent requirement.

5.2.8.2 Pulsed load requirements for type II power by category. A Type II power pulsed load may be categorized as infrequent or repetitive resulting in a dynamic waveform.

5.2.8.2.1 Infrequent pulsed load requirements. An infrequent pulsed load shall be limited by the inrush current (see 5.2.11) and the ramp load requirements (see 5.2.9). As stated in 3.10, infrequent events are defined as events occurring no more than once every 120 seconds.

5.2.8.2.2 Repetitive pulsed load requirements. These pulsed load limits maintain the standard’s modulation requirements. A pulsed load shall be limited by the following inequalities:

$S_{pulse} < 0.2583\ S_{supply}$

$P_{pulse} < 0.2500\ S_{supply}$

$Q_{pulse} < 0.0650\ S_{supply}$

resulting in:

$rf_{pulse} < 0.0650\ S_{supply}/S_{pulse}$

$pf_{pulse} < 0.2500\ S_{supply}/S_{pulse}$ (shown as the dotted line plot on figure 20)

$pf_{pulse} > sqrt[1-(0.0650\ S_{supply}/S_{pulse})^2]$ (shown as the solid line plot on figure 20)

Where S_{pulse} is the pulse apparent power, S_{supply} is the supply rated apparent power which may consist of one or more paralleled generators, P_{pulse} is the pulse real power, Q_{pulse} is the pulse inductive power, and pf_{pulse} is the pulse lagging power factor as the reactive factor, rf_{pulse}, remains positive. Figure 20 displays the plots of the pulse pf versus the apparent power of the pulse as a percentage of the supply. The pf ranges from 0 to 1.

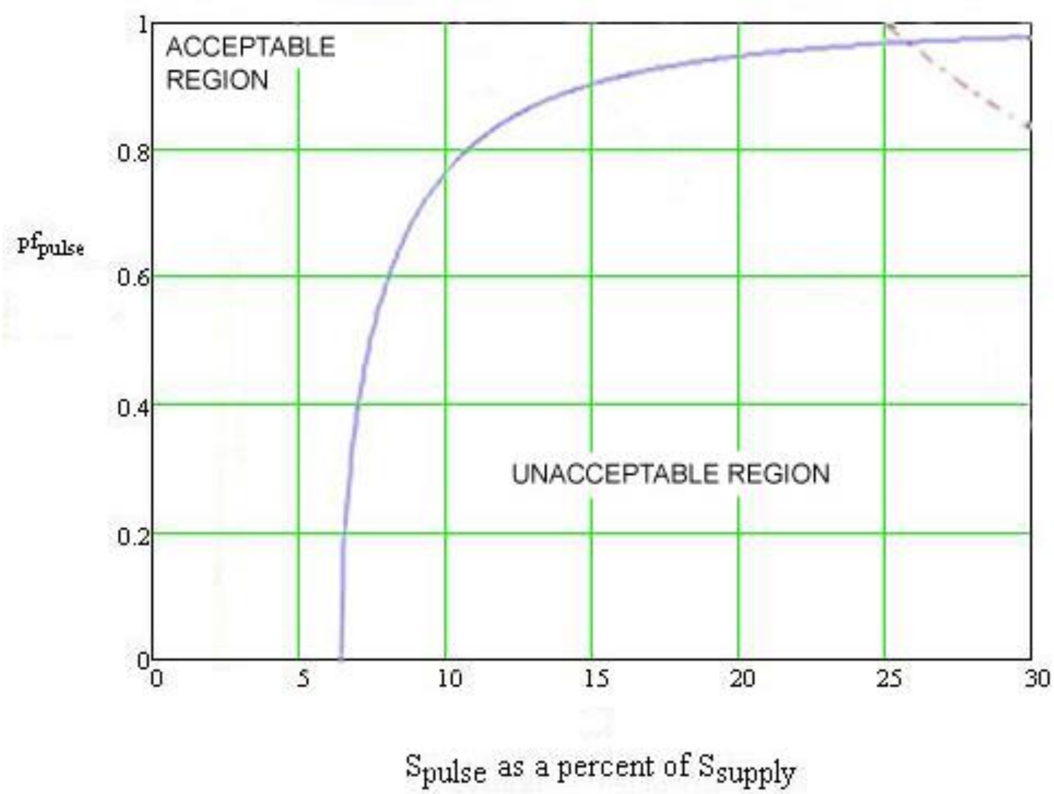


FIGURE 20. Type II pulsed load power factor vs. pulsed load apparent power.

5.2.8.3 Pulsed load requirements for type III power by category. A Type III power pulsed load may be categorized as infrequent or repetitive resulting in a dynamic waveform.

5.2.8.3.1 Infrequent pulsed load requirements. An infrequent pulsed load shall be limited by the inrush current and the ramp load requirements. As stated in 3.10, infrequent events are defined as events occurring no more than once every 120 seconds.

5.2.8.3.2 Repetitive pulsed load requirements. These pulsed load limits maintain the standard's modulation requirements. A pulsed load shall be limited by the following inequalities:

$S_{pulse} < 0.1422\ S_{supply}$

$P_{pulse} < 0.1400\ S_{supply}$

$Q_{pulse} < 0.0250\ S_{supply}$

resulting in:

$rf_{pulse} < 0.0250\ S_{supply}/S_{pulse}$

$pf_{pulse} < 0.1400\ S_{supply}/S_{pulse}$ (shown as the dotted line plot on figure 21)

$pf_{pulse} > sqrt[1-(0.0250\ S_{supply}/S_{pulse})^2]$ (shown as the solid line plot on figure 21)

Where S_{pulse} is the pulse apparent power, S_{supply} is the supply apparent power which may consist of one or more paralleled generators, P_{pulse} is the pulse real power, Q_{pulse} is the pulse inductive power, and pf_{pulse} is the pulse lagging power factor as the reactive factor, rf_{pulse}, remains positive. Figure 21 displays the plots of the pulse pf versus the apparent power of the pulse as a percentage of the supply. The pf ranges from 0 to 1.

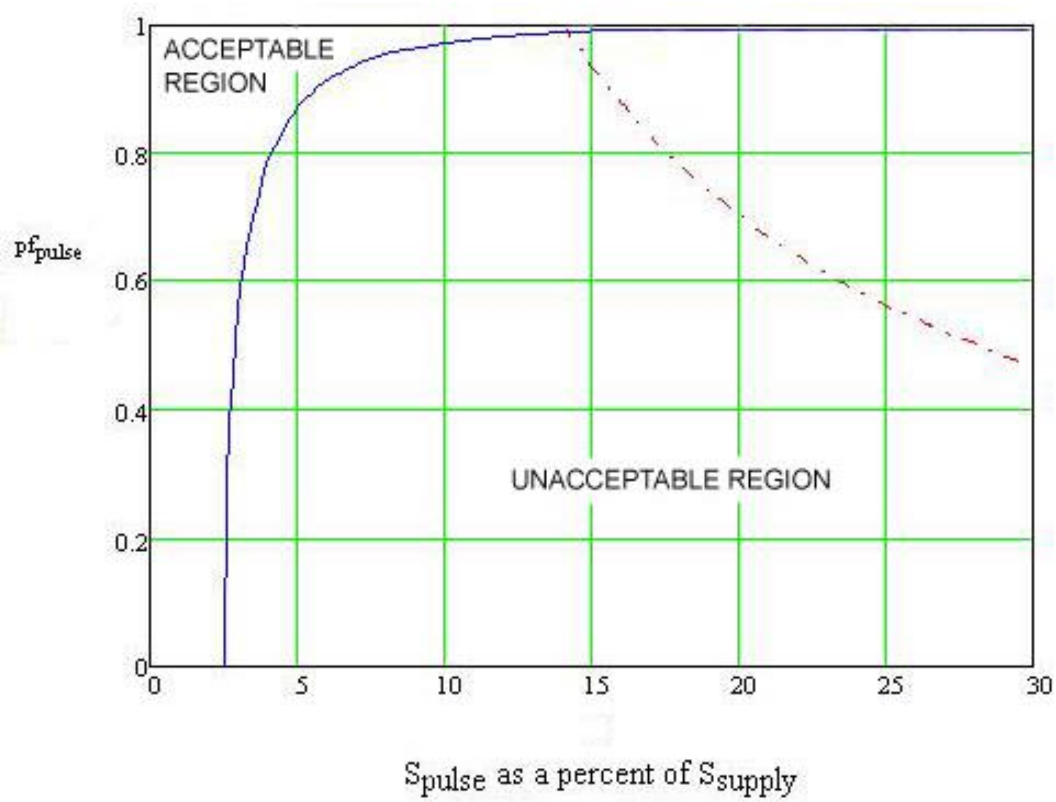


FIGURE 21. Type III pulsed load power factor vs. pulsed load apparent power.

5.2.9 Ramp load requirement. A ramp load shall be limited to 30 percent of the minimum source rating in VA on a per second basis. The source rating could result from single or paralleled generators or electronic supplies. The resulting average ramp rate can be calculated using consecutive increasing steps. If the ramp load is applied in steps rather than a smooth ramp, the maximum step size shall be 70 kVA. The use of the ramp load allowance is for achieving a desired operational power level and shall only be used for infrequent events. This does not apply for the initial energizing of line filters, converter front end capacitance, transformers, and motors for which the inrush current requirement applies.

5.2.10 Input current waveform. The operation of user equipment shall cause minimum distortion on the electrical distribution system current waveform and, thus, the voltage waveform. User equipment, for the purposes of this requirement, shall be defined as a standalone unit or the aggregate of a system with multiple like units on a single bus, e.g., lighting source power supplies. The rating of equipment with multiple power inputs from the same interface shall be the summation of all the power inputs under steady-state conditions. Harmonic current and other conducted emissions (within the 20 kHz frequency band) introduced by the load are limited in order to allow the source and distribution systems to maintain the bus voltage distortion within specified limits given in table II. Current emission magnitude limits for 60-Hz and 400-Hz user equipment at the nominal user voltage levels of table II are depicted on figures 22 through 25. The criteria defined on figures 22 and 23 are similar to the MIL-STD-461 limit criteria for the electromagnetic compatibility (EMC) test CE101 for 60 Hz fundamental tailored to 20 kHz. The criteria defined on figures 24 and 25 are similar to the MIL-STD-461 limit criteria for the EMI test CE101 for 400 Hz fundamental tailored to 20 kHz. MIL-STD-461 CE101 test results shall be used to satisfy input current waveform testing requirements. The total input current shall be measured at nominal voltage input for all operating modes and power levels. See 6.2 for large loads.

5.2.10.1 60-Hz user equipment greater than or equal to 1 kVA. User equipment operating ≥1 kVA shall have no single harmonic line current or current of any frequency above the fundamental frequency at 60 Hz to 2000 Hz that exceeds the limit line set at 3 percent of the user equipment's fundamental frequency current. Additionally, single harmonic line current or current of any frequency above 2000 Hz through 20 kHz shall not exceed the limit line set at 6000/f percent of the user equipment's fundamental frequency current, where "f" is the variable frequency. This is shown on figure 22.

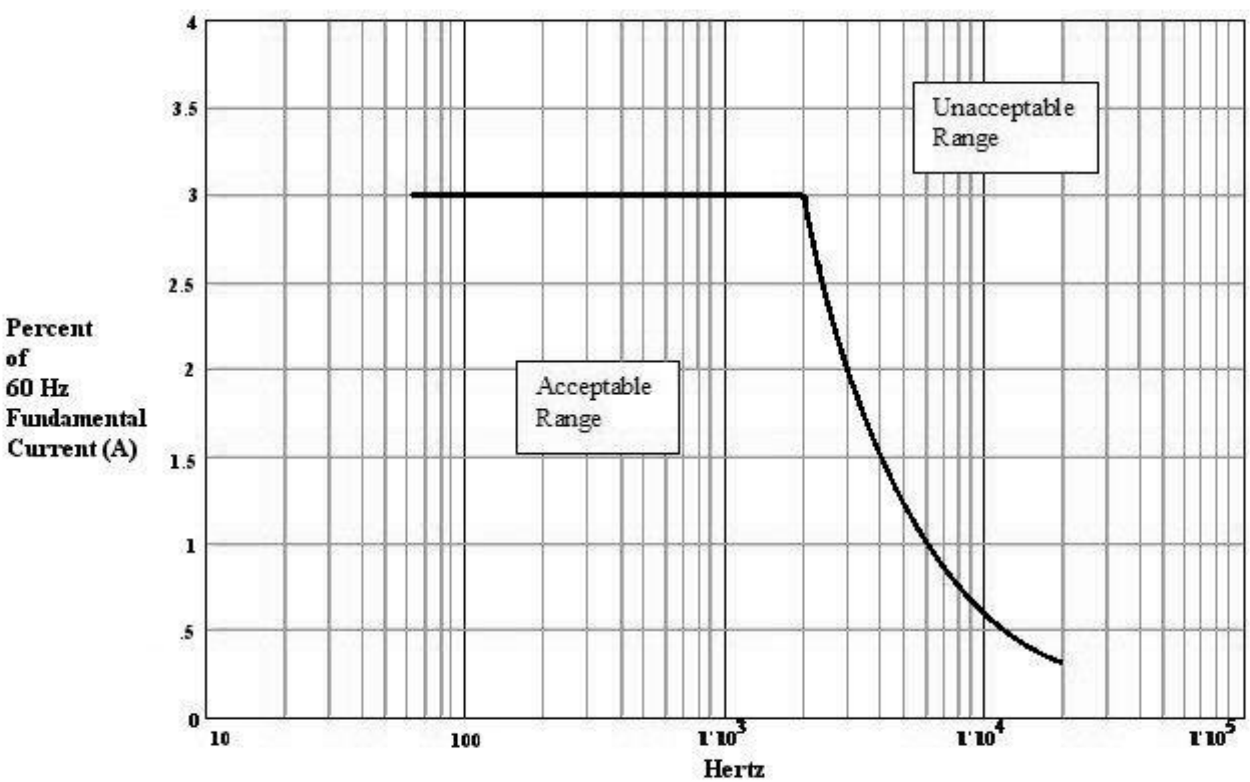


FIGURE 22. Limit line for currents at frequencies greater than 60 Hz for equipment greater than or equal to 1 kVA.

5.2.10.2 60-Hz user equipment less than 1 kVA. User equipment operating <1 kVA shall have no single harmonic line current or current of any frequency above the fundamental at 60 Hz to 20 kHz that exceeds the limit line set at 6000/f percent of the user equipment's fundamental frequency current, where "f" is the variable frequency. The limit line set at 6000/f percent of the user's fundamental frequency current shall not be set at 6000/f percent of fundamental frequency current below 1 A. This is shown on figure 23.

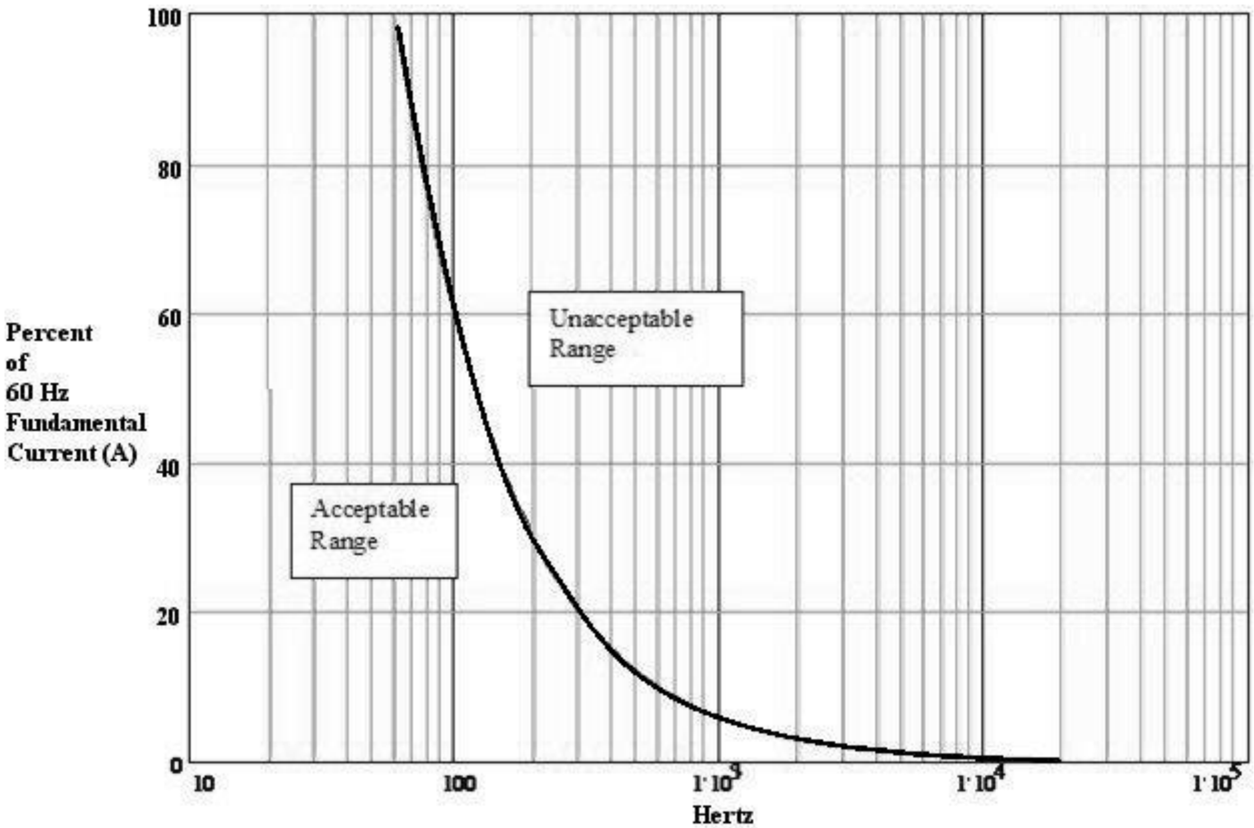


FIGURE 23. Limit line for currents at frequencies greater than 60 Hz for equipment less than 1 kVA.

5.2.10.3 400-Hz user equipment greater than or equal to 0.2 kVA. User equipment operating ≥0.2 kVA shall have no single harmonic line current or current of any frequency above the fundamental at 400 Hz to 13.33 kHz that exceeds the limit line set at 3 percent of the user equipment's fundamental frequency current. Additionally, harmonic line current or current of any frequency above 13,334 Hz through 20 kHz shall not exceed the limit line set at 40,000/f percent of the user equipment's fundamental frequency current, where "f" is the variable frequency. This is shown on figure 24.

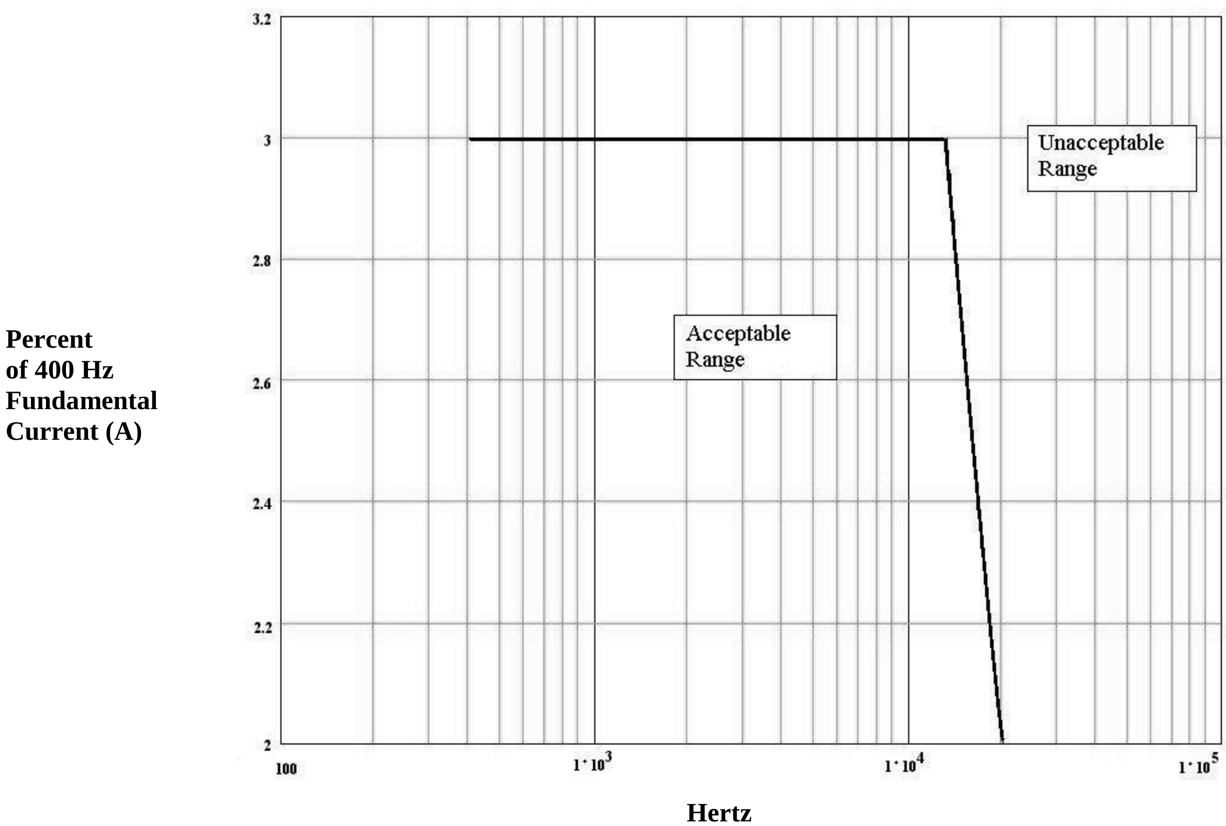


FIGURE 24. Limit line for currents at frequencies greater than 400 Hz for equipment greater than or equal to 0.2 kVA.

5.2.10.4 400-Hz user equipment less than 0.2 kVA. User equipment operating <0.2 kVA shall have no single harmonic line current or current of any frequency above the fundamental at 400 Hz to 20 kHz that exceeds the limit line set at 40,000/f percent of the user equipment's fundamental frequency current, where "f" is the variable frequency. The limit line set at 40,000/f percent of the user's fundamental frequency current shall not be set at 40,000/f percent of fundamental frequency current below 1 A. This is shown on figure 25.

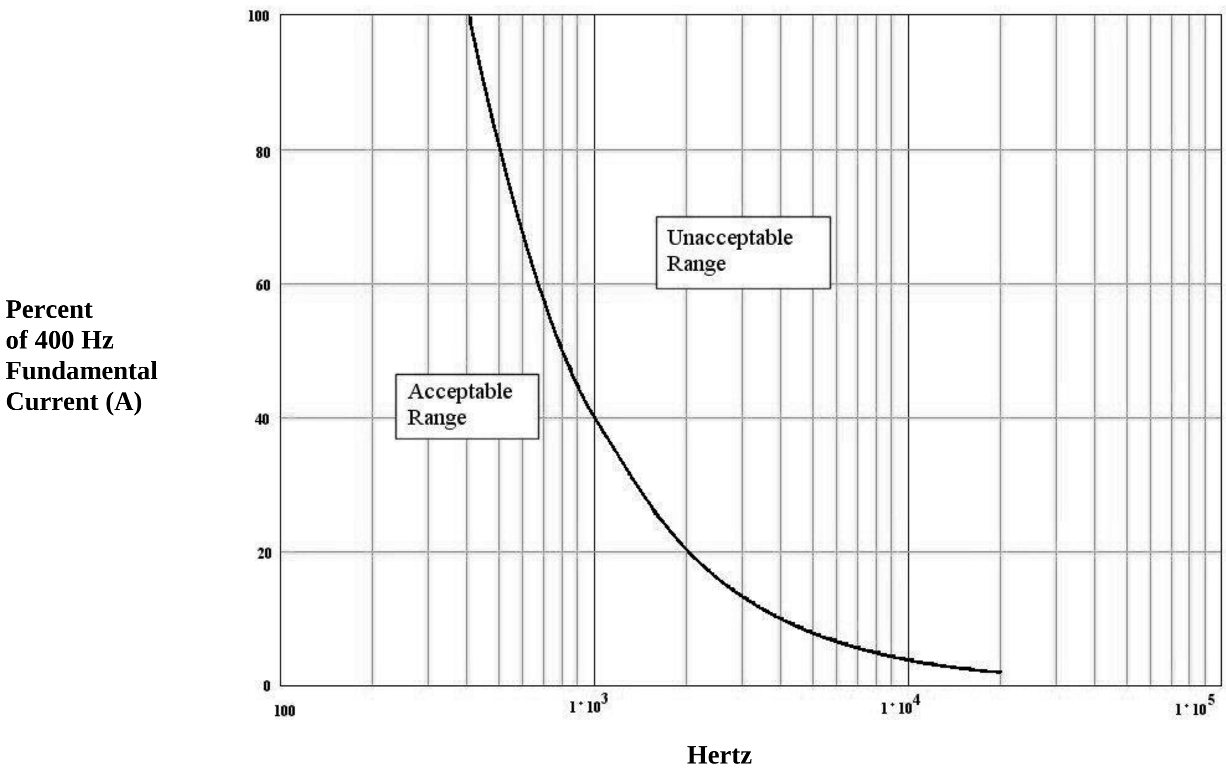


FIGURE 25. Limit line for currents at frequencies greater than 400 Hz for equipment less than 0.2 kVA.

5.2.11 Surge/inrush current. User equipment shall be constructed to limit the ratio of surge current to rated current. The ratio of the maximum surge/inrush peak current to the full rated load peak current shall be limited to the value determined from figure 26 for Type I, 60-Hz electric power and figure 27 for Types II and III, 400-Hz electric power. Load sequencing may be required to maintain an acceptable user voltage envelope at the user interface. Surge/inrush current shall be measured, recorded, and evaluated when energizing the user equipment at the nominal input voltage when the phase voltage source sine-wave passes through 0 degrees for inductive load equipment or when the sine-wave passes through 90 degrees for capacitive load equipment. In order to make allowances for balanced three-phase user equipment where the current will be shifted by -30 degrees, add 30 degrees to the voltage when energizing the EUT. Multiple surge/inrush current occurrences observed on the same event shall be addressed and evaluated individually to determine compliance with the above requirements. There is no surge/inrush current requirement for individual loads rated less than 1 kW.

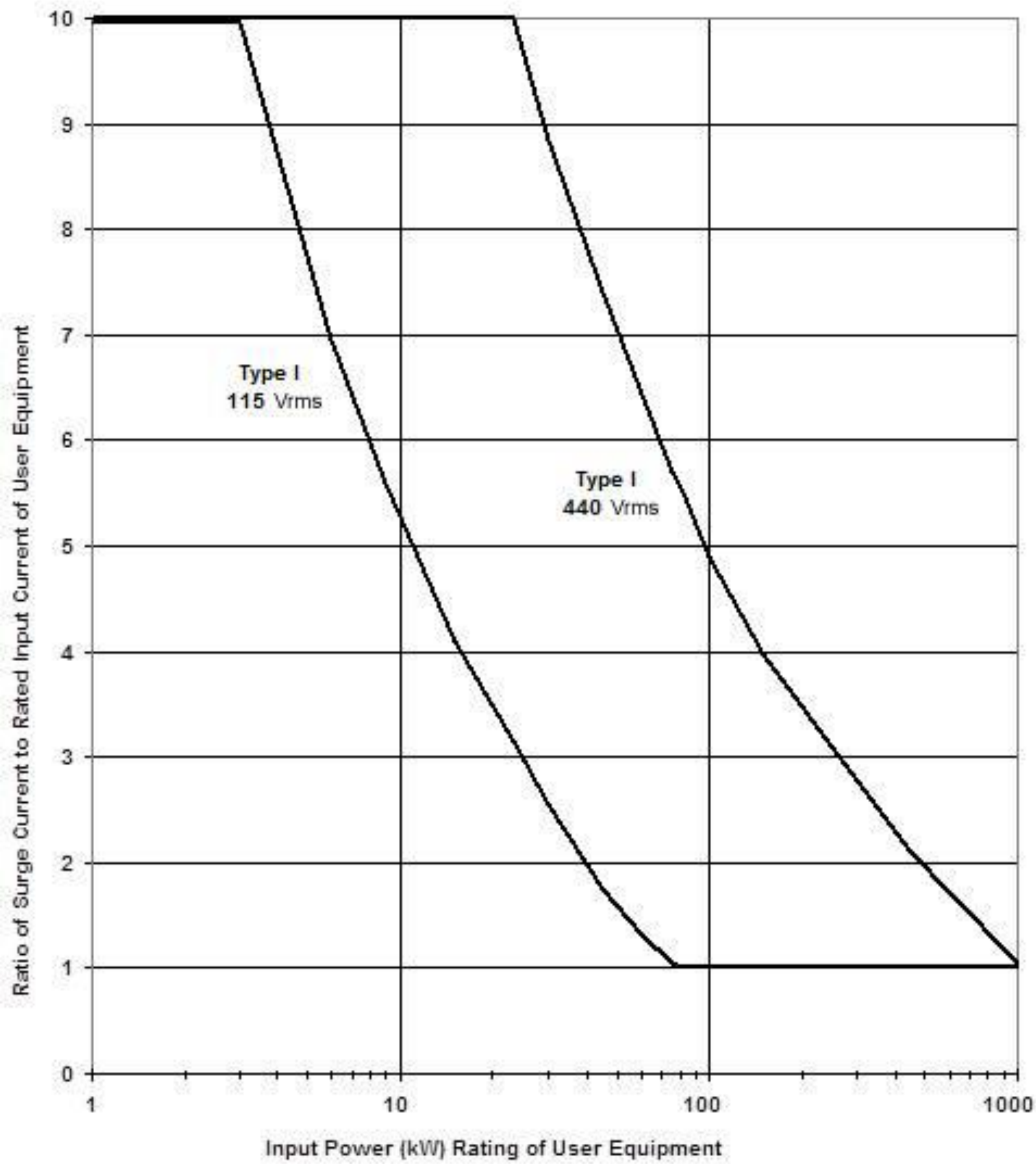


FIGURE 26. Surge current limits for load equipment using Type I power.

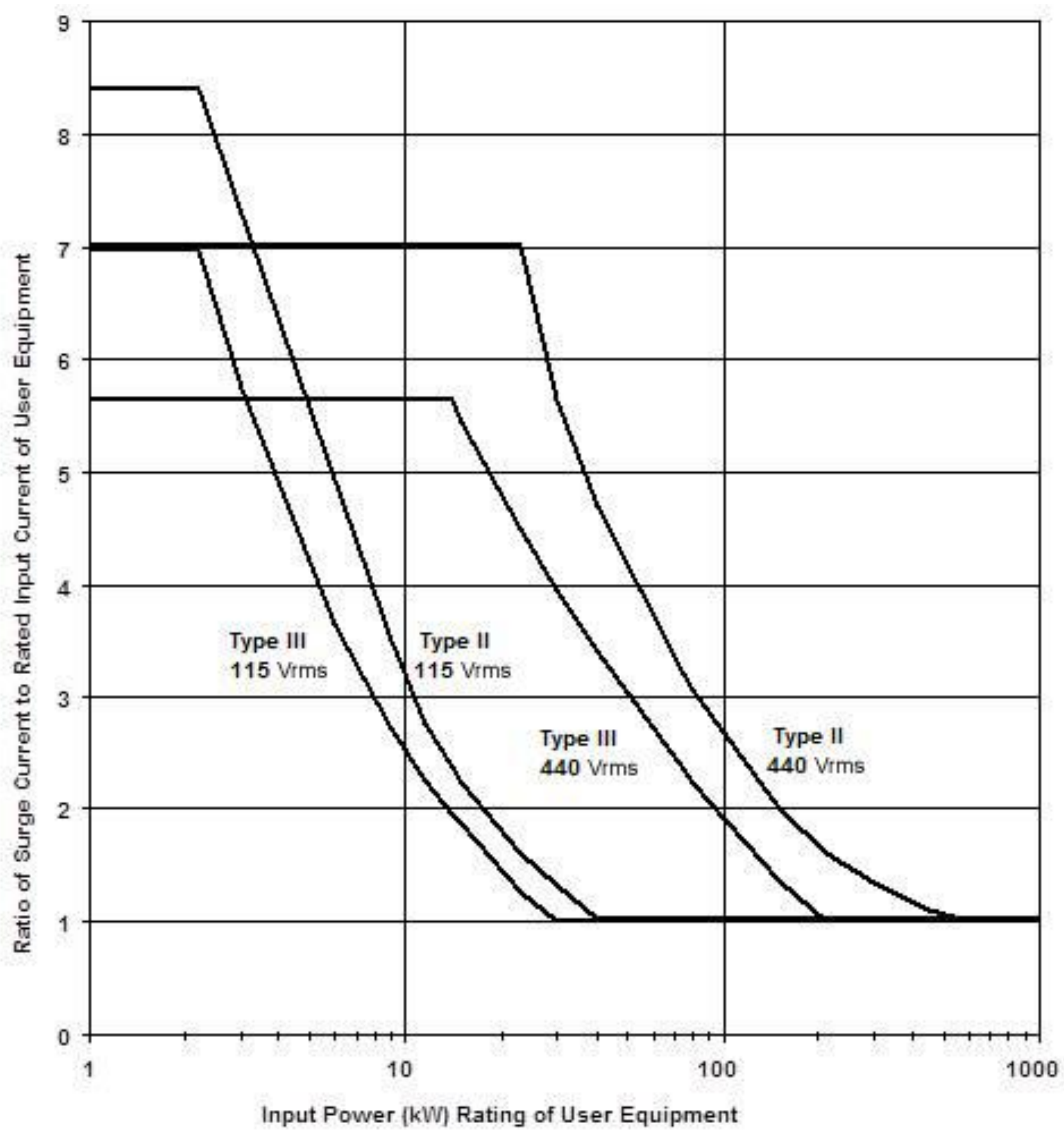


FIGURE 27. Surge current limits for load equipment using Type II or III power.

5.2.12 Insulation resistance. When un-energized, user equipment rated up to 115 V_{rms} shall tolerate the application of 150 VDC and user equipment rated for above 115 V_{rms} up to 440 V_{rms} shall tolerate the application of 500 VDC. The DC voltage shall be applied by a megohmmeter insulation resistance tester between each power conductor and ground without equipment damage, arc-over, degradation, or abnormal operation. S9086-KC-STM-010/300 procedures may be used as a guide. The resistance to ground value as measured by the megohmmeter shall be equal to or greater than 10 megohms as identified in MIL-DTL-917.

5.2.13 Active ground detection. Active ground detection shall impress DC voltage onto the Type I AC voltage from line-to-ground to stress the insulation and detect possible grounds by an increase in the DC current. When energized, user equipment rated at Type I voltages shall tolerate the additional application of the active ground detection DC voltage (normally 500 VDC on 440 V_{rms} or 150 VDC on 115 V_{rms}) between each power conductor and ground for at least 3 minutes without equipment damage, arc-over, degradation, or abnormal operation. For submarines, the AGD test is performed on all 440-V_{rms} buses and only on engine room compartment 115-V_{rms} buses.

5.2.14 Passive ground detection. Passive ground detection is accomplished by using the visual intensity of indicator lights connected from line-to-ground to determine grounded conditions. Passive ground detection operates at the user equipment rated voltage.

5.2.15 Voltage spikes. User equipment shall be designed to withstand voltage spikes (see 5.1.8.2.3) specified in table II. Equipment shall show no damage and remain operational before, during, and after experiencing a voltage spike with the characteristics shown on figure 6 and described in 3.5.9. Equipment shall not experience any operational interruption, suffer any loss of data, or require a system restart or reboot.

5.3 Test requirements. This section specifies test requirements and the associated test procedures. User equipment test requirements are intended to verify compliance to the user equipment interface requirements in this standard when tested in accordance with the procedures specified herein (see 6.2). For user equipment testing, the hardware and software of the user equipment as the Equipment Under Test (EUT) shall be representative of production. The tests presented herein are written to be adapted to the particular EUT. Test equipment and accessories required for measurement in accordance with this standard shall be calibrated under an approved calibration program traceable to the National Institute for Standards and Technology. Testing of equipment fed by a UPS shall be performed with the UPS in place. The EUT shall be tested in all modes of operation at normal operating load, including bypass mode, if present, unless the specific test has a different specific operating requirement. As presented in the following tests, the grounding test should be performed first to ensure there is no neutral ground.

5.3.1 Grounding (susceptibility) test. For ungrounded systems, the EUT shall be tested for proper operation in each operating mode with one power input line grounded. This test also checks for possible commercial neutral grounding; all single- or three-phase neutrals should be disconnected from ground for shipboard equipment. This test shall be performed at normal operating load.

5.3.1.1 Apparatus. The following apparatus is recommended for performing this test:

a. Power source of required capacity and range of voltage and frequency adjustments. A power source with a capability of having an independently programmable voltage and frequency output is recommended.

b. Voltmeter (true rms) – ±0.5-percent accuracy.

c. Frequency meter – ±0.5-Hz accuracy.

d. Storage oscilloscope having ≥ 500-kHz response per channel.

e. Current and potential transformers and probes as required.

f. Three (for three-phase) or two (for single-phase) 100,000-ohm, 450-V_{rms}, 5-W resistors.

g. Three (for three-phase) or two (for single-phase) single-pole fused switches or circuit breaker sized for the short circuit rating of the power supply.

5.3.1.2 Procedure. The intent of the test is to separately connect each power line to ground while the other power lines are connected through a 100,000-ohm resistance to ground with the EUT enclosure connected to this ground. It is recommended that an isolated power source be used for this test to prevent grounding of commercial utility power lines. A single equipment ground plane shall be used. With the power source feeding the EUT de-energized, connect each power line through a 100,000-ohm resistor to ground in parallel with an open single-pole fused switch or circuit breaker of adequate rating to ground. With all power lines connected through the parallel resistor and open switch to ground, energize the power source and the EUT. Each 100,000-ohm resistor shall have in parallel a single pole fused switch or circuit breaker of adequate rating. With the EUT operating in a normal operating mode and with voltage and frequency within the user tolerance envelope, close a switch and short one of the 100,000-ohm resistors. Leave the ground condition on for a sufficient period to determine any EUT degradation, but at least for a minimum of 5 minutes, then remove the ground by opening the switch. Take note if any fuse blows, possibly indicating a neutral is tied to ground. Ground each power line in turn in the same manner. Repeat the test for each operating mode. Recordings of each input voltage shall be made for each test. The EUT shall sustain normal operation throughout the grounding test.

5.3.2 User equipment power profile test. This test shall be used to document the EUT electrical interface and verify compliance to requirements for the following:

a. Type of power (see 5.1.1).

b. Number of phases (see 5.2.2).

c. Operating frequency (see 5.1.8.1).

d. Operating voltage (rms) (see 5.2.2).

e. Line current (at normal operating load and rated load).

f. Power (at normal operating load and rated load) (see 5.2.2).

g. pf (at normal operating load and rated load) (see 5.2.7).

h. Operating duty cycle.

i. Surge/inrush current (see 5.2.11).

j. Unbalance (at normal operating load and rated load) (see 5.2.6).

k. Pulsed loading profile (record the input power with the EUT operating at normal load for 2 minutes) (see 5.2.8).

l. Ramp loading profile (see 5.2.9).

m. Spike generation (see 5.1.8.2.3).

n. Line-to-ground capacitance (see 5.2.4).

o. Line-to-ground current (see 5.2.4).

5.3.2.1 Apparatus. The following apparatus is recommended for performing this test:

a. Power source of required capacity and range of voltage and frequency adjustments. A power source with a capability of having an independently programmable voltage and frequency output is recommended.

b. Voltmeters (true rms) having ±0.5 percent accuracy.

c. Frequency meter having ±0.5 Hz accuracy.

d. Ammeters.

e. pf meter.

f. Storage oscilloscope having ≥500 kHz response per channel.

g. Current and potential transformers and probes as required.

h. Capacitance meter, if necessary.

5.3.2.2 Procedure. The power profile test shall be repeated for each normal functional operating mode and for each EUT electrical power input. All test values shall be within limits in accordance with the applicable requirements. The power source used for this test and its characteristics shall be recorded in order to assist in analyzing the impact the equipment may have on a shipboard power system. The test power source rating and its source impedance, as well as the length and type of connecting cable used, shall be included. Determine the following:

a. The power input voltage and frequency to the EUT shall be within the user tolerance bands. List the type of power and measure and record the number of phases, frequency, power input voltages (line-to-line), each line current, and power (kVA and kW) and pf, leading or lagging. The operating duty cycle of the EUT aboard ship shall be stated. These measurements shall be made for each power input from the electric power system.

b. Surge/inrush current is discussed in 5.2.11 and limits are provided on figures 25 and 26. The EUT shall be de-energized and re-energized in accordance with the equipment operating procedures. Surge/inrush current shall be measured and evaluated when energizing the EUT at the nominal input voltage for the following cases: when the voltage source sine-wave passes through 0 degrees (for inductive load equipment) and when the sine-wave passes through 90 degrees (for capacitive load equipment). Make allowances for balanced three-phase user equipment where the current will be shifted by -30 degrees; add 30 degrees to the voltage when energizing the EUT. The larger inrush current of the two cases shall be used. During this period of de-energizing and re-energizing, oscilloscope records shall be taken of one line voltage and each line current to determine surge/inrush current during the transition. The data shall be of sufficient resolution to be able to accurately determine the magnitude and duration of the surge/inrush current.

c. Load unbalance for three-phase equipment and equipment suites that are a combination of single and three-phase loads shall be determined at normal operating load and at rated load and checked against the requirement in 5.2.6.

d. Pulsed and ramp loading profiles, discussed in 5.2.8 and 5.2.9, respectively, if applicable, shall be recorded and presented.

e. Spike generation during operation shall be noted and compared to the information in 5.1.8.2.3.

f. Line-to-ground capacitance for each power line of the EUT that has no system ground shall be determined by inspection, specification, or measurement in that order and the value shall be recorded and checked against the limit in 5.2.4. Based on available information, the determination may be assisted by one or all of the following topics in their presented order:

(1) Inspect the de-energized EUT input for the presence of filter circuitry and record the line-to-ground capacitance.

(2) Examine the circuit schematic or manufacturer's specification and record the line-to-ground capacitance. Any schematic should be included in the test report.

(3) Testing for the line-to-ground capacitance value may be performed using one or all of the following tests in the following order:

(a) With the EUT de-energized, an approximate determination may be made by temporarily shorting together all input lines and then measuring the capacitance to ground using a capacitance meter. Then divide the measurement value by the number of lines. This will be the line-to-ground capacitance. After the determination, the line-to-line shorts shall be removed.

(b) See 5.3.2 h for a more rigorous procedure to determine line-to-ground capacitance.

g. Line-to-ground fundamental frequency current for each power line of the EUT that has no system ground shall be determined by measurement and calculation and the value of line-to-ground current shall be recorded and checked against the limits in 5.2.4. See 5.3.2 h for the measurement procedure to determine line-to-ground current.

h. Line-to-ground capacitance and current for 5.3.2 f and 5.3.2.g may be determined by the following procedures. The required test equipment will be a storage oscilloscope with voltage probes and a current clamp-on probe capable of measuring milliamperes.

(1) For a single-phase EUT:

WARNING: This test may be hazardous due to the ungrounded condition of the EUT during the test. Do not touch exposed metal surfaces. Ensure the grounding test has been performed satisfactorily before performing this test.

(a) Open the input and de-energize the input voltage source V_{12} to line 1 (L_1) and line 2 (L_2).

(b) Place the EUT on an isolated, ungrounded surface.

(c) Remove the equipment ground conductor from the EUT to ground.

(d) Run a jumper no larger than a 12-American Wire Gauge (AWG) conductor from L_2 to the equipment ground G on the EUT. This will carry I_{1G}.

(e) Energize the input voltage source and apply voltage V_{12} to L_1 and L_2. Energize the EUT.

(f) Measure the rms current magnitude in the jumper. This is the current magnitude $|I_{1G}|$ from L_1 to ground and is usually mostly capacitive. Divide this line-to-ground current magnitude $|I_{1G}|$ by 2. This is the line-to-ground current; compare it to the line-to-ground current requirement in 5.2.4.

(g) Continue to determine line-to-ground capacitance.

(h) Determine the phasor magnitudes and angles of phasor V_{12} and phasor I_{1G} referenced from phasor V_{12}.

(i) Divide the phasor V_{12} by phasor I_{1G} to calculate the line-to-ground impedance Z_{1G} from L_1 to ground. From Z_{1G}, determine the line-to-ground capacitance from L_1 to ground, C_{1G}. This is calculated by $Y_{1G} = 1/Z_{1G}$ so the parallel combination of $R_{1G} = 1/\mathrm{Re}(Y_{1G})$ and $C_{1G} = \mathrm{Im}(Y_{1G})/2\pi f$ where f is the frequency. Record the line-to-ground capacitance and compare it to the requirement. The capacitance from line-to-ground can be expected to be balanced for both lines.

(j) De-energize the EUT. Open the input and de-energize the input voltage source V_{12} to L_1 and L_2.

(k) Remove the jumper from L_1 to ground, reconnect the equipment ground from the EUT to ground, and return the EUT to normal conditions.

(2) For a three-phase EUT:

WARNING: This test may be hazardous due to the ungrounded condition of the EUT during the test. Do not touch exposed metal surfaces. Ensure the grounding test has been performed satisfactorily before performing this test.

(a) Assume the line-to-ground impedances are equal in magnitude and phase.

(b) Determine phase A, phase B, and phase C for proper phase rotation.

(c) Open the input to de-energize the input voltage source to phases A, B, and C.

(d) Place the EUT on an isolated, ungrounded surface.

(e) Remove the equipment ground from the EUT.

(f) Run a jumper no larger than a 12-AWG conductor from phase C to the equipment ground on the EUT; this will carry I_{CG}, the current from C to G or ground.

(g) Energize the input voltage source and apply voltage between phases AB, BC, and CA. Energize the EUT.

(h) Measure the magnitudes and phase angles of phasors V_{AG} for the voltage from A to G, V_{BG} for the voltage from B to G, and I_{CG} with phase angles referenced to phasor V_{AG}.

(i) Using phasors with magnitude and angle, calculate the line-to-ground impedance $Z_{LG} = (-V_{AG} - V_{BG})/I_{CG}$. From Z_{LG}, determine the line-to-ground capacitance C_{LG}. The line-to-ground admittance is calculated by $Y_{LG} = 1/Z_{LG}$ so the parallel combination of the line-to-ground resistance $R_{LG} = 1/\mathrm{Re}(Y_{LG})$ and $C_{LG} = \mathrm{Im}(Y_{LG})/2\pi f$ where f is the frequency. Record the line-to-ground capacitance and compare it to the requirement. The line-to-ground capacitance can be expected to be balanced and the same for all lines-to-ground.

(j) Calculate the line-to-ground current magnitude by $(|V_{LL}|/\sqrt{3})/|Z_{LG}|$. Record the line-to-ground current magnitude and compare it to the requirement in 5.2.4.

(k) De-energize the EUT. Open the input to de-energize the input voltage source to phases AB, BC, and CA.

(l) Remove the jumper from phase C to the equipment ground G on the EUT, reconnect the equipment ground from the EUT to ground, and return the EUT to normal conditions.

5.3.3 Voltage and frequency maximum departure tolerance test. This test shall be used to evaluate the performance of EUT under the voltage and frequency conditions of table III, as applicable. Steady-state departures from nominal or tolerances with the greatest ranges are used for the test, regardless of those for surface ship or submarine, including CVN 78 class ships. The operation of the EUT shall be within the manufacturer's defined operating parameters when tested to the voltage and frequency conditions of table III, as applicable. This test shall be performed at normal operating load.

TABLE III. Voltage and frequency maximum departure tolerance test.

	User Voltage Tolerance (V_{rms})			**Frequency Tolerance (Hz)**		
	Lower Limit	**Nominal**	**Upper Limit**	**Lower Limit**	**Nominal**	**Upper Limit**
Type I, 3-phase	104 396	115 440	127 484	57	60	63
Type I, 3-phase, grounded	180	200	220	58	60	62
Type I, 1-phase	104 396	115 440	127 484	57	60	63
Type I, 1-phase, grounded	104	115	127	58	60	62
Type II, 3-phase	106 405	115 440	124 475	380	400	420
Type II, 1-phase	106 405	115 440	124 475	380	400	420
Type III, 3-phase	110 422	115 440	120 458	398	400	402
Type III, 3-phase, grounded	192	200	208	398	400	402
Type III, 1-phase	110 422	115 440	120 458	398	400	402
Type III, 1-phase, grounded	110	115	120	398	400	402

5.3.3.1 Apparatus. The following apparatus is recommended for performing this test:

a. Power source of required capacity and range of voltage and frequency adjustments. A power source with a capability of having an independently programmable voltage and frequency output is recommended.

b. Voltmeters (true rms) having ±0.5-percent accuracy.

c. Frequency meter having ±0.5-Hz accuracy.

d. Temperature meter having ±0.5 °C accuracy.

5.3.3.2 Procedure. The EUT shall first be operated in a normal operating mode within the steady-state voltage and frequency tolerance envelopes as identified on figures 10 through 16 until the equipment temperature has stabilized. Temperature stability shall be defined as when the variation between successive temperature measurements at the same location does not exceed 1 °C after a 30–minute period. Once the temperature is stabilized, all conditions of testing can be performed. The EUT shall then be subjected to the limits of the user voltage and frequency tolerance envelopes of table III. The following combinations shall be set:

a. Voltage upper limit and frequency upper limit

b. Voltage upper limit and frequency lower limit

c. Voltage lower limit and frequency lower limit

d. Voltage lower limit and frequency upper limit

The EUT shall be operated at each combination until its temperature has stabilized and for 30 minutes thereafter. This test shall be repeated for each mode of equipment operation. Voltage, frequency, and internal equipment temperatures shall be measured and recorded at 10-minute intervals. During and after testing, equipment shall operate normally with a stable temperature and with no operational degradation to show compliance with this test.

5.3.4 Voltage and frequency transient tolerance and recovery (susceptibility) test. The EUT performance shall be evaluated under the transient frequency and voltage conditions (from nominal) specified in table IV. Frequency testing can be accomplished on a component basis in lieu of larger modules or complete unit testing. This test shall be performed at normal operating load.

TABLE IV. Voltage and frequency transient tolerance and recovery test.

Condition	Type I Power		Type II Power		Type III Power	
	Voltage	**Frequency**	**Voltage**	**Frequency**	**Voltage**	**Frequency**
Upper Limit	+20%	+5.5%	+20%	+6.5%	+5.5%	+1.5%
Lower Limit	-20%	-5.5%	-20%	-6.5%	-5.5%	-1.5%

5.3.4.1 Apparatus. The following apparatus is recommended for performing this test:

a. Power source of required capacity and range of voltage and frequency adjustments. A power source with a capability of having an independently programmable voltage and frequency output is recommended.

b. Voltmeters (true rms) having ±0.5-percent accuracy.

c. Frequency meter having ±0.5-Hz accuracy.

d. Storage oscilloscope having ≥500-kHz response per channel.

e. Current and potential transformers and probes as required.

f. Temperature meter having ±0.5 °C accuracy.

5.3.4.2 Procedure. The EUT shall be operated in a normal operating mode within the user voltage and frequency tolerance envelopes as shown on figures 10 through 16, as applicable, until the equipment temperatures have stabi1ized. Temperature stability shall be defined as when the variation between successive temperature measurements at the same location does not exceed 1 °C after a 30–minute period. Once the temperature is stabilized, all conditions of testing can be performed. The input voltage and frequency shall then be simultaneously changed within 0.1 second to the applicable upper limit of table IV. Return the voltage and frequency to the user tolerance band within the applicable recovery time of table II, Items 6 and 15. The initial condition of voltage, frequency, and line current shall be measured and recorded before the start of each test. Input voltages, frequency, and input line currents shall be recorded before initiation of the voltage and frequency transient and until the transient is completed. Repeat the test for the applicable lower limit of voltage and frequency given in table IV. Repeat the test for each normal mode of operation at the applicable upper and lower limits of transient voltage and frequency given in table IV. During and after testing, equipment shall operate normally with no operational degradation to show compliance with this test.

5.3.5 Voltage spike (susceptibility) test. A voltage spike test shall be conducted to evaluate the capability of the EUT to withstand and operate before, during, and after the voltage spike as specified on figure 6 (see 3.5.9). It is recommended that the voltage spike be applied as close as possible, but not more than 1.5 meters from the input terminal of the EUT. This test shall be performed with the EUT operating normally.

5.3.5.1 Apparatus. The following apparatus is recommended for performing this test:

a. AC power source – A power source providing the required shipboard voltage and frequency as shown on figures 28 through 32. It may be 440 or 115 V_{rms}, three-phase, 60 Hz or 400 Hz or 115 V_{rms}, single-phase, 60 Hz, depending on the EUT. The power source shall withstand the voltage spike test.

b. Voltage spike attenuation circuit – If necessary, to reduce the magnitude of the voltage spikes imposed on the power source during testing, between the power source and the test circuit, an isolation transformer and a spike suppression filter may be used at the output of the AC power source.

(1) The isolation transformer, either single-phase for single-phase testing or three-phase ungrounded secondary for three-phase testing may be sufficient as a low-pass filter for spike suppression. The transformer power requirements should be rated for the EUT operation.

(2) For the spike suppression filter, a metal oxide varistor (MOV) can be installed from each line-to-line connection from the power supply. The MOV shall be rated for the test to protect the power supply. Also, it may be necessary to connect a one-microfarad capacitor across each set of MOVs to filter out the high frequencies present on the leading edge of the voltage spike generated by the spike generator. After the parallel MOV and capacitor circuit placed across each line-to-line terminal, between the power source and the test circuit, a series 0.5-millihenry inductor shall be installed in each line to prevent attenuation of the spike presented to the EUT. The inductance should be as high as practicable without causing a voltage drop of such magnitude that the input voltage to the EUT is below the limit specified in this standard. The current drawn by the EUT will determine the maximum allowable inductor value. Appropriate damping resistors should be connected across each inductor to eliminate unwanted oscillations.

c. Voltage spike generator (VSG) – The VSG shall be capable of injecting the required spike waveshape at the specified magnitudes and angles on the source line-to-line voltage to the input terminals of the EUT. The VSG shall be rated for 8-MW peak into a 0.5-ohm load for 440-V_{rms} equipment and 1.28-MW peak into a 0.5-ohm load for 115-V_{rms} equipment to verify the capacity of the EUT and any protective circuitry for these spike events. VSGs of lower power ratings that are capable of producing the required spike voltage at the input of the EUT may be used with NAVSEA (see 6.4) approval. This shall entail recording the power rating of the device and demonstrating that the required spike will be present across a simulated load resistance based on the load size of the EUT. The following is information and components used with the acceptable Solar Models 7399-1, -2, or -3, or equal, VSGs:

(1) VSG, Solar Models 7399-1, -2, or -3.

(2) Solar plug-in box, part number 739950 or equivalent for parallel spike injection.

(3) R_s (two variable resistors: 0-1 ohm, 1 percent, 10 watt and 0-16 ohm, 1 percent, 50 watt, series connected) for Solar VSG spike width adjustment.

(4) R_d (resistor, 1 ohm, 1 percent, 120 watt, preferably low inductance) for Solar VSG output damping.

(5) Transformer (440 V_{rms} to 115 V_{rms}, 50 VA) used for conditioning the Sync Input to the Solar VSG when conducting 440-V_{rms} voltage spike tests.

d. Oscilloscope – The device should have a minimum bandwidth of 30 megahertz (MHz) and a high voltage probe.

e. Circuit components:

(1) C_g – AC capacitors, 660 V_{rms}, to support the range of 5 to 35 microfarads (typically consisting of 5-, 10-, and 20-microfarad values with 10-percent tolerance) to provide a high frequency path between line and ground on figures 28 through 32.

(2) L_g – Inductors, 5.7 mH with 10-percent tolerance, 370 V_{rms}, 2 A, used in power Types II and III testing to provide a high frequency path between line and ground on figures 31 and 32.

5.3.5.2 Procedure. The following paragraphs provide guidance for performing the test:

a. Figures 28 through 30 show the single-phase 115-V_{rms}, three-phase 115-V_{rms}, and three-phase 440-V_{rms} voltage spike test circuit configuration diagrams, respectively, for Type I power. Figures 31 and 32 show the voltage spike test circuit configuration diagrams for Types II and III power. Spikes will be simultaneously applied line-to-ground and line-to-line through the C_g capacitors shown on the figures.

b. For open-circuit voltage spike calibration purposes with the attenuation circuit connected, the EUT shall be disconnected from the power source and the voltage spike waveform representative of figure 6 shall be superimposed on the power source voltage. With the EUT disconnected, the voltage spike shall be calibrated for the four synchronization angle positions on the line-to-line voltages shown in table V and table VI, depending on either single- or three-phase systems. The voltage spike waveform can be achieved between any two power lines and from the power line under test to ground through the test capacitances, C_g. C_g may need to be adjusted for proper spike width. The spike shall have a rise time of 1.2 microseconds to its peak voltage and a 50-microsecond decay to half the peak voltage as shown on figure 6. The voltage spike exhibited during open-circuit calibration shall have a peak value of 2400- to 2500-V peak for 440-V_{rms} systems and 900- to 1000-V peak for 115-V_{rms} systems. A spike set for 0 degrees on a line-to-line voltage waveshape may be shifted 30 degrees on a line-to-ground waveshape.

c. When using the Solar VSG, a 1-ohm (preferably low inductance) damping impedance, R_d, shall be utilized in series with the high-voltage output line of the voltage spike generator; adjustable resistor, R_s, on the plug-in box controls the spike width. The Solar VSG should be synchronized across the phase of the power source that does not have the spike injected. For example, if the spike is injected from A through the capacitors, C_g, to ground, C_g to B and C_g to C, then the VSG should be synchronized across B to C. Following, if the spike is injected from B through the capacitors, C_g, to ground, C_g to A and C_g to C, then the VSG should be synchronized across C to A. Also, if the spike is injected from C through the capacitors, C_g, to ground, C_g to B and C_g to A, then the VSG should be synchronized across A to B.

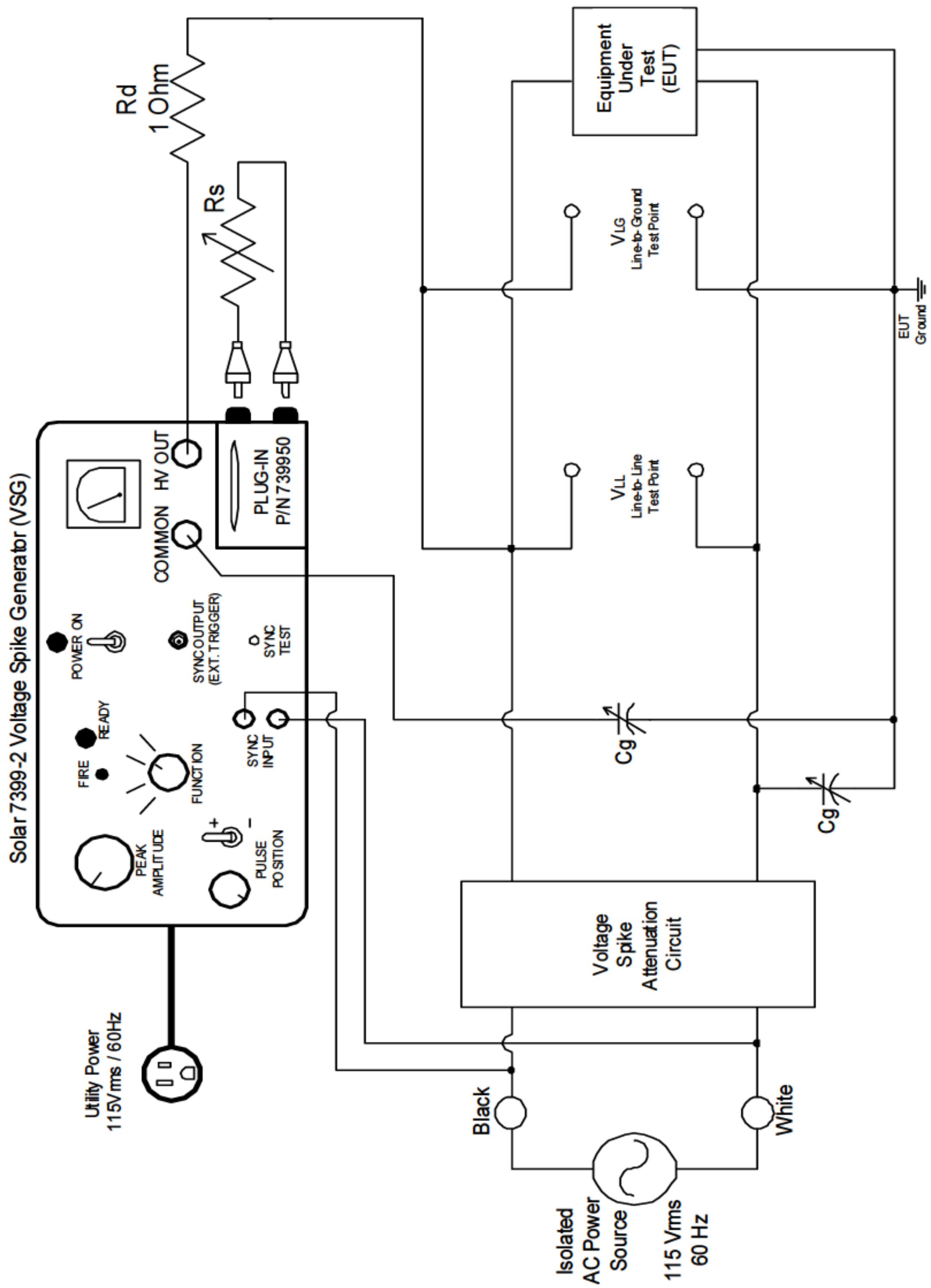
d. After establishing the open-circuit calibrated voltage spike, the EUT shall be reconnected. The following spikes shall be applied and verified at the EUT line-to-line and line-to-ground test point terminals: five positive polarity voltage spikes at the rate of two per minute shall be applied at 0 degrees and five positive polarity voltage spikes at the rate of two per minute shall be applied at 90 degrees. Then, after reversing the "high voltage out" and "common" connections, five negative polarity voltage spikes at the rate of two per minute shall be applied at 0 degrees and five negative polarity voltage spikes at the rate of two per minute shall be applied at 270 degrees. The test shall be repeated for each line through C_g to ground and through each C_g to each line; reconfigure the test circuit (the capacitors and, if required, parallel inductors to ground shall not be connected to the line having the spike applied, but to the remaining lines). Respective line-to-ground voltage, line-to-line voltage, and spike voltage parameter data shall be monitored and recorded to ensure proper testing. Equipment shall remain operational before, during, and after each applied voltage spike. The EUT shall not experience any operational interruption, suffer any loss of data, or require a restart or reboot.

TABLE V. Single-phase system voltage spike test conditions.

Spike Peak (Including Fundamental AC Voltage Waveform)	Conductor-To-Ground	Synchronization Angle	Polarity
2400- to 2500-V peak ($440\text{-}V_{rms}$ systems) or 900- to 1000-V peak ($115\text{-}V_{rms}$ systems)	Black (hot)	0°	positive
		90°	positive
		0°	negative
		270°	negative
	White (return)	0°	positive
		90°	positive
		0°	negative
		270°	negative

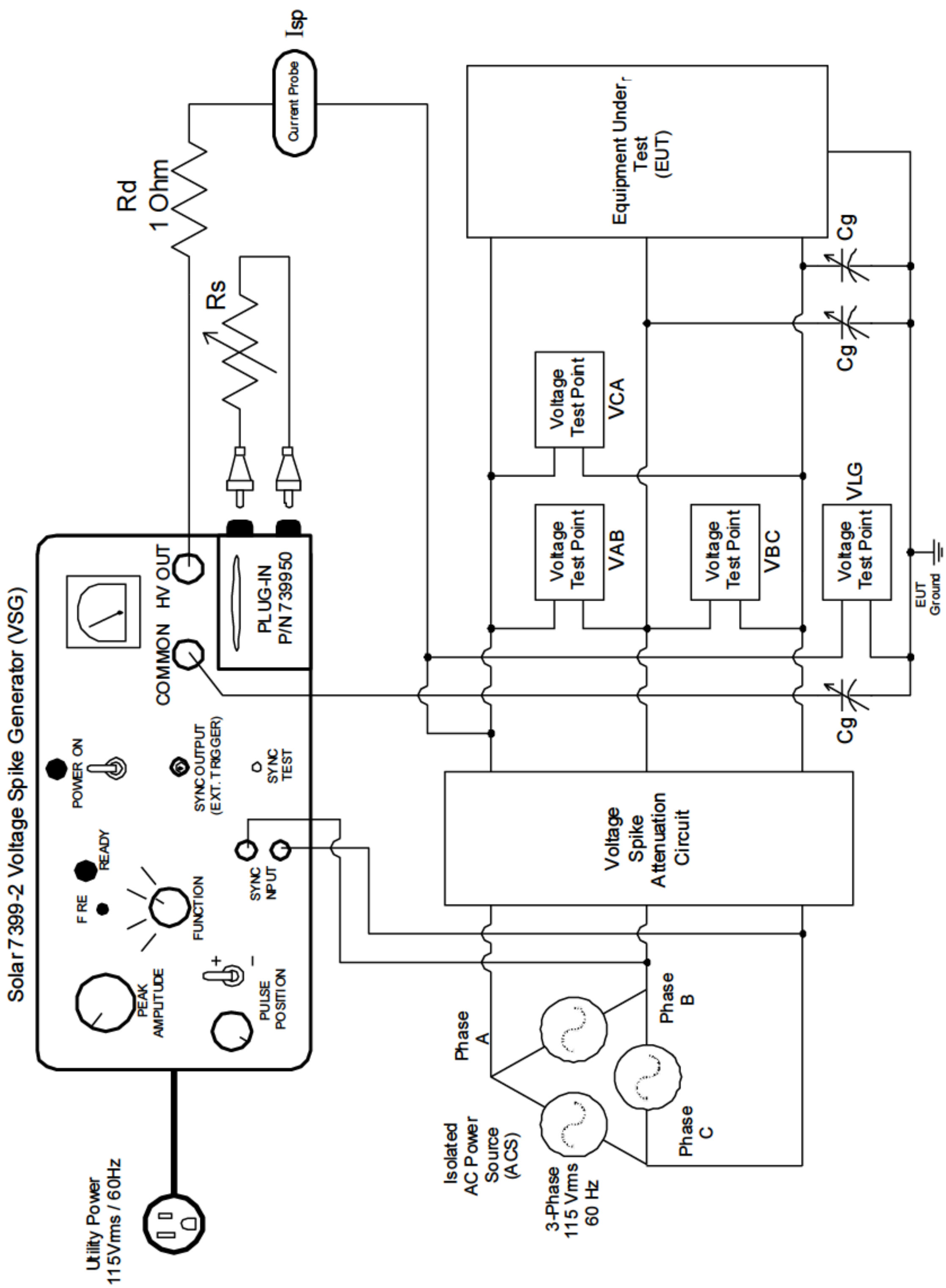
TABLE VI. Three-phase system voltage spike test conditions.

Spike Peak (Including Fundamental AC Voltage Waveform)	Conductor-To-Ground	Synchronization Angle	Polarity
2400- to 2500-V peak ($440\text{-}V_{rms}$ systems) or 900- to 1000-V peak ($115\text{-}V_{rms}$ systems)	Line A	0°	positive
		90°	positive
		0°	negative
		270°	negative
	Line B	0°	positive
		90°	positive
		0°	negative
		270°	negative
	Line C	0°	positive
		90°	positive
		0°	negative
		270°	negative



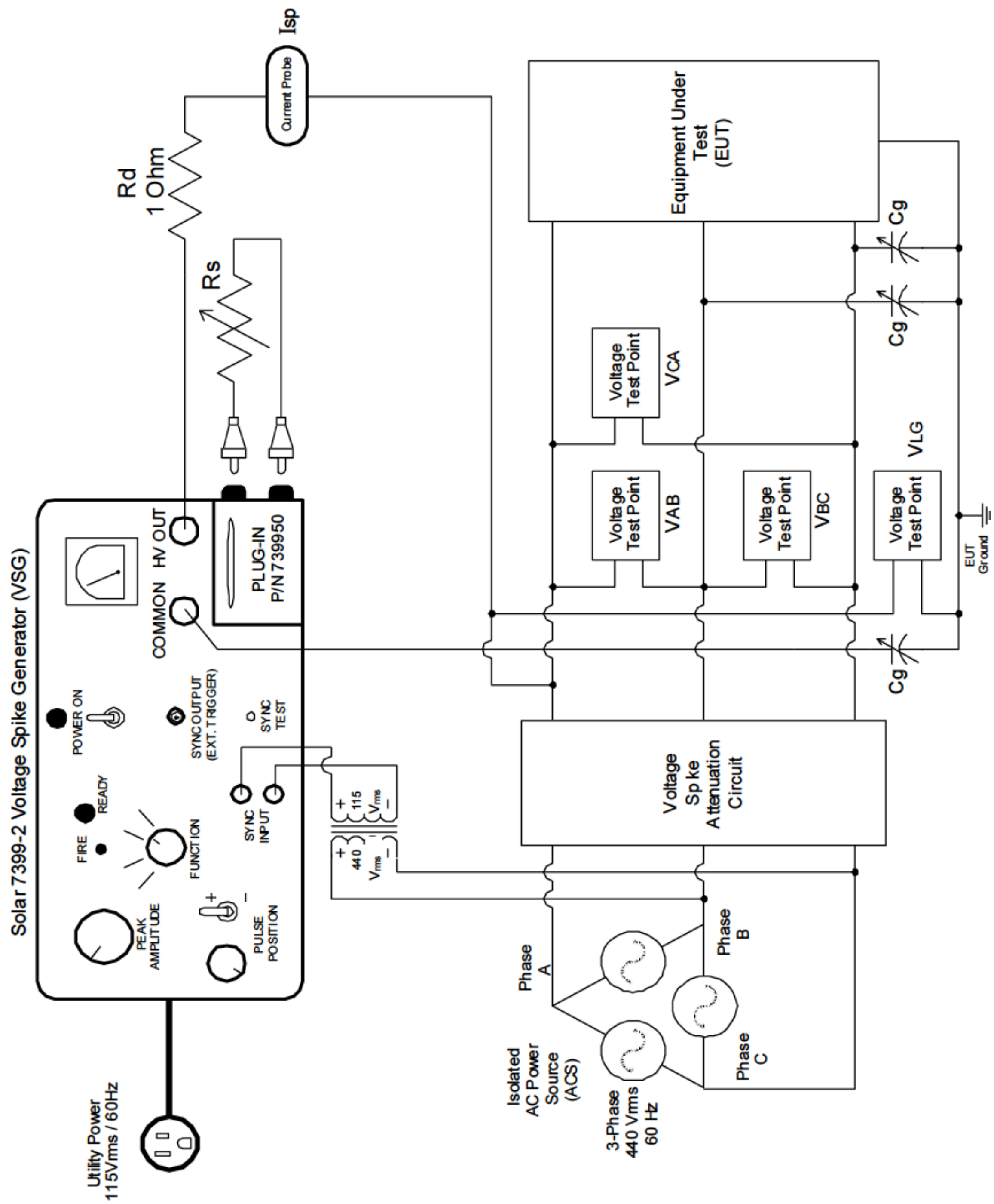
NOTE: 115-V_{rms} positive polarity black-to-ground test circuit is shown for illustrative purposes.

FIGURE 28. Single-phase, 115-V_{rms}, Type I power voltage spike test circuit configuration.



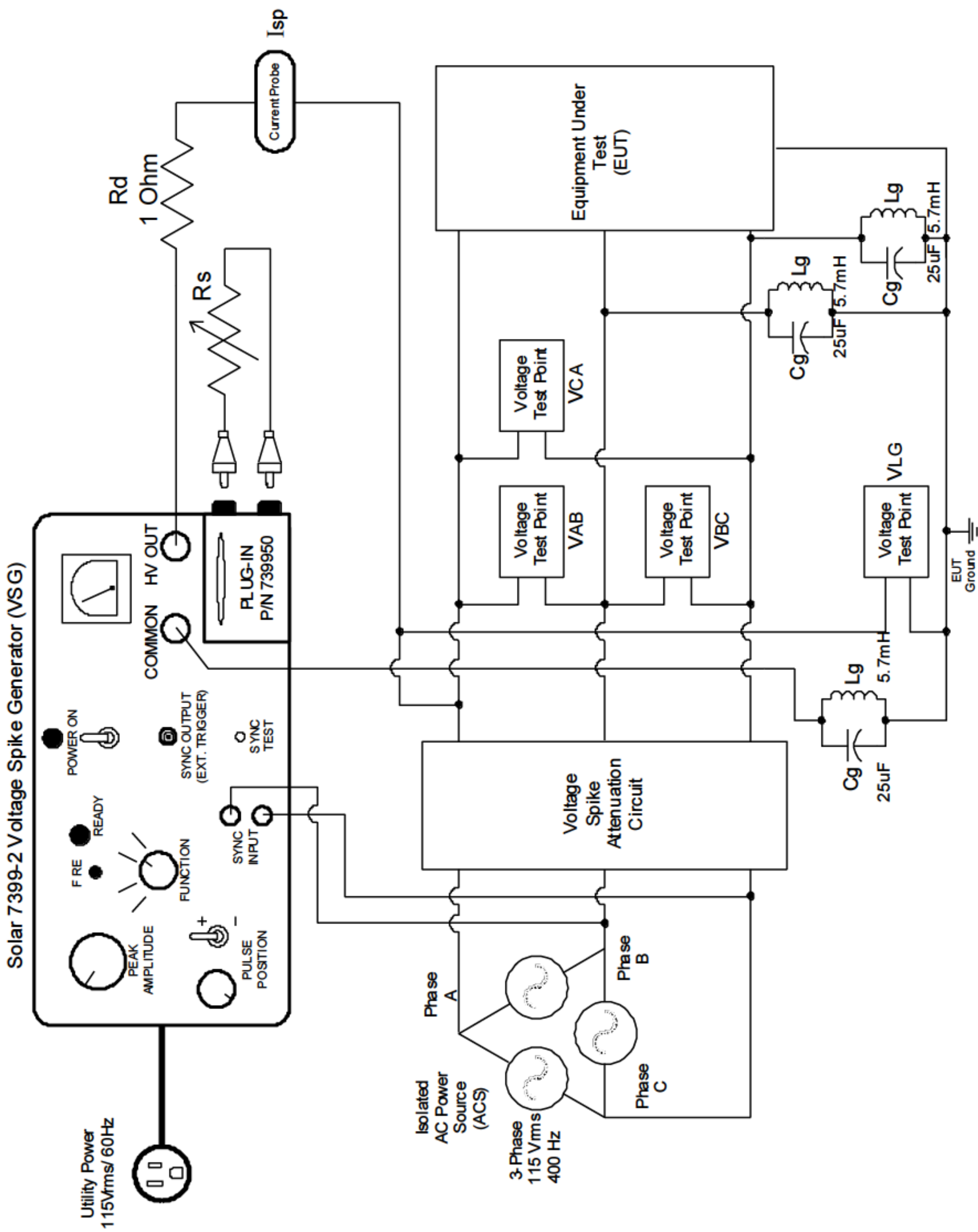
NOTE: Positive polarity Phase A-to-ground test circuit is shown for illustrative purposes.

FIGURE 29. Three-phase, 115-V_{rms}, Type I voltage spike test circuit.



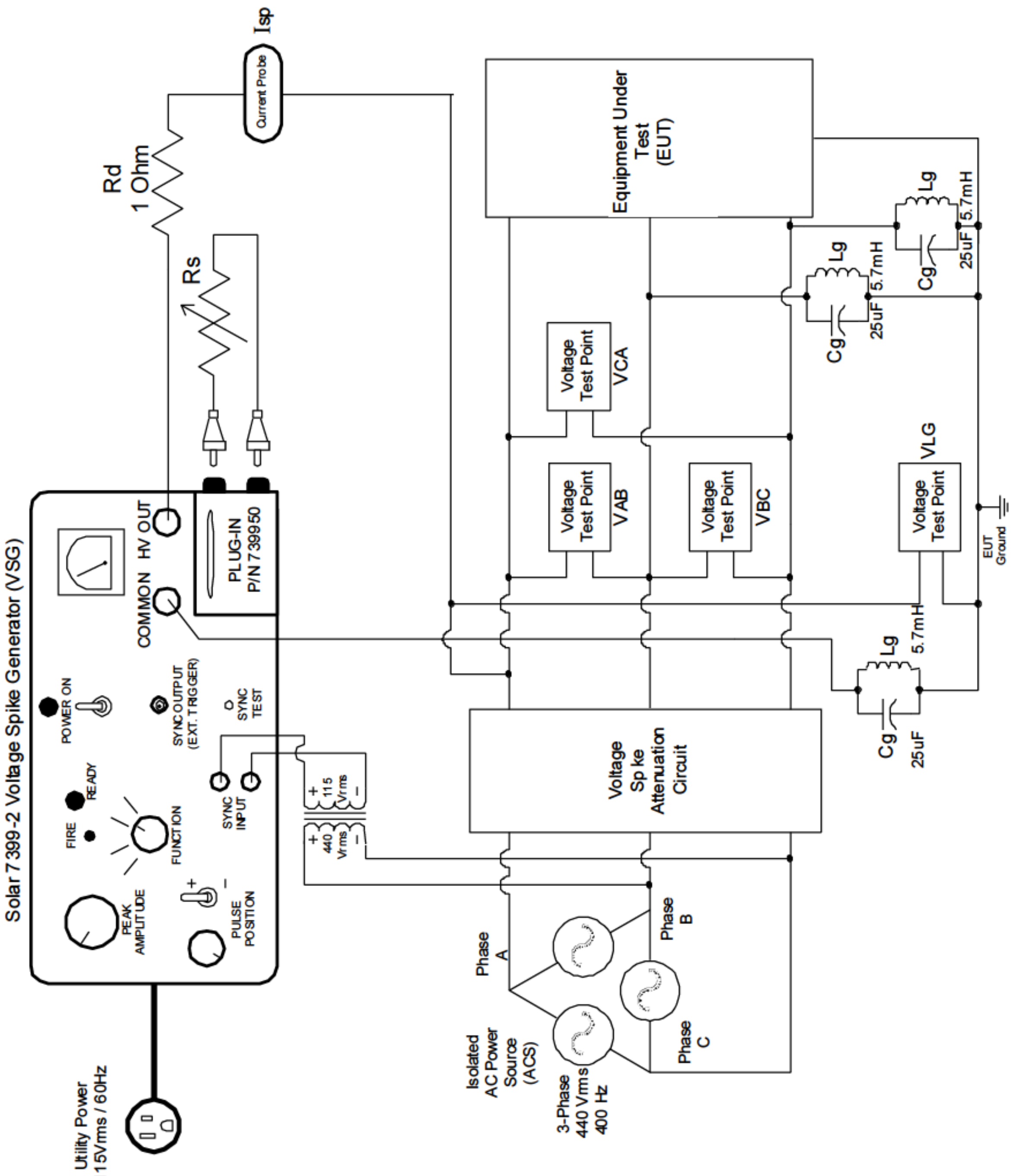
NOTE: Positive polarity Phase A-to-ground test circuit is shown for illustrative purposes.

FIGURE 30. Three-phase, 440-V_{rms}, Type I voltage spike test circuit configuration.



NOTE: Positive polarity Phase A-to-ground test circuit is shown for illustrative purposes.

FIGURE 31. Three-phase, 115-V_{rms}, Types II and III voltage spike test circuit configuration.



NOTE: Positive polarity Phase A-to-ground test circuit is shown for illustrative purposes.

FIGURE 32. Three-phase, 440-V_{rms}, Types II and III voltage spike test circuit.

5.3.6 Emergency conditions (susceptibility) test. The emergency conditions test is composed of the following subtests to evaluate EUT performance. This test shall be performed at normal operating load.

a. t_r power interruption subtest (simulated ABT/SABT).

b. t_s power interruption subtest (simulated power interruption due to emergency power reconfiguration).

c. Power source decay subtest (simulated loss of generator set prime mover).

d. Positive excursion subtest (simulated loss of generator voltage regulation).

5.3.6.1 Apparatus. The following apparatus is recommended for performing this test:

a. Power source of required capacity and range of voltage and frequency adjustments. A power source with a capability of having an independently programmable voltage and frequency output is recommended.

b. Voltmeters (true rms) – ±0.5-percent accuracy of reading.

c. Frequency meter – ±0.5-Hz accuracy of reading.

d. Storage oscilloscope having ≥500-kHz response per channel.

e. Current and potential transformers and probes as required.

f. Frequency to voltage transducer.

g. Temperature meter – ±0.5 °C accuracy.

5.3.6.2 Procedure. The EUT shall be operated in a normal operating mode and with the power input voltage and frequency within the user tolerance envelopes as shown on figures 10 through 16, as applicable, until the equipment temperatures have stabilized. Temperature stability shall be defined as when the variation between successive temperature measurements at the same location does not exceed 1 °C after a 30–minute period. Once the temperature is stabilized, all conditions of testing can be performed.

5.3.6.2.1 t_r power interruption subtest. If t_r is unknown, 70 milliseconds shall be used. The input power at nominal voltage and frequency shall be suddenly interrupted. After an interval no less than t_r, the input power shall be suddenly reapplied to nominal voltage and frequency. This power interruption shall be accomplished by switching the power at the power source and not by using the power switch or equivalent at the EUT. This cycle shall be repeated in all operating modes. Power source frequency, line voltage (one-phase), and line current shall be measured at the EUT power input terminals and recorded before the start and during each cycle. Equipment shall operate as specified in 5.2.3.

5.3.6.2.2 t_s power interruption subtest. If t_s is unknown, 2 minutes shall be used. After the EUT has been operated long enough to detect any performance degradation and with the equipment in normal operating mode, the power to the EUT shall be suddenly interrupted for an interval of t_s followed by the sudden reapplication of input power to the EUT. This power interruption shall be accomplished by switching the power at the power source and not by using the power switch or equivalent at the EUT. No manual intervention shall be allowed until the power is reapplied after the power interruption. This test shall be repeated in all operating modes. Equipment shall operate as specified in 5.2.3. Inrush current surges observed during power interruption tests shall be addressed as described in 5.2.11.

5.3.6.2.3 Power source decay subtest. The power source shall be modified as required to provide a voltage and frequency decay characteristic approximating that shown on figure 9 for the "Half-load on Generator" curve. With the EUT operating in one of the normal operating modes and with the power input voltage and frequency at nominal, initiate the power source output voltage and frequency decay characteristics specified above. The voltage and frequency shall follow the decay curves provided on figure 9 extrapolated down to 0. If the test equipment source frequency does not extend down to 0, lower the frequency to the 50-percent value or lower and de-energize the test equipment source. After the time specified in Item 23b of table II since the initiation of the decay characteristic has passed, the power source output shall immediately return to nominal voltage and frequency. Line voltage, line current, and frequency shall be measured and recorded before the initiation of and during the power source decay test. This test shall be repeated in all operating modes. Equipment shall operate as specified in 5.2.3.

5.3.6.2.4 Positive excursion subtest. Upon completion of the power source decay test, the EUT shall be subjected to the emergency conditions positive excursion tolerances specified in table II, Items 20 through 23, and duplicated in table VII. The EUT shall be operated in a normal mode with the power input voltage and frequency at nominal. The power input voltage shall be varied from nominal in accordance with the positive excursion limits and time duration specified in table VII. At the end of the excursion duration, the power input voltage shall be immediately returned to nominal voltage. Then the power input frequency shall be varied from nominal in accordance with the positive excursion limits and time duration specified in table VII. At the end of the excursion duration, the power input frequency shall be immediately returned to nominal frequency. Finally, the power input voltage and frequency shall be varied simultaneously from nominal in accordance with the positive excursion limits and time duration specified in table VII. At the end of the excursion duration, the power input voltage and frequency shall be immediately returned to nominal voltage and frequency. Line voltage, one line current, and frequency shall be measured and recorded before, during, and after each positive excursion test. Repeat the positive excursion test for each operating mode of the EUT. Equipment shall operate as specified in 5.2.3.

TABLE VII. Emergency conditions test.

Emergency Conditions	**Voltage Tolerance Percent of Nominal**	**Frequency Tolerance Percent of Nominal**
Maximum Excursion:	+35	+12
Duration - Type I power systems	2 minutes	2 minutes
Duration - Type II power systems	0.17 second	0.17 second
Duration - Type III power systems	0.17 second	0.17 second

5.3.7 Current waveform (emission) test. The MIL-STD-461 CE101 test shall be performed from just above the nominal input line fundamental frequency up to 20 kHz on the current waveform in the EUT power input lines for each operating mode, with the limits as shown on figures 22 through 25. The EUT shall be placed in an operating mode with load that produces maximum emissions. For EUTs with several available modes, a sufficient number of modes shall be tested for emissions such that all circuitry is evaluated. The harmonic current of the EUT shall be in compliance with the requirements in 5.2.10. A non-regulated power source shall be used for this test as regulated power source switching produces inconsistent current waveform data. Testing of equipment fed by a UPS shall be accomplished with the batteries drained from full voltage to 80-percent voltage to observe the effects of the battery charging circuit during the test; testing of equipment fed by a UPS shall also be performed with the UPS in bypass mode, if so equipped. The CE101 test results shall be provided as specified (see 6.2).

5.3.8 Voltage and frequency modulation (susceptibility) test. EUT performance shall be evaluated under the voltage modulation and frequency modulation conditions specified in table II, Items 2 and 9, and further expanded in table VIII (see 3.4.2 and 3.5.3). The periodicity of voltage modulation should be considered to be longer than one cycle time at nominal frequency and less than 10 seconds. The periodicity of frequency modulation should be considered as not exceeding 10 seconds. This test shall be performed at normal operating load.

TABLE VIII. Voltage and frequency modulation test.

	Voltage Modulation				Frequency Modulation			
	Limit (%)	**Nominal (V_{rms})**	**Minimum (V_{rms})**	**Maximum (V_{rms})**	**Limit (%)**	**Nominal (Hz)**	**Minimum (Hz)**	**Maximum (Hz)**
Type I, 3-phase	2 2	115 440	112.70 431.20	117.30 448.80	0.5	60	59.7	60.3
Type I, 3-phase, grounded	2	200	196.00	204.00	0.5	60	59.7	60.3
Type I, 1-phase	2 2	115 440	112.70 431.20	117.30 448.80	0.5	60	59.7	60.3
Type I, 1-phase, grounded	2	115	112.70	117.30	0.5	60	59.7	60.3
Type II, 3-phase	2 2	115 440	112.70 431.20	117.30 448.80	0.5	400	398	402
Type II, 1-phase	2 2	115 440	112.70 431.20	117.30 448.80	0.5	400	398	402
Type III, 3-phase	1 1	115 440	113.85 435.60	116.50 444.40	0.5	400	398	402
Type III, 3-phase, grounded	1	200	198.00	202.00	0.5	400	398	402
Type III, 1-phase	1 1	115 440	113.85 435.60	116.15 444.40	0.5	400	398	402
Type III, 1-phase, grounded	1	115	113.85	116.15	0.5	400	398	402

5.3.8.1 Apparatus. The following apparatus is recommended for performing this test:

a. Power source of required capacity and range of voltage and frequency adjustments. A power source with a capability of having an independently programmable voltage and frequency output is recommended.

b. Voltmeters (true rms) – ±0.5-percent accuracy.

c. Frequency meter – ±0.5-Hz accuracy.

d. Storage oscilloscope having ≥500-kHz response per channel.

e. Current and potential transformers and probes as required.

f. Temperature meter – ±0.5 °C accuracy.

5.3.8.2 Procedure. The EUT to be tested shall be operated in a normal operating mode within the user voltage and frequency tolerance band until the equipment temperatures have stabilized. Temperature stability shall be defined as when the variation between successive temperature measurements at the same location does not exceed 1 °C after a 30–minute period. Once the temperature is stabilized, all conditions of testing can be performed. The voltage and frequency modulation test produces a voltage and frequency modulation on the input waveform from nominal to within the modulation limits defined by table VIII for the applicable power type. The input voltage and frequency shall be varied separately and then simultaneously. The input voltage (at least two phases for three-phase power equipment), input line current (at least two line currents for three-phase equipment), and frequency shall be recorded before initiation of modulating voltage and frequency and continue throughout each test run. The following are the periods for the individual tests:

a. Voltage modulation test: With the frequency held constant at nominal, vary the voltage from minimum to maximum for periods of 50 milliseconds, 500 milliseconds, 1 second, and 10 seconds. Repeat each cycle of modulation ten consecutive times before moving to the next modulation period, starting at 50 milliseconds and ending at 10 seconds.

b. Frequency modulation test: With the voltage held constant at nominal, vary the frequency from minimum to maximum for periods of 50 milliseconds, 500 milliseconds, 1 second, and 10 seconds. Repeat each cycle of modulation ten consecutive times before moving to the next modulation period, starting at 50 milliseconds and ending at 10 seconds.

c. Combined voltage and frequency modulation test: Simultaneously vary the voltage from minimum to maximum and the frequency from minimum to maximum for periods of 50 milliseconds, 500 milliseconds, 1 second, and 10 seconds. Repeat each cycle of modulation ten consecutive times before moving to the next modulation period, starting at 50 milliseconds and ending at 10 seconds.

The EUT shall operate normally with no operational degradation during all test conditions to show compliance with this test. The recording quality shall be sufficient to show that the proper modulation limits were conducted.

5.3.9 Simulated human body impedance ground current test. This test measures the current that would flow through a simulated human body impedance in contact with the equipment enclosure if the equipment ground conductor is disconnected.

5.3.9.1 Apparatus. The following apparatus is recommended for performing this test:

a. Operational circuit configuration defined by figure 33 for single-phase systems, by figure 35 for single-phase systems derived from line-to-line of a three-phase wye and by figure 36 for three-phase systems.

b. Metering circuit defined by figure 37 for low or high frequency operation. Resistors and capacitors in the metering circuit should have tolerances of 10 percent.

c. Power source defined by the circuit configuration as either a single-phase center-tapped source or a three-phase wye source of required capacity determined by the EUT. The line voltage unbalance shall be less than 3 percent.

d. Voltmeter should be true rms of ±0.5-percent accuracy; the frequency response should be within measurement requirements.

e. Insulated probe, such as an oscilloscope probe.

5.3.9.2 Procedure. If the EUT consists of powered subassemblies, NAVSEA (see 6.4) will determine whether the subassemblies shall be separately tested using the applicable method for the type of electrical connections shown on figures 33 through 36. With power disconnected, place the EUT on an isolated surface. The EUT shall be isolated from any earth, power, or instrument ground. The following describe the test connections:

a. A single-phase EUT shall be connected as on figure 33 if it operates connected across one single phase (hot line-to-hot line of a single-phase source).

b. A single-phase EUT shall be connected as on figure 34 if it operates connected across one single phase (hot line-to-neutral line of a single-phase source).

c. A single-phase EUT shall be connected as on figure 35 if it operates connected across two phases (line-to-line of a wye source or line-to-line of a delta source).

d. A three-phase EUT shall be connected as on figure 36 if it operates connected across three phases (line-to-line-to-line of a wye or delta source).

The appropriate metering circuit shall be used for the intended frequency range, shown on figure 37. Every mode of operation at operating load shall be tested. The current shall be determined by measuring the voltage drop across the measuring circuit. The voltage measured across the measuring circuit, when equal to 1.0 V_{rms}, represents 2.0 milliamperes of current. The overall measurement error shall not exceed 5 percent. The current limits are identified in 5.2.5.1 for low frequency and 5.2.5.2 for high frequency. Where there is risk for current paths to any control or external surface component, the insulated probe shall be used on all control or external surface components such as case, connector housings, recessed calibration or adjustment controls, and control shafts with knobs removed.

5.3.9.3 Method of test.

WARNING: This test may be hazardous due to the ungrounded condition of the EUT during the test. Do not touch exposed metal surfaces.

a. Determine the applicable configuration from figures 33, 34, 35, or 36 for the EUT.

b. The power source shall be de-energized. Connect the EUT as in the applicable figure utilizing the low or high frequency metering circuit as required. Leave the power source unconnected.

c. Place the EUT ON-OFF switch in the OFF position.

d. Place the SAFETY GROUND switch in the CLOSED or GROUND position.

e. Connect and energize the power source.

f. Observe the WARNING. Place the SAFETY GROUND switch in the OPEN or UNGROUNDED position.

g. Place the EUT ON-OFF switch in the ON position.

h. Record the voltmeter reading.

i. Place the EUT ON-OFF switch in the OFF position.

j. Place the SAFETY GROUND switch in the CLOSED or GROUND position.

k. Repeat steps f through j for each and every mode of operation.

NOTES:

1. The safety ground conductor shall not carry load current.

2. Tests for delta loads shall use a wye power source providing balanced line-to-line open circuit voltages with a voltage unbalance characteristic of 3 percent or less.

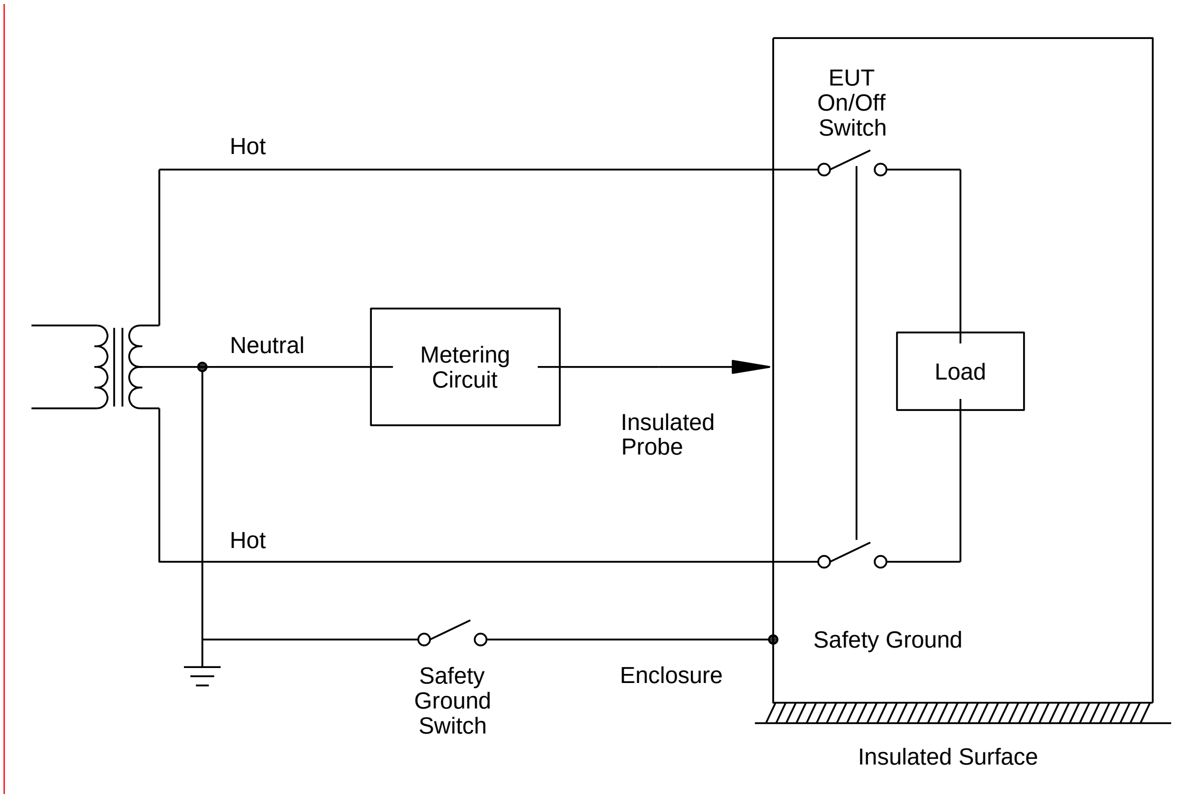


FIGURE 33. Single-phase simulated human body impedance ground current test setup if the EUT is connected to one single-phase voltage source from (hot) line to (hot) line.

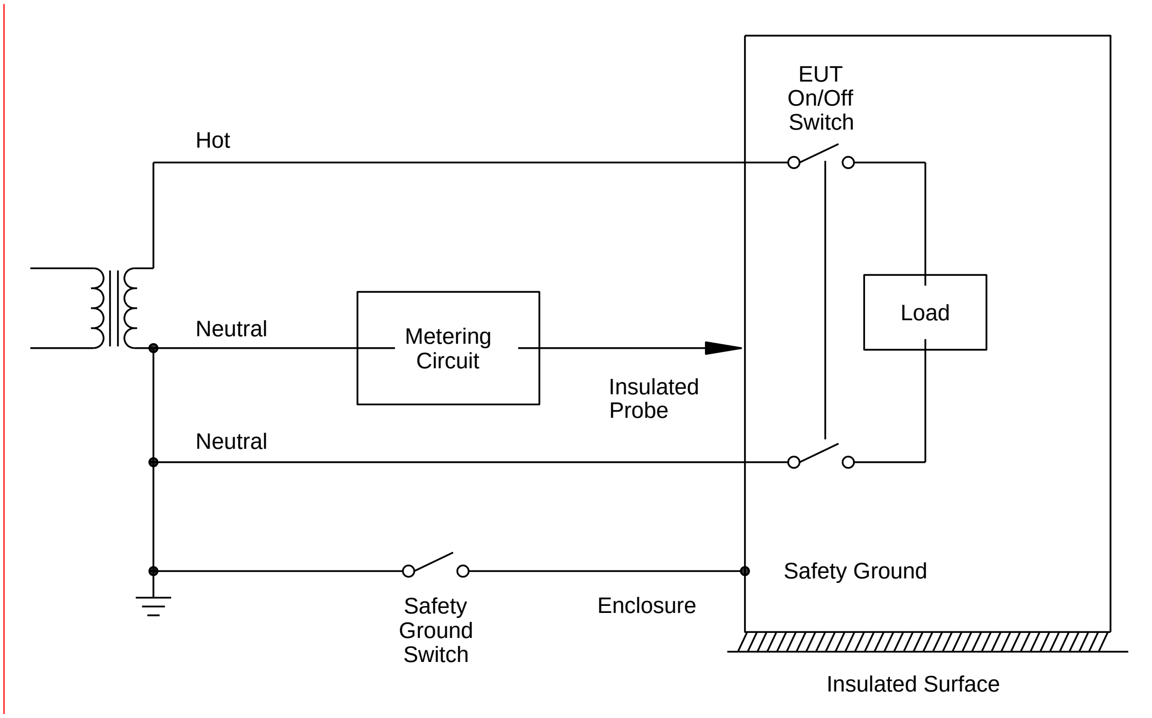


FIGURE 34. Single-phase simulated human body impedance ground current test setup if the EUT is connected to one single-phase voltage source from (hot) line to (neutral) line.

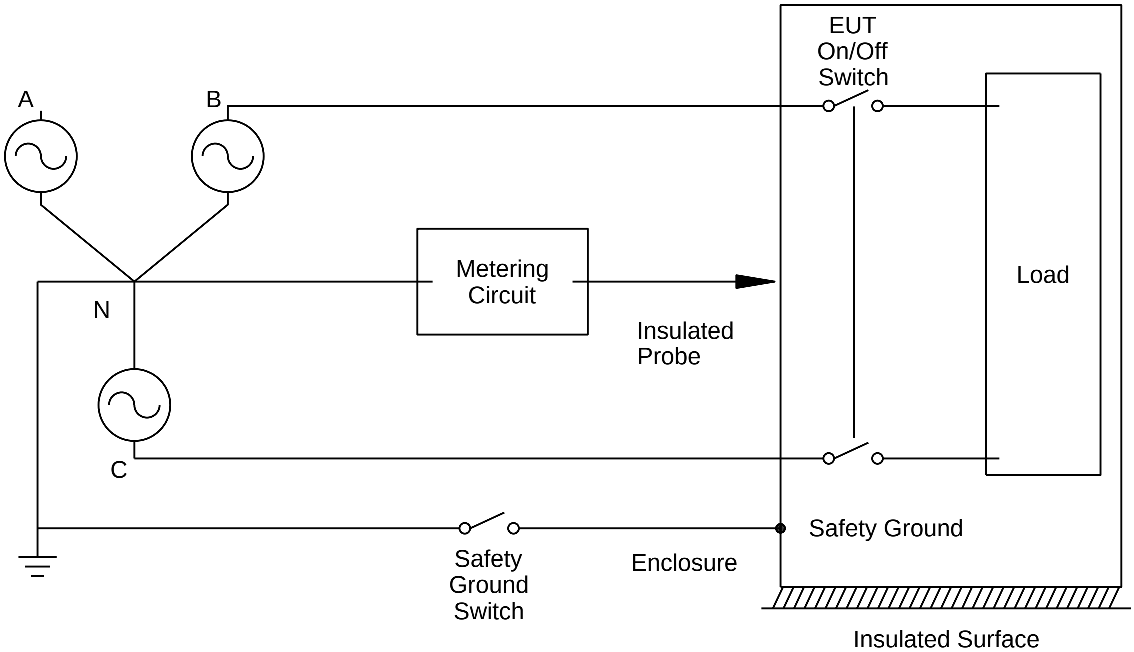


FIGURE 35. Single-phase simulated human body impedance ground current test setup if the EUT is connected to one single phase of a three-phase voltage source.

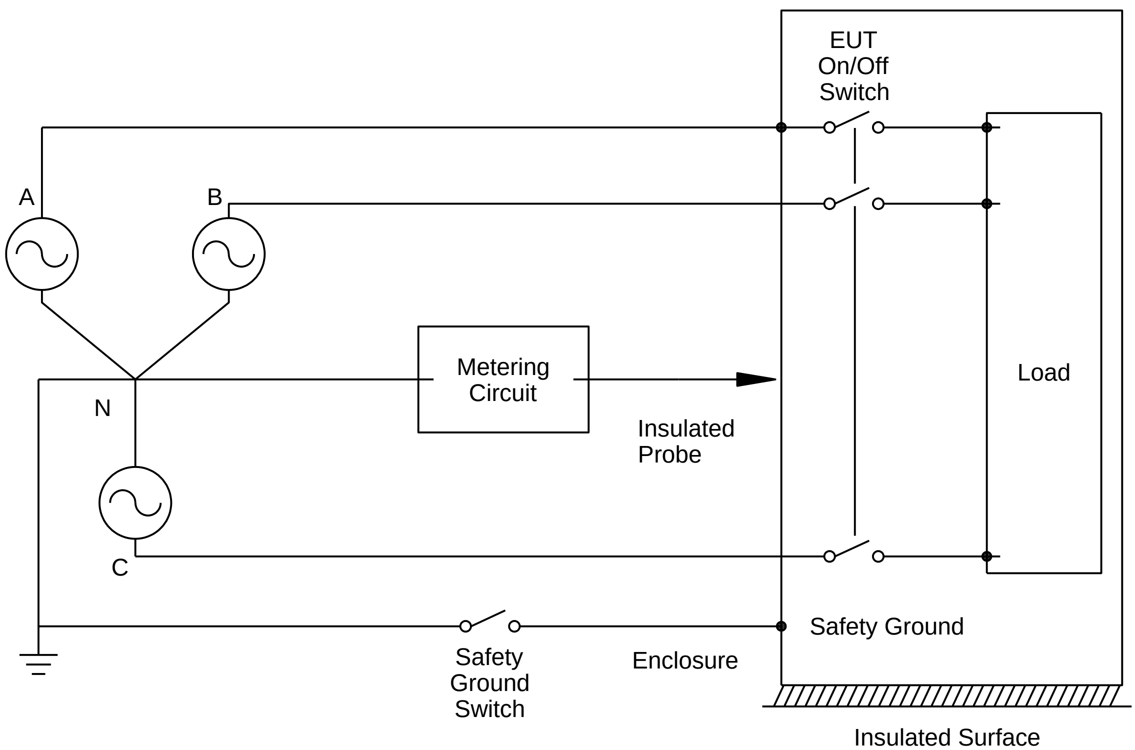


FIGURE 36. Three-phase simulated human body impedance ground current test setup if the EUT is connected to a three-phase voltage source.

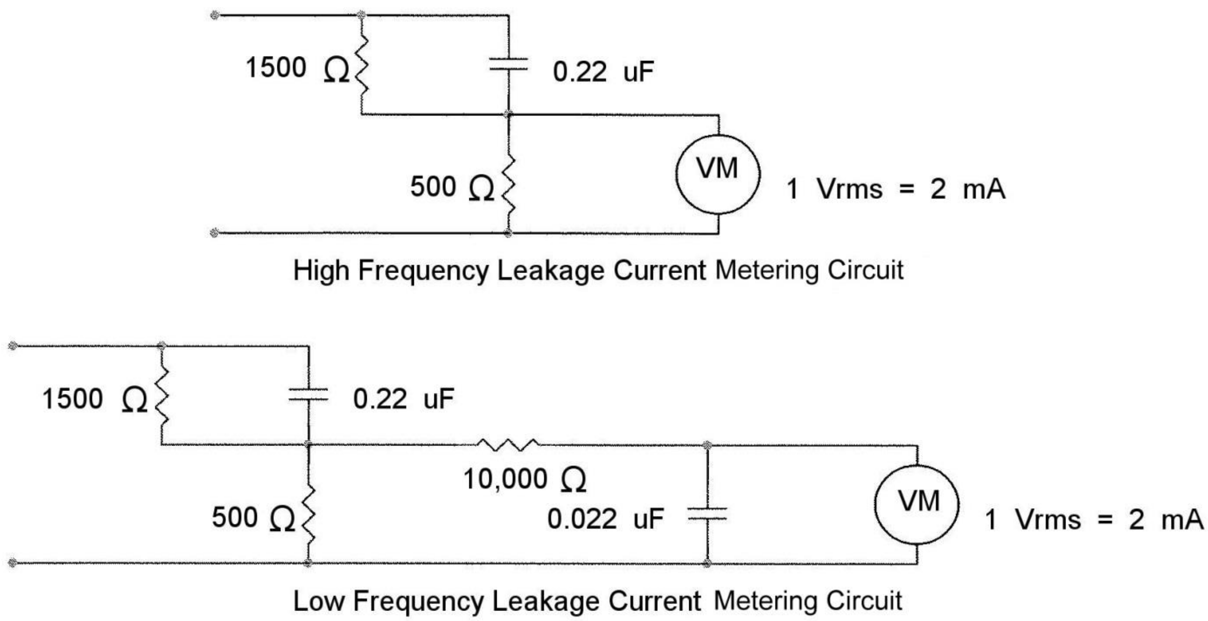


FIGURE 37. Metering circuits for high and low frequency simulated human body ground current tests.

5.3.10 Equipment line-to-ground voltage (susceptibility) test. User equipment to be installed aboard ship shall be subjected to a voltage withstand test to determine input line resistance to ground. User equipment to be installed on ships with an AGD shall also be subjected to an AGD test.

5.3.10.1 Megohmmeter test. With the input power disconnected, use a megohmmeter insulation tester (megger) to conduct an insulation resistance test at 150 VDC for user equipment rated at 115 V_{rms} and at 500 VDC for user equipment rated above 115 V_{rms}. With the EUT enclosure grounded, the test shall be conducted on the EUT between each power conductor and ground for a minimum period of 60 seconds after the reading stabilizes for each conductor. The EUT shall tolerate the 150-VDC or 500-VDC level without equipment damage, arc-over, or degradation. This test shall be performed with (filter) components connected line-to-ground to determine the voltage withstand capability and insulation resistances. The resistance to ground level as measured with the megohmmeter shall be equal to or greater than 10 megohms (see 5.2.12).

5.3.10.2 AGD test. This voltage withstand test is conducted to determine an EUT's tolerance to a worst case line-to-ground voltage. This voltage will consist of a DC voltage applied from line-to-ground on the line-to-line AC voltage supply. The AC line-to-line voltages shall include an upper tolerance factor of 1.08 and an upper transient tolerance factor of 1.20. The AGD DC voltage, V_{AGD} on figures 38 and 39, shall include an upper tolerance factor of 1.12, an unfiltered factor of 1.57, and an unregulated factor of 1.20. Do not disconnect any line-to-ground components as this circuitry is being tested for robustness. The user equipment shall tolerate the combined AC and DC voltage stress without equipment damage, arc-over, or degradation during this period. No abnormal operation of the user equipment during or after the test shall be permitted.

a. Figures – For a three-phase EUT, as shown on figure 38, the EUT shall be connected to an isolated, ungrounded, three-phase AC source. For a single-phase EUT, as shown on figure 39, the EUT shall be connected to an isolated, ungrounded, single-phase AC source. In both figures, a DC source shall be connected with the positive terminal through a resistance, R_{AGD}, to ground, and the negative terminal through a switch, S, to an AC line. R_{AGD} shall be 50 kohm, 10 W, 5-percent tolerance. An equipment ground shall be run from the EUT to ground.

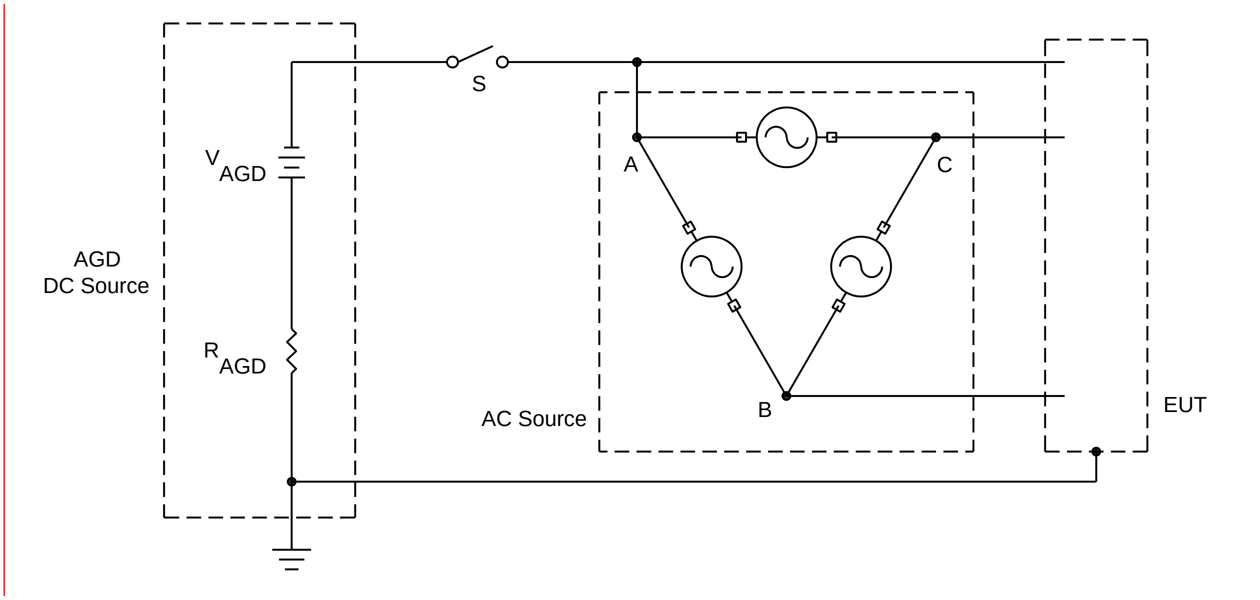


FIGURE 38. AGD test circuit for three-phase EUTs.

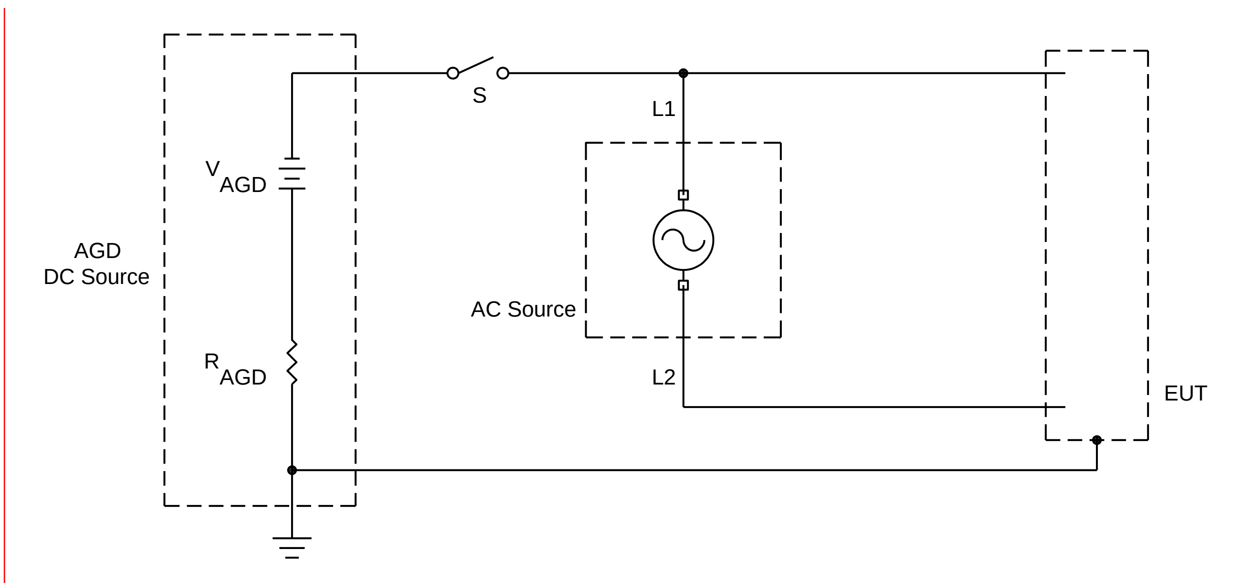


FIGURE 39. AGD test circuit for single-phase EUTs.

b. Test voltages for Type I systems:

For a 440-V_{rms} EUT, the AC source voltage shall be:
$440 \times 1.08 \times 1.20 = 570\ V_{rms}$
The DC source voltage shall be:
$500 \times 1.12 \times 1.57 \times 1.20 = 1055$ VDC

For a 115-V_{rms} EUT, the AC source voltage shall be:
$115 \times 1.08 \times 1.20 = 150\ V_{rms}$

The DC source voltage shall be:

$150 \times 1.12 \times 1.57 \times 1.20 = 317$ VDC

c. Procedure – To conduct the test, the EUT shall be energized for normal operation. Then the DC source shall be energized and the switch, S, shall be closed for 3 minutes. Record the EUT operation. The line-to-ground voltage shall be measured and recorded with an oscilloscope for the AC and DC components. Then the switch, S, shall be opened. De-energize the DC source. Record the EUT operation. Then de-energize the EUT.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use. This standard is intended to be used in designing surface ship and submarine low voltage AC electrical power systems and in designing and testing user equipment.

6.2 Acquisition requirements. Acquisition documents should specify the following:

a. Title, number, and date of this standard.

b. The approval authority for testing, if necessary (see 4.2).

c. Requirements for deviations, waivers, and tailoring requests (see 4.4 and 6.4).

d. Values for t_r and t_s for MCE (see 5.2.3.1).

e. Requirements for repetitive pulsed loads for pulsed loads with peak-to-peak real pulsed power greater than 25 percent of the minimum prime mover real power rating or greater than 2 MW (see 5.2.8.1.2.1 and 5.2.8.1.2.2.a).

f. Requirement for a listing of the modified algorithm used to perform the DFT, if the algorithm differs from Appendix A (see 5.2.8.1.2.2.b).

g. Loads judged to greatly distort the current and, in turn, the voltage waveform due to large size or unusual operation should have requirements set on a current THD requirement of 5 percent, similarly as defined by the voltage THD in 3.5.10.3. This requirement should be placed in the purchase specifications (see 5.2.10).

h. Report of results derived from tests listed in 5.3.

(1) Create test procedures by tailoring the current version of DI-EMCS-80201 so requirements 1 through 2.2; 2.4.a; 2.6.a, b, e, and f; and 2.7.b, c, and e are used, substituting “interface” for “EMI” and MIL-STD-1399-300-1 as the applicable military standard.

(2) Create test procedures by tailoring the current version of DI-EMCS-80200 so requirements 1 through 2.2.a, b, f, g, i, m, and o and 2.3 are used, substituting “interface” for “EMI” and MIL-STD-1399-300-1 as the applicable military standard.

i. Requirements for CE101 test results (see 5.3.7).

j. If the equipment is mission critical.

6.3 Subject term (key word) listing.

Delta- and wye-connected systems

Frequency decay

Leakage current

Power factor

Transient limits

Worst case frequency excursion

6.4 Deviation, waiver, and tailored requirement requests. Requests for deviations, waivers, and tailored requirements are to be submitted for approval to the NAVSEA Technical Authority for ship electrical power systems (NAVSEA 05Z32).

6.5 Changes from previous issue. Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extent of the changes.

POWER RIPPLE ANALYSIS PROCEDURE

A.1 SCOPE

A.1.1 Scope. The power ripple analysis requires digital signal processing. This section provides a step-by-step guide to performing the analysis, along with example code that will execute the necessary calculations when provided a power waveform signal and sampling period. There is also a section titled “Additional DFT Notes” (see A.6) that may be useful to someone new to DFT analysis. This Appendix is not a mandatory part of the standard. The information contained herein is intended for guidance only.

A.2 PROCEDURE

The power ripple analysis procedure is as follows:

Step 1. Collect 100 seconds of the instantaneous power waveform sampled at 4 kHz or greater. It is recommended to keep the sampling frequency below 50 kHz to keep the memory usage of the computer reasonable during the DFT calculation. It is assumed that an even number of samples are taken, which will have an effect on the Nyquist-frequency bin location in later steps.

Step 2. Compute the average value of the 100-second sampled signal and subtract this average value from the signal prior to performing the DFT. Keep the average power for later use.

Step 3. Generate the 100-second long Kaiser window (beta = 7) and calculate the coherent gain (CG) and equivalent noise bandwidth (ENBW). CG and ENBW can be calculated with the following equations:

$$CG = \sum_{n=0}^{N-1} w(n)$$

$$ENBW = N \frac{\sum_{n=0}^{N-1}(w(n)^2)}{(\sum_{n=0}^{N-1} w(n))^2}$$

Where N is how many samples long the window is and w is the values of the Kaiser window. Note that the ENBW includes zero padding in the number of samples, N, while the CG does not include zero padding.

Step 4. Sample multiply the 100-second long power waveform by the window function and divide by the CG of the window, which corrects the DFT output amplitude error due to the gain of the windowing function and the window length, N. Add zero padding, equal to nine times the length of the signal, after the windowing function is applied. If using the Fast Fourier Transform (FFT) for faster computations, zero padding can be added such that the new total signal length (including zero padding) is a power of two and at least ten times longer than the original signal length.

Step 5. Perform the DFT with the necessary zero padding and take the absolute value for each frequency component. For real signals, because the negative frequencies have the same information as the positive frequencies, multiply all the amplitudes of the positive frequency components (except 0 Hz and the Nyquist frequency, bins 0 and N/2) by two to achieve the proper amplitude.

Step 6. All negative frequency components may be discarded.

Step 7. The sampling frequency is f_s. The bin frequency spacing is f_s/N, where N includes zero padding. The bin numbers are now 0 to N/2, where N includes zero padding. With only the positive frequencies present, convert the bin numbers to frequencies by multiplying the bin numbers by f_s and dividing by the total number of samples, N, where N includes zero padding.

Step 8. Save the spectrum from 0.01 Hz to 1 Hz. The higher frequencies will be determined from the 4-second rolling window.

Step 9. Perform multiple DFTs on the 100-second time-domain signal by using a rolling 4-second window, whereby each subsequent 4-second window will have 75 percent overlap with the preceding window (shift the window by 1 second each time). Adjust the amplitudes as done for the 100-second DFT to account for windowing, the sample number, and the negative frequency components from steps 3 through 6. Remove the average value of each 4-second window of data before taking the DFT. Record the results of each 4-second DFT calculation.

Step 10. Record the maximum amplitude at each frequency bin across all 4-second rolling-window DFTs from the above step. These maximums will represent the DFT results for frequencies from 1 Hz to 2 kHz. This is similar to a “Max Hold” function on a spectrum analyzer.

Step 11. Perform a TSD calculation on each separate 4-second rolling window DFT from step 9 above. The maximum TSD of all 4-second rolling-window DFTs is to be the reported TSD value to be compared against the 5 percent requirement. In this case, including a value for the equivalent noise bandwidth correction term, the equation for TSD is:

$$TSD = \frac{\sqrt{P_k^2 + P_{k+1}^2 + P_{k+2}^2 + \cdots + P_n^2}}{\sqrt{2 \cdot \mathrm{ENBW}} \cdot P_{av}}$$

Where P_k is the 1-Hz bin, P_n is the 2-kHz bin (if 2 kHz is the Nyquist frequency, ending at the preceding bin is acceptable), ENBW is the equivalent noise bandwidth of the DFT window, and P_{av} is the average power calculated over the entire 100 seconds of power waveform data.

Step 12. Normalize all DFT results by dividing by P_{av}, the average value over the 100 seconds of power waveform data calculated in step 2.

Step 13. Combine the 0.01 Hz to 1 Hz DFT results from the 100-second window with the 1 Hz to 2 kHz DFT data from step 10. This is the final data to be reported and compared against the power ripple frequency requirement.

A.3 TEST EQUIPMENT SETTINGS

Test equipment settings are as follows:

A.3.1 Instrument accuracy. The combined full-scale accuracy of the measuring instrument and full-scale accuracy of the measuring probes should be better than 3 percent.

a. Errors in the full-scale measurement will primarily result in gain and offset errors in the measured amplitudes and error in the subsequent total signal distortion (TSD) results. This is separate from resolution, which must have higher precision.

b. Assuming all error in the measurement is due to gain and offset errors (i.e., negligible nonlinearity of the measuring instrument and probe), this results in a reported DFT amplitude accuracy of ±0.1 percent. For example, if a power ripple frequency exists at 3 percent of the average power, the reported amplitude will be between 2.9 and 3.1 percent.

A.3.2 Digitizer resolution. The digitizer of the measuring instrument should have at least 10 effective bits of resolution.

a. The resolution is needed to accurately capture the power dynamics as well as define the maximum noise floor.

b. 10 effective bits of resolution provides approximately 0.1 percent resolution.

A.3.3 Measurement skew. The skew between all simultaneous measurements, at all required frequencies, should be less than 15 microseconds (~11 degrees at 2 kHz).

a. When two sine waves separated by 11 degrees are multiplied (i.e., voltage and current), the resulting sine wave (i.e., power) has an amplitude within 0.2 percent of the two original sine wave amplitudes being multiplied together (no phase shift).

A.3.4 Anti-aliasing filters. Proper anti-aliasing filters should be used to prevent energy at frequencies higher than the Nyquist frequency from being folded into the frequency spectrum of interest.

a. This also drives the minimum sampling frequency of the measurement equipment, such that there is sufficient room between the maximum measured frequency component and the Nyquist frequency for the anti-aliasing filter to reach the desired attenuation level.

A.4 RECOMMENDED EQUIPMENT

A.4.1 Dranetz HDPQ Guide.

a. Source information: http://www.dranetz.com/product-services/current-dranetz-products/dranetz-hdpq-guide/, or equal.

b. This can capture and store 10,000 60-Hz cycles of data (166 seconds of data at a 32.5-microsecond sample rate), which has a fixed configuration of eight channels (four voltage, four current). It has internal 4GB memory with universal serial bus (USB), Ethernet, and wireless connections to retrieve data. One of the channels could be used to trigger the 100-second recording event.

A.4.2 Yokogawa PX8000.

a. Source information: https://tmi.yokogawa.com/solutions/products/digital-power-analyzers/digital-power-analyzers/px8000-precision-power-scope/, or equal.

b. The base model can capture 10 million samples per channel with a maximum sample rate of 100 million samples per second (e.g., 200 seconds of data at a 20-microsecond sample rate), which is configurable up to eight channels. It has secure digital (SD) card and USB mass storage device support, as well as Ethernet, GP-IB, and USB communications support to retrieve data. There are numerous triggering options, including remote single-shot manual trigger for the 100-second recording event.

A.5 EXAMPLE CODE

A.5.1 MATLAB functions. The following example could be performed with any suitable analysis software. MATLAB software was chosen due to its wide use in industry. The following code provides working MATLAB functions that will execute the above steps and plot the results. There are two functions. The first, powerDFT, is a support function that executes the actual DFT given a power waveform signal, sampling period, window length (in seconds), and overlap percentage. The second, powerRippleAnalysis, provides the parameters to the first function and pieces together the different parts of the DFTs, as well as calculating TSD. To aide in the understanding of the code, a script is provided that comes with a test signal and calls the powerRippleAnalysis function.

A.5.2 MATLAB function usage. To use the code, save each function and script in a common directory. Use the name powerDFT.m for the first function, powerRippleAnalysis.m for the second function, and example m for the short test script. To test the code, run example.m, and MATLAB will output two graphs in a single figure as shown on figure A-1 (a time domain of the test signal and the DFT output of the test signal with the corresponding calculated TSD).

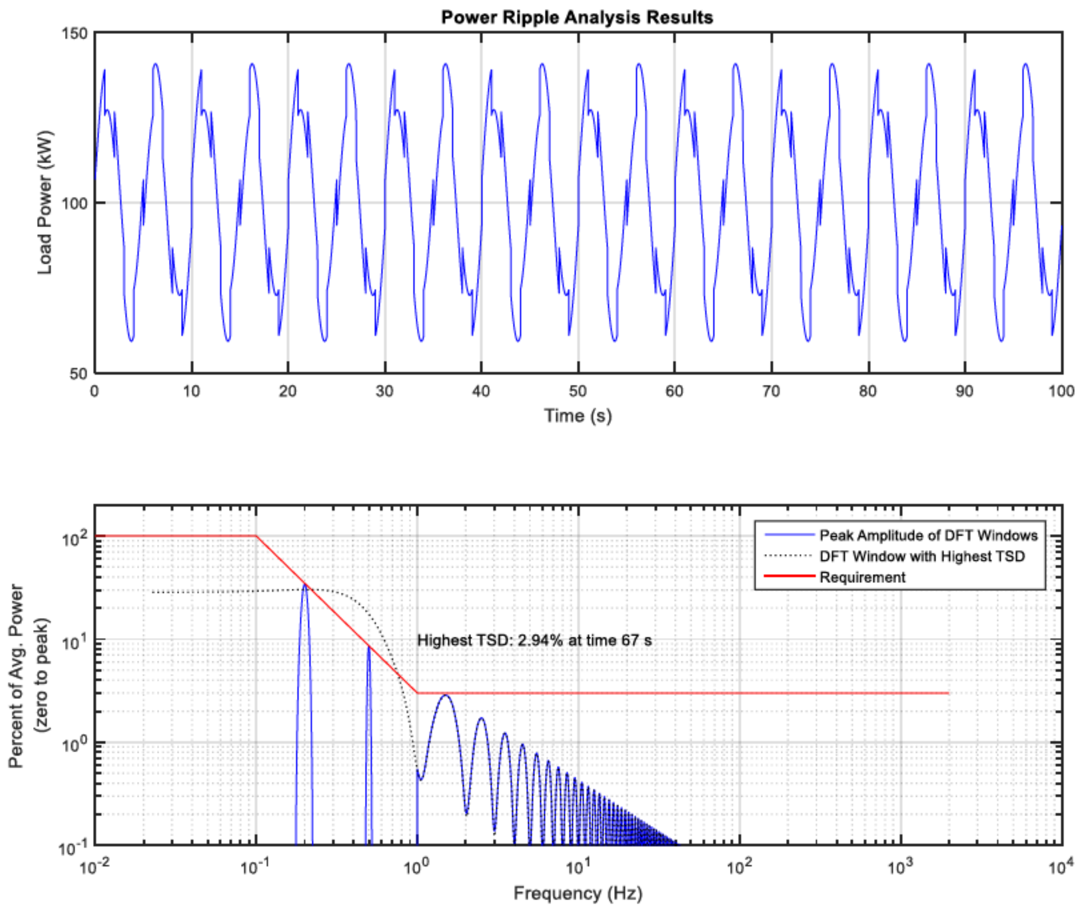


FIGURE A-1. MATLAB output - time domain test signal with corresponding DFT with TSD results.

A.5.3 MATLAB Function powerDFT.m.

```
function [ frequency, DFT, Pavg, ENBW ] = powerDFT( P, Ts, windowLength,
overlapPercent )
%powerDFT - outputs the results of the DFT process used for the
%MIL-STD-1399-300-1 power ripple requirement. This is a support function
%that is called from powerRippleAnalysis(). Please use powerRippleAnalysis
%for evaluating against the power ripple requirement.

    % Convert window length to the number of samples
    N_win = round( windowLength / Ts );
    % How much zero padding to add in multiples of the length of data, plus
    % one for the original data length
    zeroPadMultiplier = 9 + 1;
    % Define the length of the DFT that will be run. Make sure it's even.
    NDFT = round(N_win*zeroPadMultiplier);
    if ( mod(NDFT,2) )
        NDFT = NDFT + 1;
    end
    % If faster speed is desired, increase NDFT to the next power of 2 so
```

```
    % that the Fast Fourier Transform algorithm can be used
    NDFT = 2^nextpow2(NDFT);
    % Define the number of samples the DFTs slide between windows
    FFTslide = round( (1 - overlapPercent/100) * N_win );
    % Define the number of DFTs to run
    N = floor( (length(P)-N_win)/FFTslide ) + 1;

    % Create the Kaiser window of length N_win with Beta = 7
    beta = 7;
    % same as kaiser(NDFT,beta)
    n = 0:(N_win-1);
    win = besseli( 0, beta*sqrt(1-(2*n/(N_win-1)-1).^2) )';
    % Calculate the Coherent Gain of the window
    CG = sum(win);
    % Calculate the Equivalent Noise Bandwidth of the window
    ENBW = sum(win.^2)/sum(win)^2 * NDFT;

    % Initialize arrays
    DFT  = zeros(N,NDFT/2);
    Pavg = zeros(1,N);

    % Calculate the DFTs
    for i = 1:N
        % Where to start and end the DFT within P
        iStart = 1 + (i-1)*FFTslide;
        iEnd = iStart + N_win - 1;

        % Grab the part of the waveform we want
        X = P(iStart:iEnd);
        % Find the average value
        Pavg(i) = mean(X);
        % Subtract the average before running the DFT
        X = X - Pavg(i);
        % Perform the DFT with a window length of NDFT
        Y = fft( X(:) .* win/CG, NDFT);

        % We only want positive frequencies, but the DFT creates both
        % positive and negative frequencies with half amplitude of a purely
        % real input. This corrects for the half amplitude. The zeroth bin
        % for the DFT does not need to be doubled. We also do not want the
        % complex values, but the absolute values. The Nyquist bin is
        % thrown out.
        DFT(i,:) = [abs(Y(1)) 2*abs(Y(2:(NDFT/2))')];
    end

    % Generate the frequency vector for the DFTs.
    % f = (bin number)*(sampling frequency) / (DFT length with zero padding)
    frequency = ( 0 : NDFT/2-1 ) * (1/Ts) / NDFT;
end
```

A.5.4 MATLAB Function powerRippleAnalysis.m.

```
function [ f_final, DFT_final, TSD_max ] = powerRippleAnalysis( P, Ts )
%powerRippleAnalysis - Calculates and plots the DFT analysis for the
%                      MIL-STD-1399-300-1 power ripple requirements.
%-
%   Usage:
%   [ f_final, DFT_final, TSD_max ] = powerRippleAnalysis( P, Ts )
%-
%   Input:
%   P is the input power waveform and Ts is the sampling rate. It is
%   recommended to downsample the power waveform to under 20 kHz in order
%   to keep the memory usage to a reasonable amount (~1 GB at 20 kHz for
%   100 seconds).
%-
%   Output:
%   f_final is the pieced-together frequency bins from the 100-s DFT and
%   the 5-s DFT windows. DFT_final is the pieced-together DFT outputs from
%   the 100-s DFT (<1 Hz) and the maximum for each frequency across all 5-s
%   DFTs (>=1Hz). TSD_max is the maximum TSD of any single 5-s DFT.

    % Define the window length in seconds
    windowLength = 5;
    % Define the overlap percentage
    overlapPercent = 80;
    % Create a time vector
    time = ( 0:(length(P)-1) ) * Ts;

    % Run the DFT analysis with the long window
    [f_long,DFT_long,Pavg_long,ENBW_long] = powerDFT(P,Ts,time(end)+Ts,0);
    % Run the DFT analysis with the rolling short window
    [f, DFT, Pavg, ENBW] = powerDFT(P, Ts, windowLength, overlapPercent);

    % Calculate the 1-Hz bin indexes
    index1Hz_long =  ceil( 1.0 * Ts * (length(f_long)-1)*2 + 1 );
    index1Hz      = round( 1.0 * Ts * (length(f)-1)*2 + 1 );
    % Find the bin number for 2 Hz in the rolling DFT outputs
    index2kHz     = round( 2e3 * Ts * (length(f)-1)*2 + 1 );
    % If 4-kHz or lower sampling rate is used, use the last non-Nyquist bin
    if (index2kHz > size(DFT,2))
        index2kHz = size(DFT,2);
    end

    % Initialize array
    TSD = zeros(1,size(DFT,1));
    for i = 1:size(DFT,1)
        % Calculate the total power distortion (TSD) using the short window
        % for 1Hz <= f <= 2kHz
        TSD(i) = sqrt( sum( DFT(i,index1Hz:index2kHz).^2 ) ) ...
                / ( sqrt(ENBW) * sqrt(2) * Pavg_long ) * 100;
    end

    % Find the maximum amplitude of each frequency across all DFT windows
    DFT_peaks = max(DFT,[],1);
```

```
    % Find the DFT window with the highest TSD
    [TSD_max, TSD_max_index] = max(TSD);
    % Find what time (in seconds) the highest TSD occurred.
    TSD_max_time = TSD_max_index * windowLength * ...
                    (1 - overlapPercent/100) + windowLength/2;

    % Generate the final results by concatenating the long window DFT with
    % frequencies below 1 Hz and the rolling window peaks (maximum of each
    % frequency over all windows) with frequencies 1 Hz and above.
    DFT_final = [DFT_long(1:index1Hz_long-1), DFT_peaks(index1Hz:end)] ...
                / Pavg_long * 100;
    f_final = [f_long(1:index1Hz_long-1), f(index1Hz:end)];

    % Generate the requirement to compare against
    req_f   = [0.01, 0.1,                 logspace(-1,0,100), 1, 2e3];
    req_amp = [ 100, 100, 3*logspace(-1,0,100).^(log10(3)-2), 3,   3];

    %% Plot the results
    figure(1)
    set(gcf,'Position',[100 100 1000 800])

    subplot(211)
    plot((0:length(P)-1)*Ts, P/1e3, '-b', 'LineWidth',2)
    grid on
    xlabel('Time (s)')
    ylabel('Load Power (kW)')
    title('Power Ripple Analysis Results')

    subplot(212)
    loglog(f_final, DFT_final, '-b','LineWidth',2); hold on
    loglog(f, DFT(TSD_max_index,:)/Pavg_long*100, ':k','LineWidth',1)
    loglog(req_f, req_amp, '-r','LineWidth',2); hold off
    axis([0.01, 10e3, 0.1, 200])
    grid on
    xlabel('Frequency (Hz)')
    ylabel({'Percent of Avg. Power','(zero to peak)'})
    legend('Peak Amplitude of DFT Windows','DFT Window with Highest
TSD','Requirement')
    text(1.5,80,['Highest TSD: ' num2str(TSD_max,'%5.2f') '% at time ' ...
         num2str(TSD_max_time,'%3.0f') ' s'])
end
```

A.5.5 MATLAB Script example m.

```
%% Example Power Ripple - example.m
% Use the following as a test signal to ensure the functions have been
% copied or implemented correctly. The main lobes at 0.2 Hz, 0.5 Hz, and
% 1.5 Hz should all be very close to the requirement. The remaining lobes
% above 1.5 Hz should be placed in 1 Hz increments above 1.5 Hz (e.g. 2.5
% Hz, 3.5 Hz, etc.) and are gradually decreasing. The highest TSD should be
% 2.938%.

Ts = 1/20e3;
t  = 0:Ts:(100-Ts);
P  = 100e3 + 34e3*sin(0.2*2*pi*t) + 6.75e3*square(0.5*2*pi*t);

[ f_final, DFT_final, TSD_max ] = powerRippleAnalysis(P, Ts);
```

A.6 ADDITIONAL DFT NOTES

A.6.1 MATLAB's DFT function. MATLAB's DFT function decomposes a time domain signal into a set of cosine and sine waveforms. The DFT function returns an array of real and imaginary numbers at both positive and negative frequencies. When the components of the positive and negative frequencies are appropriately combined, the real numbers represent the amplitude of the cosine waveforms and the imaginary numbers represent the amplitudes of the sine waveforms (following Euler's formula). The location of the real and imaginary numbers in the array gives the bin number, or frequency value, for each cosine and sine wave, and the location in the array will define if the frequency is negative or positive for each real and imaginary number.

a. For real signals, the components in the negative frequency bins are the complex conjugate of the components stored in the positive frequency bins, c = a + jb and c* = a - jb. Hence, the magnitudes of the positive and negative frequency components are equal.

b. A single cosine real tone (with no phase shift) is represented as two real numbers in the frequency domain: one with a positive frequency and one with a negative frequency, with the imaginary components being equal to zero. The amplitude of each of the frequencies is half the value of the original single-tone amplitude. This result can be shown via Euler's formula. For purely real signals, the time domain amplitude can be computed by multiplying the DFT amplitude of the positive frequency components by two.

c. In a similar fashion for a single sine real tone (with no phase shift), the real components are zero and the imaginary values represent the sine waveform.

d. If the decomposed signal consists of cosine terms and sine terms, or cosine terms with a phase shift, then both imaginary numbers and real numbers will exist in the DFT amplitudes of the associated frequency bins. By taking the absolute value of the DFT output at each frequency and multiplying by two, the amplitude of the equivalent cosine waveforms can be determined. The corresponding phase shift of the cosine waveform can be found by computing the arctangent of the imaginary component over the real component. Recall that the summation of a cosine wave with a sine wave for a given frequency can be represented as a cosine wave at the same frequency with the added phase shift, θ; Acos(x) + Bsin(x) = Mcos(x + θ), where M =$\sqrt{A^2 + B^2}$ and θ = arctan(B/A).

A.6.2 Sampling frequency. If the sampling frequency is f_s (samples per second), then the highest frequency component that can be determined is $f_s/2$ (the Nyquist frequency) and $1/f_s$ is the sampling period, T_s.

A.6.3 Windowing. Windowing is a technique used to mitigate the spectral leakage effect due to sampling a non-integer number of cycles. When non-integer cycles are sampled, discontinuities between the beginning and end point exist. The non-rectangle windows intentionally taper the beginning and ending points to get rid of this discontinuity and, hence, mitigate the spectral leakage. In so doing, the time domain signal is distorted and the resulting amplitude of the DFT is reduced and will need to be adjusted accordingly.

A.6.4 Signal window width. The width (in time) of the signal window determines the frequency resolution, $df = 1/T_{window}$. For instance, if you want to be able to resolve 61-Hz and 60-Hz components from one another, then you need at least 1 second's worth of samples, not including any zero padding samples. As such, the length (in time) of the sampled signal must be long enough to capture at least one full cycle of the frequency of interest.

A.6.5 Bin frequency. The frequency of a DFT bin is found by, (Bin Number)*f_s/(total # of samples including zero padding). The MATLAB indices correspond to (bin# + 1) because the first MATLAB index is 1, not zero.

A.6.6 Zero padding. Zero padding can be used to effectively eliminate scalloping losses, as well as increase the number of frequency bins to pin-point the exact frequencies of the signal. Zero padding increases the number of frequency bins and subsequently decreases the space between frequency bins. Zero padding means you are doing the DFT for more frequencies, achieving more resolution, such that $df = f_s/N_{dft}$, where N_{dft} is the total number of samples, including the zero padding length. Zero padding is helpful when you have a full cycle of data, but the window is not an integral number of cycles, hence, the frequency components will lay between the frequency bins if zero padding is not used. Note that zero padding does not add any information to the signal; it only helps in distinguishing frequencies. It simply adds more sampled data points to the DFT, or more data points along the sinc-like shape of the DFT output.

A.6.7 Scalloping losses. Scalloping losses are terms used to describe the reduction in amplitude of the DFT output when the frequency of the time domain signal does not match a specific DFT frequency bin. The maximum loss in amplitude occurs when the frequency of the signal lies exactly in the middle between two bins. For a single tone, centering a continuous-time-domain Fourier Transform of the window function (the DFT filter) on the frequency location corresponding to the actual frequency value of the signal, and observing where the first bins above and below this frequency value intersects the continuous-time filter will give the actual observed reduced DFT amplitudes for the two bins closest to the real frequency value. In other words, the DFT of a single frequency is a sampled version of the continuous sinc-like function that is the DFT filter. Zero padding can be used to add more samples along this sinc-like function.

A.6.8 Rectangle window with zero padding. If using a rectangle window and zero padding the time domain signal prior to taking the DFT (by simply adding zeros to the time-domain signal), the value $1/T_{window}$ is the space between nulls of the side-lobes of the resulting frequency domain sinc function, whereby T_{window} does not include the zero padding samples, and $2/T_{window}$ is the width of the main lobe between nulls of the sinc function.

A.6.9 Windowing for low level signals. Windowing (such as using the Taylor or Kaiser windows) allows the resolution of low level signals when strong signals are in the near vicinity due to the decreased side lobe levels.

A.6.10 Windowing for frequency resolution. Windowing functions increase the main lobe width, but decreases the side-lobe amplitude when compared with a rectangular window. By increasing the signal window length, the main lobe width can be decreased, hence, increasing the frequency resolution.

A.6.11 Coherent gain. The amplitudes of the DFT must be divided by a correction factor, the Coherent Gain (CG), specific to the window. The CG compensates for the change in amplitude of the DFT output due to applying the window function as well as the window length, N. For the simplest case of using a rectangle window, CG equals N, where N does not include zero-padding.

A.6.12 TSD calculation. When the TSD is calculated, the correction term, called Equivalent Noise Bandwidth (ENBW), is used to negate the inflation of the TSD value due to the energy that appears in the side lobes as well as the additional energy due to the main lobe bandwidth increase.

A.6.13 MATLAB FFT frequency bins. The MATLAB function fft(. . .) outputs frequency bins 0 to $N - 1$. The frequencies between 0 to N/2 are positive, and the frequencies from N/2 to $N - 1$ are negative. Sample N/2 corresponds to frequency $f_s/2$, the Nyquist frequency, provided an even number of samples were fed into the fft function.

A.6.14 MATLAB FFT frequency bin order. For MATLAB, the order of fft frequencies or bins is defined as [0, 1, 2, …, (N/2), (−N/2) + 1, (−N/2) + 2, …, −2, −1]. Performing a DFT on a time-domain signal with eight samples, N = 8, will produce the frequency bin order [0, 1, 2, 3, 4, −3, −2, −1] while the corresponding MATLAB indices will be [1, 2, 3, 4, 5, 6, 7].

A.6.15 References.

[1] F. Harris, "On the Use of Windows for Harmonic Analysis with the Discrete Fourier Transform", *Proceedings of the IEEE*, Vol. 66, No. 1, pp. 51–83, January 1978.

[2] S. W. Smith, *The Scientist & Engineer's Guide to Digital Signal Processing*. California Technical Pub, 1997. [Online]. Available: http://www.dspguide.com/pdfbook htm.

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[4] R. G. Lyons, *Understanding Digital Signal Processing*, Pearson Education, 2011.

CONCLUDING MATERIAL

Custodians:
Army – AV
Navy – SH

Preparing activity:
Navy – SH
(Project 1990-2017-001)

Review activities:
Navy – AS, OS, YD

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