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METRIC
MIL-STD-1399
SECTION 680
24 APRIL 2008

DEPARTMENT OF DEFENSE
INTERFACE STANDARD

SECTION 680

HIGH VOLTAGE ELECTRIC POWER, ALTERNATING CURRENT

AMSC N/A FSC 1990

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FOREWORD

1. Preamble. This military standard is approved for use by the Department of the Navy and is available 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 high voltage (industry: medium voltage) alternating current (AC) 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 AC user equipment to this standard.

5. Invoking the standard. The Principal Development Activity (PDA) will consider the mission requirement of the user equipment being developed or acquisitioned. The PDA 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. The PDA 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. Numerical quantities. Numerical quantities are expressed in metric (SI) units.

7. Contact information. Comments, suggestions, or questions on this document should be addressed to Commander, Naval Sea Systems Command, ATTN: SEA 05M2, 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 http://assist.daps.dla.mil.

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1. SCOPE

1.1 Scope. This military standard section establishes electrical interface characteristics for shipboard equipment utilizing AC electric power to ensure compatibility between user equipment and the electric power system. 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 of electric power systems and the design and testing of user equipment.

1.2 Classification. Shipboard power supplied from the electric power system is classified as shown in Table I.

TABLE I. Voltage classes.

Class	Maximum	Nominal
I	5.0 kVrms	4.16 kVrms
II	8.7 kVrms	6.60 kVrms
III	15.0 kVrms	11.00 kVrms
		13.80 kVrms

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 STANDARDS

MIL-STD-1399 - Interface Standard for Shipboard Systems

(Copies of this document are available online at http://assist.daps.dla.mil/quicksearch/ or http://assist.daps.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.3 Order of precedence. 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.

3.1.1 Electrical interface. The interface is the boundary between the electric power system and the user equipment where the electric power system characteristics and the user equipment compatibility requirements apply.

3.2 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.

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3.2.1 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. 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.

3.2.2 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.

3.2.3 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.

3.3 Frequency. Units are Hertz (Hz).

3.3.1 Nominal frequency. Nominal frequency ($f_{nominal}$) is the designated frequency in Hz.

3.3.2 Frequency tolerance. Frequency tolerance is the maximum permitted departure from nominal frequency during normal operation, excluding transients and modulation. This includes variations such as those caused by load changes, environment (temperature, humidity, vibration, inclination), and drift. Tolerances are expressed in percentage of nominal frequency.

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3.3.3 Frequency modulation. Frequency modulation is the permitted periodic variation in frequency during normal operation, calculated by Equation 1 and shown in Figure 1. For purposes of definition, the periodicity of frequency modulation should be considered as not exceeding 10 seconds.

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

EQUATION 1

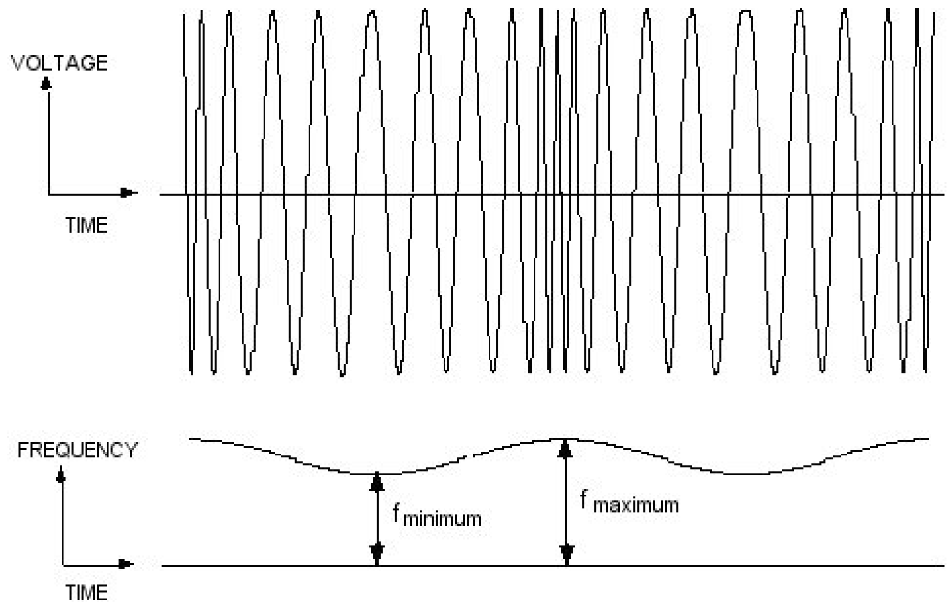

FIGURE 1. Frequency modulation.

3.3.4 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 msec) after the initiation of the disturbance.

3.3.4.1 Frequency transient tolerance. Frequency transient tolerance is the maximum permitted departure from nominal user frequency during transient conditions. The frequency transient tolerance is in addition to the frequency tolerance limits.

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

3.4 Voltage. Units are Volts (V). Unless otherwise specified, voltages in this standard are root- mean-square (rms) values. Tolerances are expressed in percent of the nominal user voltage.

3.4.1 Navy high voltage. For Navy applications, high voltage is considered to be a value above 1000 Vrms.

3.4.2 Nominal user voltage. Nominal user voltage ($V_{nominal}$) is the designated voltage at the interface.

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3.4.3 User voltage tolerance. User voltage tolerance is the maximum permitted departure from nominal user voltage during normal operation, excluding transients and modulation. User voltage tolerance includes variations caused by load changes, the environment (temperature, humidity, vibration, inclination), and drift. Tolerances are expressed in percentage of nominal voltage. The average line-to-line voltage tolerance is calculated in Equation 2 and the line-to-line voltage tolerance is calculated in Equation 3. Voltages are either all rms or all peak (sinusoidal crest) values.

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

Where:

The average voltage is the sum of the line-to-line voltages divided by the number of line-to-line voltages and the nominal user voltage is provided in Table II, item 7.

EQUATION 2

$$\text{Line-to-line voltage tolerance (percent)} = \left(\frac{\text{Line-to-line voltage - Nominal user voltage}}{\text{Nominal user voltage}}\right)\times 100$$

Where:

The line-to-line voltage is each line-to-line voltage and the nominal user voltage is provided in Table II, item 7.

EQUATION 3

3.4.4 Voltage unbalance (line-to-line). The line-to-line voltage unbalance is the maximum deviation of any of the three line-to-line voltages from the average voltage divided by the average voltage. Voltages are either all rms or all peak (sinusoidal crest) values as shown in Equation 4.

$$\text{Line-to-line voltage unbalance (percent)} = \left(\frac{\text{Maximum deviation from the average voltage}}{\text{Average voltage}}\right)\times 100$$

Where:

The average voltage is the sum of the line-to-line voltages divided by the number of line-to-line voltages.

EQUATION 4

3.4.5 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 in Figure 2. The periodicity of voltage modulation is considered to be longer than 1 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.

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

EQUATION 5

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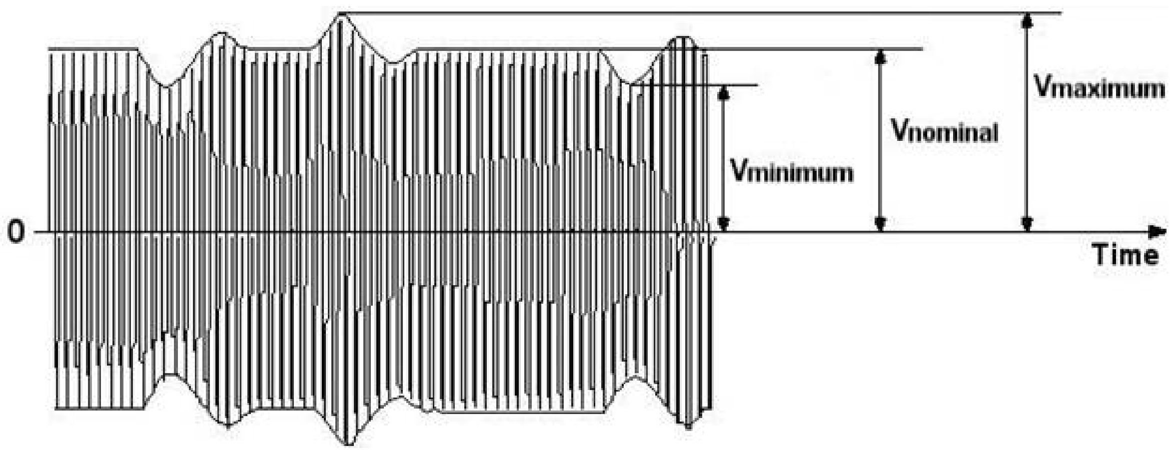

FIGURE 2. Voltage amplitude modulation.

3.4.6 Voltage transients. A voltage transient (excluding voltage spikes) is a sudden change in voltage that goes outside the user voltage tolerance limits and returns to and remains within these limits within a specified recovery time (longer than 1 msec) after the initiation of the disturbance.

3.4.6.1 Voltage transient tolerance. Voltage transient tolerance is the maximum permitted departure from nominal user voltage during transient conditions. The voltage transient tolerance is in addition to the user voltage tolerance limits.

3.4.6.2 Voltage transient recovery time. Voltage transient recovery time is the time elapsed from the instant when 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. This is shown in Figure 3.

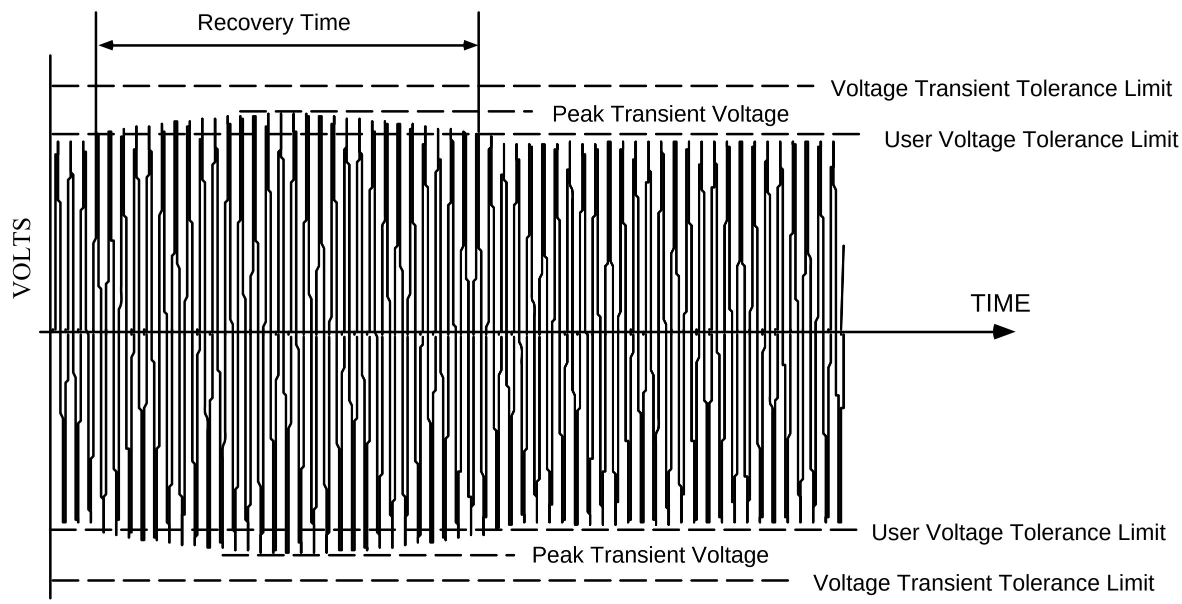

FIGURE 3. Voltage transient tolerance.

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3.4.7 Voltage spike. A voltage spike is a voltage change or impulse of very short duration (less than 1 msec) represented in Figure 4. Voltage spikes in shipboard power systems are generally of an oscillatory nature and not unidirectional as those often used in testing.

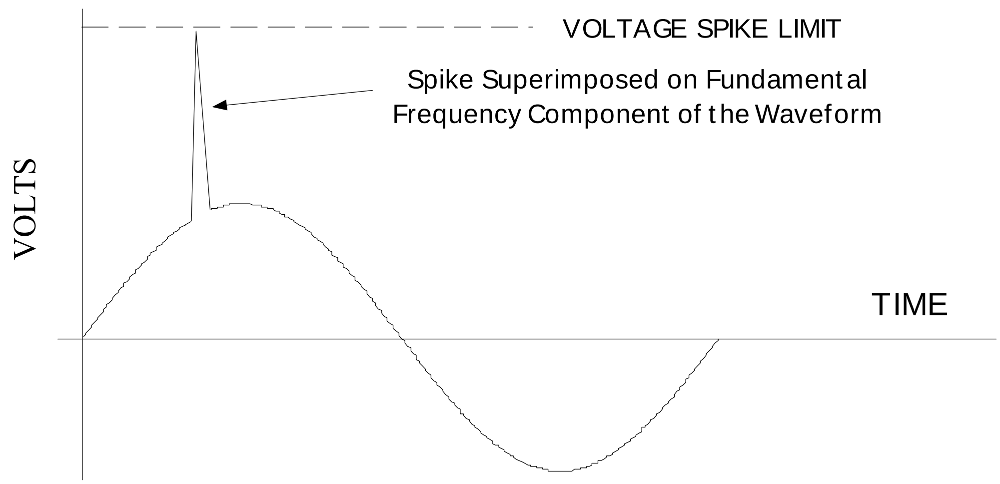

FIGURE 4. Voltage spike.

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

3.4.8.1 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.

3.4.8.2 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.

3.4.8.3 Voltage total harmonic distortion (THD). Total harmonic distortion 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 6.

$$\text{Voltage THD (percent)} = 100 \times \sqrt{\sum_{h \neq 1} \left(\frac{V_h}{V_{fundamental}} \right)^2}$$

Where:

V_h is the voltage of individual harmonics

$h \geq 2$

$V_{fundamental}$ is the voltage at 60 Hertz

EQUATION 6

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3.4.8.4 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 7 and shown in Figure 5. 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 7

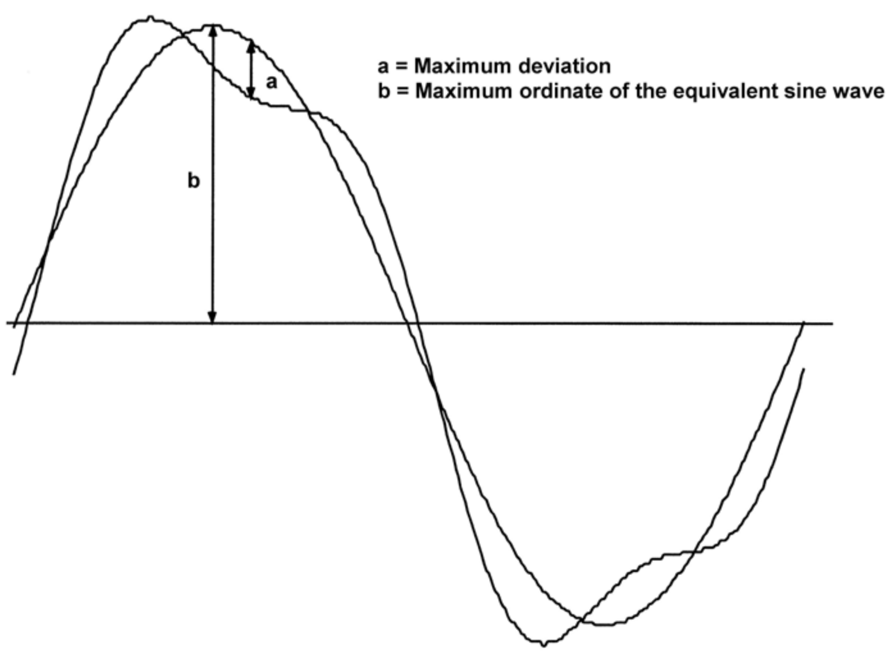

FIGURE 5. Voltage deviation factor variables.

3.5 Current. Units are in Amperes (A). Unless otherwise specified, currents in this standard are rms values.

3.5.1 Current unbalance. Current unbalance for three-phase loads is the ratio of the maximum line current minus the minimum line current to the average of the three line currents in amperes, shown in Equation 8. Currents used in the following equation are rms values.

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

EQUATION 8

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

3.5.2.1 Current single harmonic. A current single harmonic is a sinusoidal component of the current's periodic waveform having a frequency that is an integral multiple of the fundamental frequency.

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3.5.2.2 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.

3.5.3 Surge/inrush current. Surge 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 (msec) and decay to rated value in several msec to several seconds.

3.6 Power factor (pf). Pf is the ratio of the real power in watts to the product of the rms voltage and rms current. For voltage waveforms with minimal distortion, pf can be approximated as the product of the displacement pf (dpf) and the distortion (μ). This is shown in Equation 9.

$$\text{Pf} = \frac{\text{P (watts)}}{\text{Vrms Irms}} \approx \mu \text{ dpf}$$

EQUATION 9

3.6.1 Displacement power factor (dpf). The dpf is defined as the cosine of the angle between the fundamental frequency component of the input voltage and the fundamental frequency component of the current shown in Equation 10. 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).

$$\text{Dpf} = \cos(\varphi_V - \varphi_I)$$

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 10

3.6.2 Distortion component of power factor. The distortion component (μ) of power factor is the ratio of the rms magnitudes of the fundamental frequency current to the total current, shown in Equation 11.

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

Where:

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

I_{total} is the rms value of the total current

EQUATION 11

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

3.7.1 Real power. Real power, or average power, is defined as the product of the rms voltage and rms current multiplied by the power factor (pf). The unit of real power is the watt. Real power provides work over time.

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3.7.2 Reactive power. Reactive power is defined as the product of the rms voltage and rms current multiplied by a reactive factor. The unit of reactive power is volt-ampere reactive (VAR). Reactive power provides no net energy transfer over time; the average reactive power is zero.

3.7.3 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.

3.8 Pulse. A pulse is a brief excursion of power lasting longer than 1 cycle at nominal frequency and less than 10 seconds.

3.9 Pulsed load. A pulsed load may be user equipment, which demands frequent or regular repeated power input. A pulse load is measured as the average power during the pulse interval minus the average power during the same interval immediately preceding the pulse. An example of a pulsed load is sonar or radar. A pulsed load can result in modulation in the system voltage amplitude and frequency.

3.10 Ramp load. A ramp load is a load that is applied to the electrical system as a smooth ramp or in steps (increments of the total load).

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

3.12 Emergency condition. An emergency condition is an unexpected occurrence of a serious nature that may result in electrical power system deviations as specified under emergency conditions. Emergency conditions include but are not limited to battle damage and malfunction/failure of equipment.

4. GENERAL REQUIREMENTS

4.1 Interface requirements. The specific interface requirements and constraints established herein are mandatory and shall be adhered to by SYSCOMs, project managers, contractors and all others engaged in 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).

4.2 Conformance test requirements. Requirements and tests (see 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.

4.3 Deviations. The power interfaces in this standard are based on a traditional AC electric power system. To meet the intent of this section for non-traditional electric power systems, deviation of requirements will be considered. The deviation provisions in MIL-STD-1399 shall be adhered to during the early development stage of user equipment, as specified (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 propulsion motors, weapon systems, communication equipment, and computers. Electric power is generated and distributed throughout the ship to the user equipment served. Characteristics of shipboard electric power systems at the interface shall be as specified in Table II.

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TABLE II. Electric power system characteristics at the interface.
(NOTE: Characteristic percentages are defined in Section 3.)

Characteristics	**5 kV Class**	**8.7 kV Class**	**15 kV Class**
Frequency			
1. Nominal frequency	60 Hz	60 Hz	60 Hz
2. Frequency tolerance	±3%	±3%	±3%
3. Frequency modulation	0.5%	0.5%	0.5%
4. Frequency transient tolerance	±4%	±4%	±4%
5. Worst case frequency excursion from nominal resulting from items 2, 3, and 4 combined, except under emergency conditions	+5.5%	+5.5%	+5.5%
6. Recovery time from items 4 or 5	2 seconds	2 seconds	2 seconds
Voltage			
7. Nominal user voltage	4.16 kVrms	6.60 kVrms	11 kVrms, 13.80 kVrms
8. Line-to-line voltage unbalance	3%	3%	3%
9. User voltage tolerance			
a. Average line-to-line voltage from nominal	±5%	±5%	±5%
b. Line-to-line voltage from nominal, including items 8 and 9.a	±7%	±7%	±7%
10. Voltage modulation	2%	2%	2%
11. Maximum departure voltage from nominal resulting from items 8, 9a, 9b, and 10 combined, except under transient or emergency conditions	±8%	±8%	±8%
12. Voltage transient tolerance	±16%	±16%	±16%
13. Worst case voltage excursion from nominal resulting from items 8, 9.a, 9.b, 10 and 12 combined, except under emergency conditions	±20%	±20%	±20%
14. Recovery time from items 12 or 13	2 seconds	2 seconds	2 seconds
15. Voltage spike	25 kV peak	40 kV peak	75 kV peak
Waveform (voltage)			
16. Maximum total harmonic distortion	5%	5%	5%
17. Maximum single harmonic	3%	3%	3%
18. Maximum deviation factor	5%	5%	5%
Emergency conditions			
19. Frequency excursion	-100% to +12%	-100% to +12%	-100% to +12%
20. Duration of frequency excursion	2 minutes	2 minutes	2 minutes
21. Voltage excursion	-100% to +35%	-100% to +35%	-100% to +35%
22. Duration of voltage excursion			
a. Upper limit (+35%)	2 minutes	2 minutes	2 minutes
b. Lower limit (-100%)	2 minutes	2 minutes	2 minutes

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5.1.1 Power interruption. From time-to-time, the electric power will be interrupted and may also be rapidly re-energized in less than 1 second. The power interruption may range from less than 1 msec to several minutes. The interruptions can occur as a result of an equipment casualty, training exercise, or operator error. The electric power system shall incorporate system protection and power management to permit controlled restoration of power.

5.1.2 System grounding. Electric power systems shall be high-resistance grounded. Under faulted conditions, a fault current shall be limited to a value that shall not exceed 10 amperes unless otherwise approved by NAVSEA. The system shall continue to operate with a single phase faulted.

5.1.3 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.

5.1.3.1 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, 4-wire system (with neutral), the angular displacement between phases shall not exceed 120 degrees ±1 degree under balanced load conditions.

5.1.4 Electrical power system protection. Some protection through relaying and circuit breakers is provided by the electric power system for voltage and frequency excursions exceeding the transient limits specified in Table II.

5.1.4.1 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 (spikes) of very short duration (see Figures 4 and 12)

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

5.1.5 Electric power system parameters. Electric power system parameters shall be as specified in 5.1.5.1 through 5.1.5.3.

5.1.5.1 System frequency. System frequency is 60 Hz. Where there are overriding design features demanding a different frequency, deviations from this requirement are subject to the requirements of 4.3.

5.1.5.1.1 60 Hz frequency transient. Figure 6 illustrates the system frequency tolerance and worst-case frequency excursion 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.

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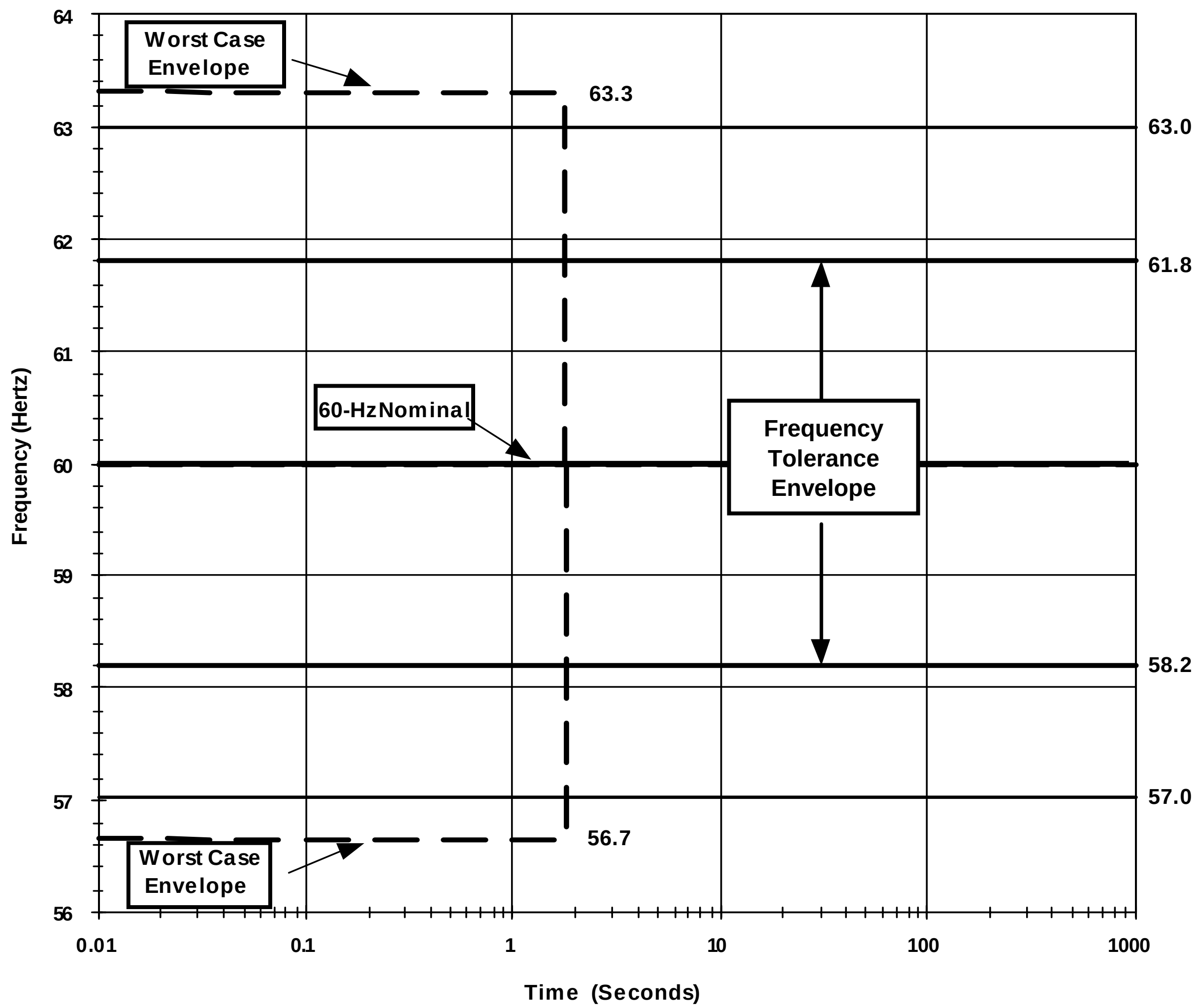

FIGURE 6. Frequency tolerance and worst case envelopes.

5.1.5.2 System voltage. System voltages are as follows:

a. 4160 Vrms, 3-phase, 3-wire, high resistance-grounded.

b. 6600 Vrms, 3-phase, 3-wire, high resistance-grounded.

c. 11000 Vrms, 3-phase, 3-wire, high resistance-grounded.

d. 13800 Vrms, 3-phase, 3-wire, high resistance-grounded.

See 5.2.2 and Table I for voltage classes.

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5.1.5.2.1 60 Hz voltage transient. Figures 7, 8, 9, and 10 illustrate the user voltage tolerance and worst-case voltage excursion envelope limits specified in Table II. The time to reach the transient maximum may vary from 0.001 to 0.03 second, or to reach the transient minimum may vary from 0.001 to 0.06 second depending on the rating of the generator and the type regulator and excitation system employed. The sudden application of user equipment electric power system may cause the voltage to decrease to the transient voltage minimum value within 0.001 to 0.06 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 will occur within 2 seconds. The sudden removal of a user equipment from the electric power system may cause the voltage to increase to the transient voltage maximum within 0.001 to 0.03 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.

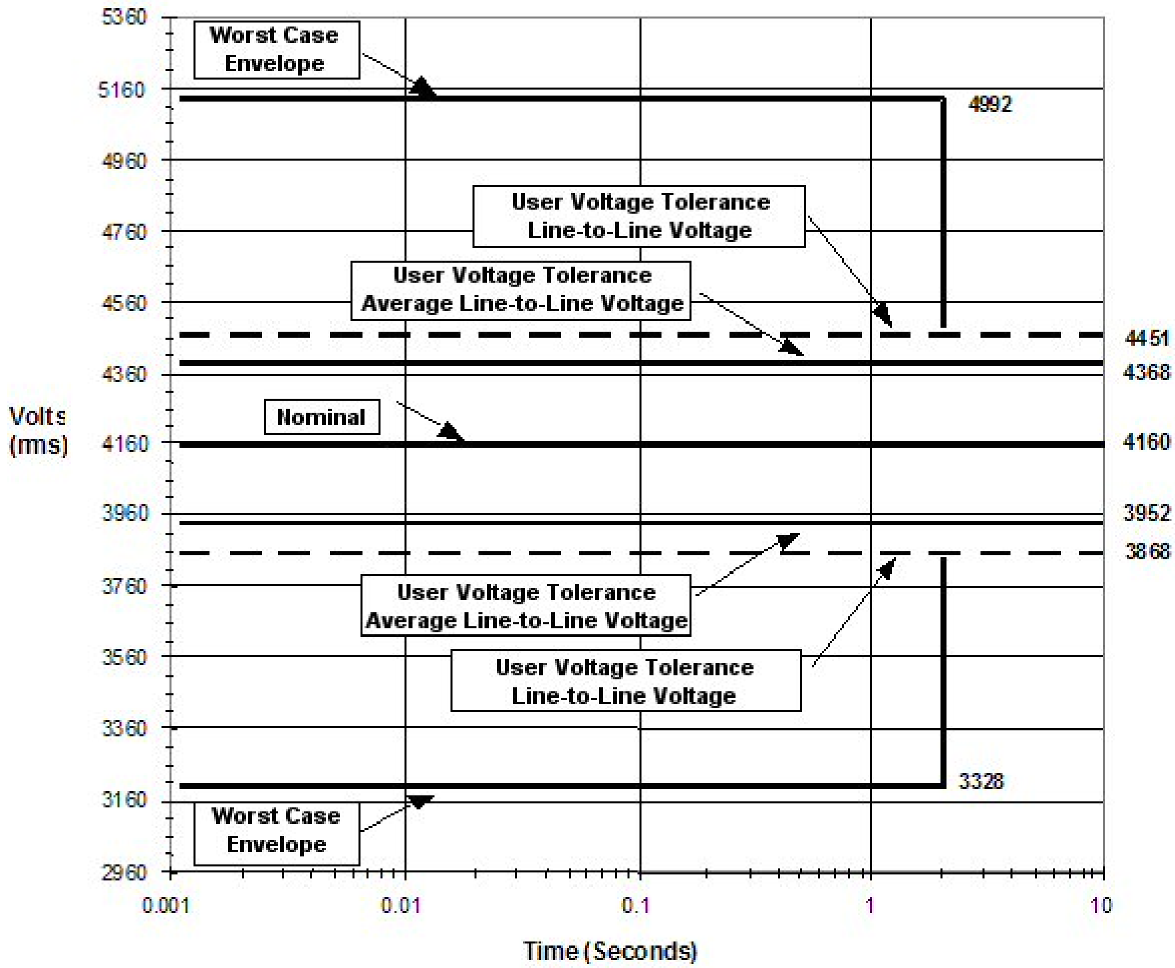

FIGURE 7. 4160 Vrms nominal voltage tolerance and worst case envelopes.

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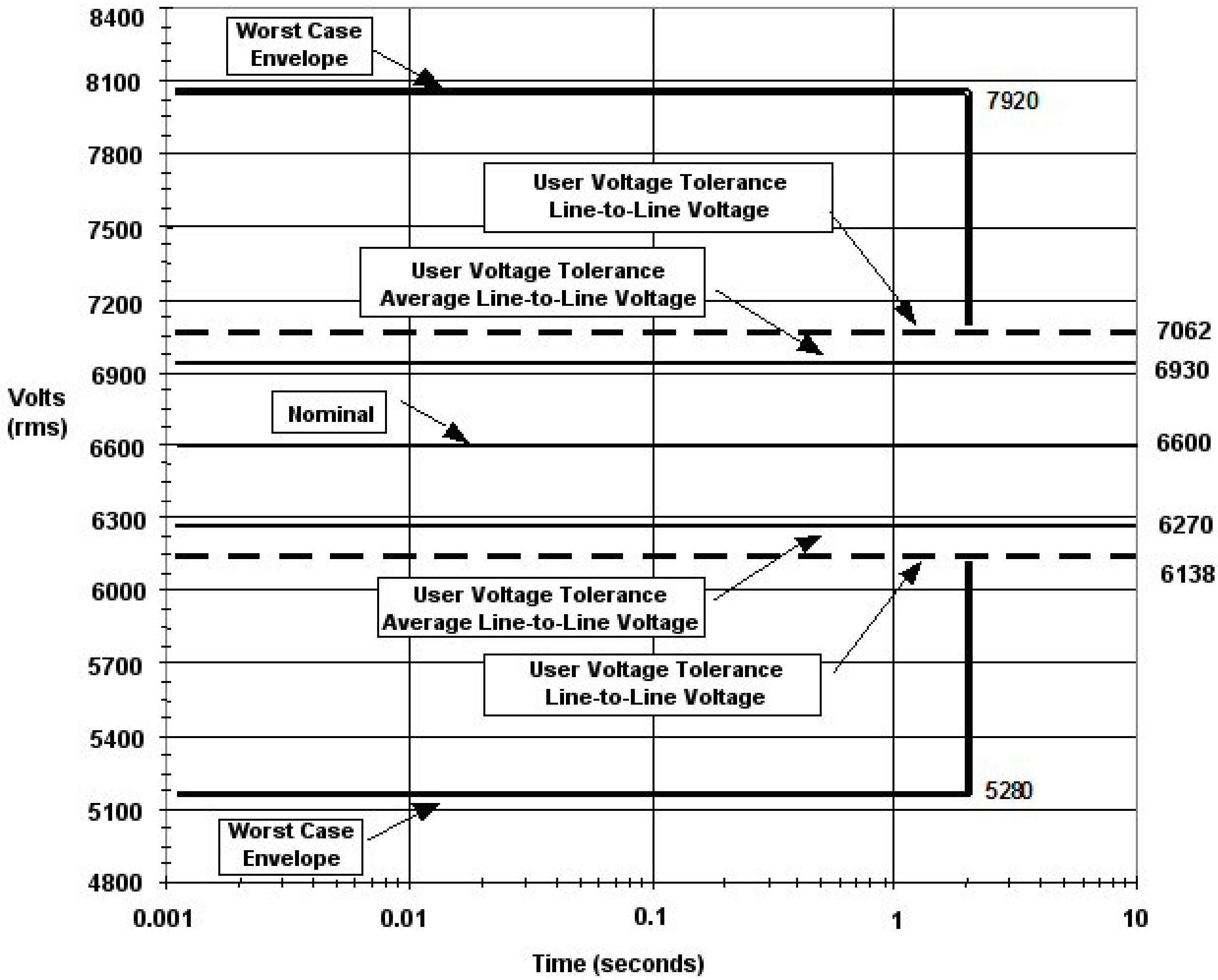

FIGURE 8. 6600 Vrms nominal voltage tolerance and worst case envelopes.

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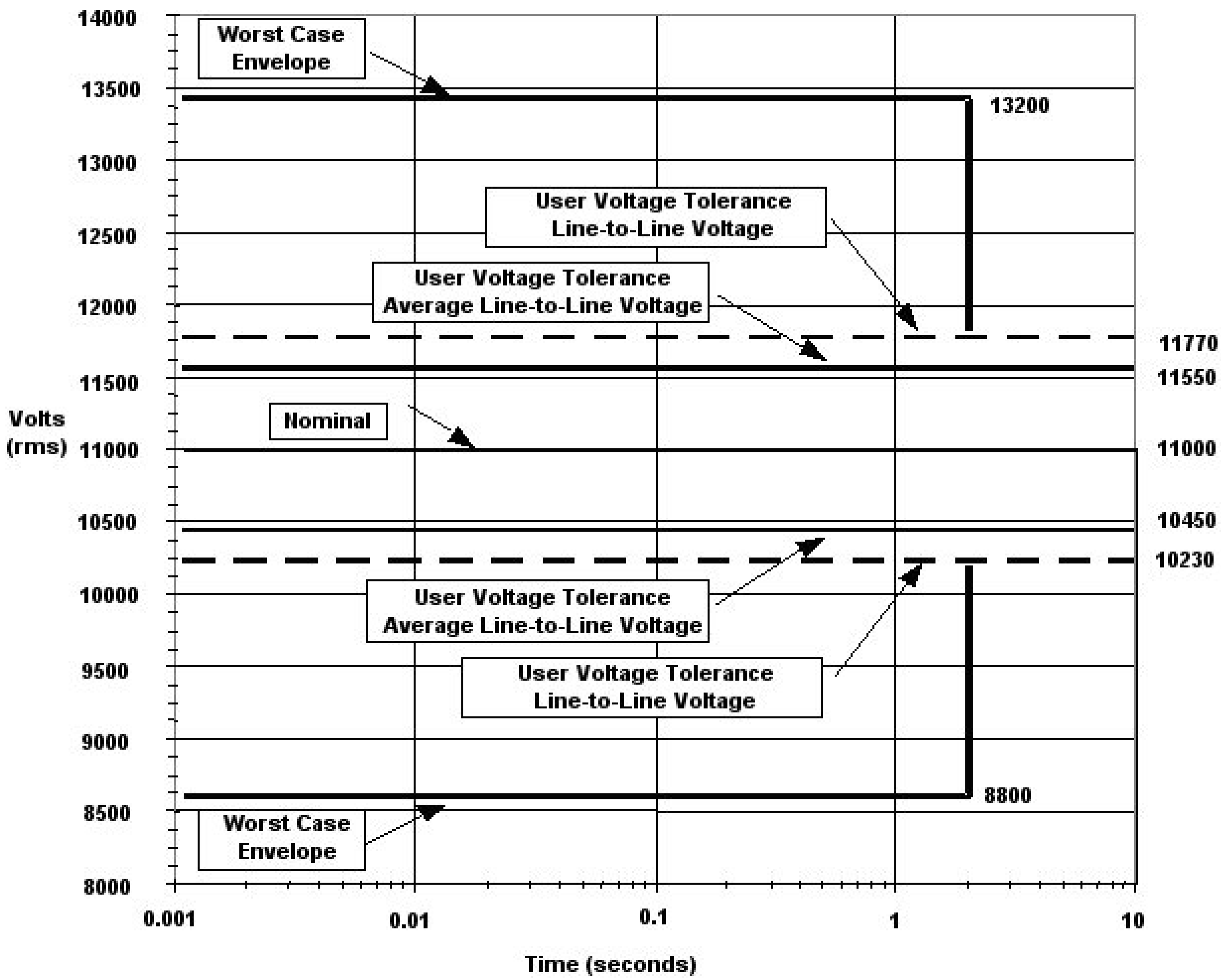

FIGURE 9. 11000 Vrms nominal voltage tolerance and worst case envelopes.

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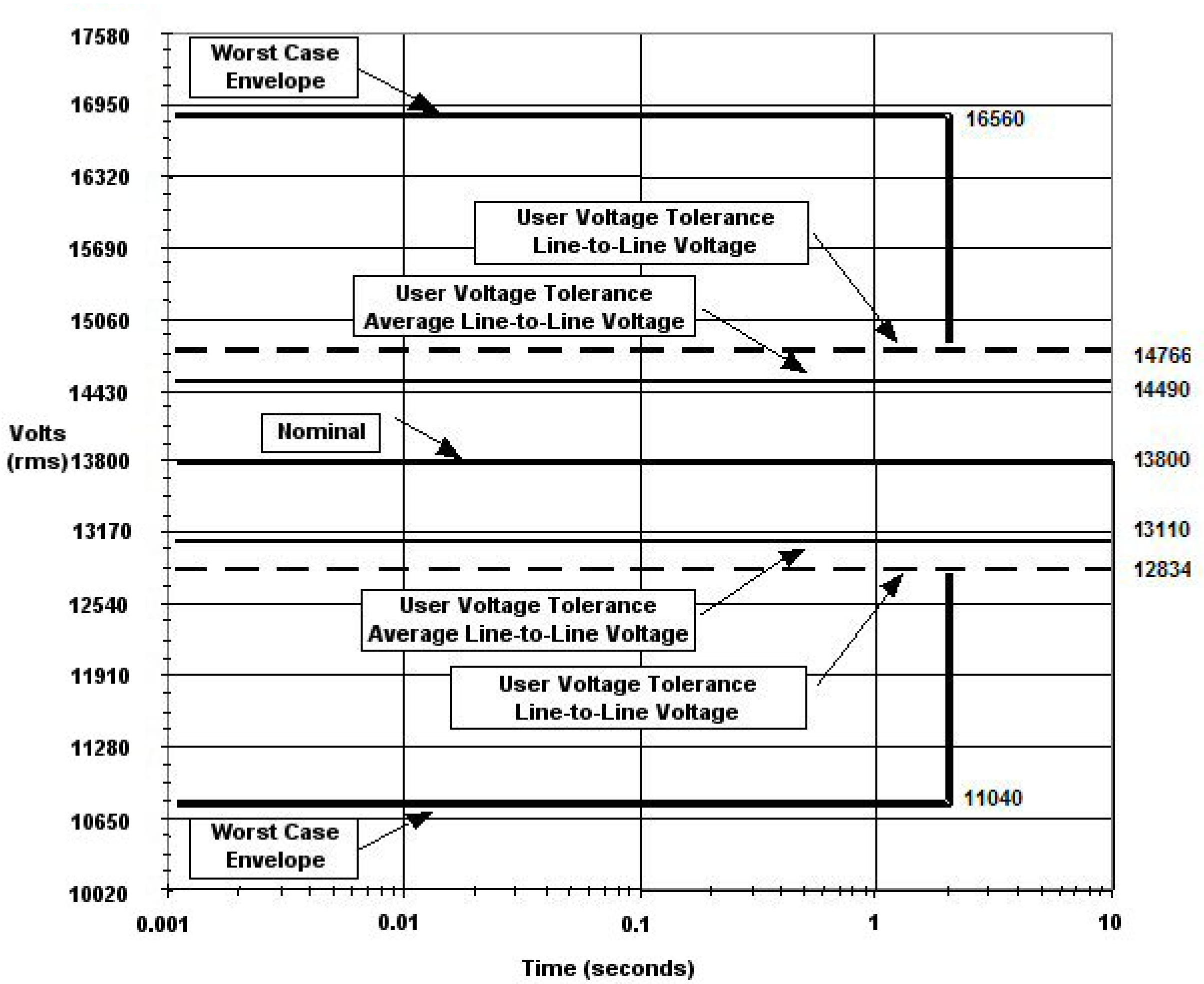

FIGURE 10. 13800 Vrms nominal voltage tolerance and worst case envelopes.

5.1.5.2.2 Voltage spike characteristics. Voltage spikes may be present on the electrical power system between line-to-line and between line-to-ground (or neutral). The amplitude and waveform of voltage spikes will vary depending on system parameters.

5.1.5.3 Shipboard electric power system operating power factor. Shipboard electric power systems are designed to operate with an overall pf of 0.8 lagging to 0.95 leading for 60 Hz power systems.

5.2 User equipment interface requirements. User equipment shall meet the requirements specified in 5.2.1 through 5.2.10 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 Type of power. User equipment shall be designed to operate in a voltage class in Table I.

5.2.3 Emergency conditions. User equipment shall withstand electric power interruptions, rapid reapplications of power (see 5.1.1), and the emergency conditions specified in Table II without damage.

5.2.4 Grounding. User equipment shall operate on a distribution system using a high resistance-grounding scheme.

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5.2.4.1 Insulation resistance testing. User equipment shall be tested to demonstrate the robustness of insulation systems by imposing 5000 VDC across insulation to ground, corrected to 25 °C.

5.2.5 Current unbalance. User equipment 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 of the user equipment rating under normal operating conditions and during normal operating modes when measured with a voltage source having a line voltage unbalance less than 1 percent. Three-phase current unbalance shall be calculated as defined in 3.5.1.

5.2.6 Power factor. User equipment shall operate within the user frequency and voltage tolerance envelopes of Figures 6 through 10 as applicable with an overall pf within the range of 0.8 lagging to 0.95 leading for 60 Hz equipment under normal steady state operating conditions, excluding start-ups and pulsed loads.

5.2.7 Pulsed load. The on-line generator source shall withstand repeated pulsed load transients of not more than one transient every 45 seconds and not greater than 30 percent of the total capacity (see 3.9).

5.2.8 Ramp load. The on-line generator source shall withstand ramp loading and unloading that shall be limited to an average rate of 30 percent of the on-line generator source rating per second (see 3.10).

5.2.9 Input current waveform. The operation of user equipment or the aggregate shall not cause single harmonic line current or current of any frequency above the fundamental at 60 Hz to 2000 Hz to be generated that is greater than the limit line set at 3 percent of the unit's full rated load fundamental current. Additionally, 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 full load fundamental current, where f is the nominal frequency. This is shown in Figure 11. User equipment, for the purposes of this requirement, shall be defined as a system with 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.

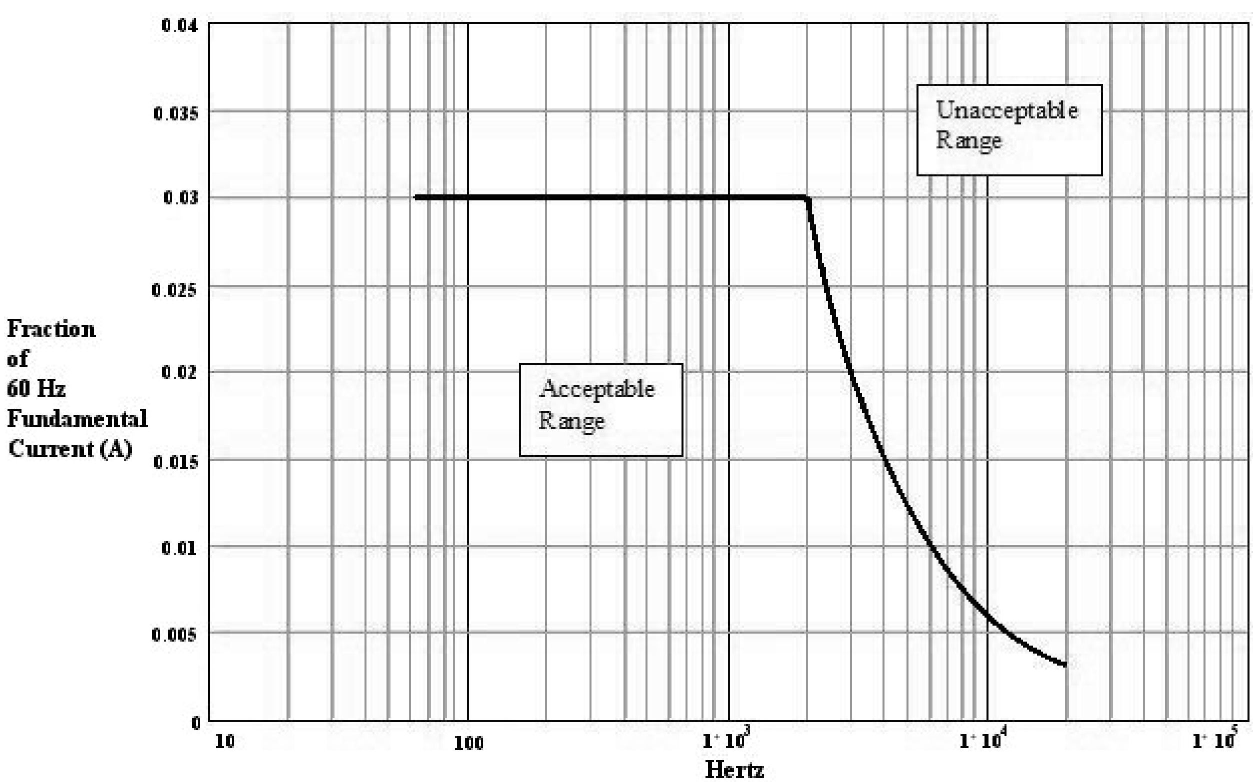

FIGURE 11. Limit line for currents at frequencies greater than 60 Hz.

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5.2.9.1 User equipment in the unacceptable range. When user equipment cannot meet the input current waveform limits specified in 5.2.9, the equipment shall be electrically isolated from the power source.

5.2.10 Protection of user equipment.

a. User equipment shall be designed so that it will not sustain damage as a result of 5000 VDC insulation resistance tests.

b. User equipment shall self-protect from a power interruption (see 5.1.1) and be capable of realignment after a power interruption.

c. User equipment shall not sustain damage as a result of the voltage spike (see 5.1.5.2.2) specified in Table II.

5.3 Test requirements. This section specifies user equipment test requirements and test procedures. User equipment test requirements verify compliance to the user equipment interface requirements specified in this standard when tested in accordance with the procedures specified herein. For user equipment testing, the hardware and software of a Unit Under Test (UUT) shall be representative of production. NAVSEA reserves the right to tailor test requirements.

5.3.1 Voltage and frequency tolerance test. This test shall be used to evaluate the performance of user equipment under the voltage and frequency conditions of Table III, as applicable. The operation of the user equipment shall be within the manufacturer's defined operating parameters when tested to the voltage and frequency conditions of Table III, as applicable.

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TABLE III. Voltage and frequency tolerance test.

	User voltage tolerance (Vrms)			Frequency tolerance(Hz)		
	Lower limit	Nominal	Upper limit	Lower limit	Nominal	Upper limit
4160 Vrms system grounded, line-to-line						
Average of three line-to-line voltages	3922	4160	4368	58.2	60	61.8
Any one line-to-line voltage	3869	4160	4451	58.2	60	61.8
4160 Vrms system grounded, line-to-ground						
Average of three line-to-line voltages	2280	2400	2520	58.2	60	61.8
Any one line-to-line voltage	2232	2400	2568	58.2	60	61.8
6600 Vrms system grounded, line-to-line						
Average of three line-to-line voltages	6270	6600	6930	58.2	60	61.8
Any one line-to-line voltage	6138	6600	7062	58.2	60	61.8
6600 Vrms system grounded, line-to-ground						
Average of three line-to-line voltages	3620	3811	4002	58.2	60	61.8
Any one line-to-line voltage	3544	3811	4078	58.2	60	61.8
11000 Vrms system grounded, line-to-line						
Average of three line-to-line voltages	10450	11000	11550	58.2	60	61.8
Any one line-to-line voltage	10230	11000	11770	58.2	60	61.8
11000 Vrms system grounded, line-to-ground						
Average of three line-to-line voltages	6033	6351	6669	58.2	60	61.8
Any one line-to-line voltage	5906	6351	6796	58.2	60	61.8
13800 Vrms system grounded, line-to-line						
Average of three line-to-line voltages	13110	13800	14490	58.2	60	61.8
Any one line-to-line voltage	12834	13800	14766	58.2	60	61.8
13800 Vrms system grounded, line-to-ground						
Average of three line-to-line voltages	7569	7967	8365	58.2	60	61.8
Any one line-to-line voltage	7409	7967	8525	58.2	60	61.8

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. Voltmeters (true rms) - ±0.5 percent accuracy

c. Frequency meter - ±0.5 Hz accuracy

d. Temperature meter - ±0.5 °C accuracy

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5.3.1.2 Procedure. The user equipment shall first be operated in a normal operating mode within the steady-state voltage and frequency tolerance envelopes as identified in Figures 6 through 10 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 30 minutes. The user equipment shall then be subjected to the limits of the user voltage and frequency tolerance envelopes of Table III. Set the following combinations:

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 user equipment 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.

5.3.2 Voltage and frequency transient tolerance and recovery test. The user equipment performance shall be evaluated under the transient frequency and voltage conditions specified in Table IV. The operation of the user equipment shall be within the manufacturer's defined operating parameters when tested to the transient voltage and frequency conditions of Table IV.

TABLE IV. Transient voltage and frequency tolerance and recovery test.

Condition	Voltage	Frequency
Upper limit	+20%	+5½%
Lower limit	-20%	-5½%

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) - ±0.5 percent accuracy

c. Frequency meter - ±0.5 Hz accuracy

d. Storage oscilloscope having 500 kHz response

e. Current and potential transformers and probes as required

f. Temperature meter - ±0.5 °C accuracy

5.3.2.2 Procedure. The user equipment shall be operated in a normal operating mode within the frequency and applicable voltage tolerance envelopes shown on Figures 6 through 10 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 30 minutes. The power 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 14. 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 at 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 of Table IV. During and after testing, equipment shall operate normally with no operational degradation to show compliance with this test.

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5.3.3 Insulation tests and ratings. Electric power and distribution apparatus assigned a given insulation class shall be capable of withstanding, without flashover or apparent damage, a high-potential voltage and a 1.2/50 full-wave impulse voltage (see Figure 12) of specified crest kV. This specified crest voltage is the basic impulse insulation level (BIL) of the equipment. Electric power and distribution apparatus shall be tested for compatibility with the high potential and BIL voltages specified in Table V, as appropriate.

TABLE V. High-potential and BIL test voltages per voltage classes.

Voltage Class (see Table I)	High-Potential (2 x nominal +1000)	BIL
I	9.32 kVrms	30 kV
II	14.20 kVrms	60 kV
III	28.60 kVrms	95 kV

The impulse/surge wave-shape is illustrated in Figure 12. The 1.2/50 designation means that a voltage impulse increases from virtual zero volts to its crest value in 1.2 µs (t_1) and declines to one-half crest value in 50 µs (t_2). A current wave of the same wave-shape accompanies the voltage wave.

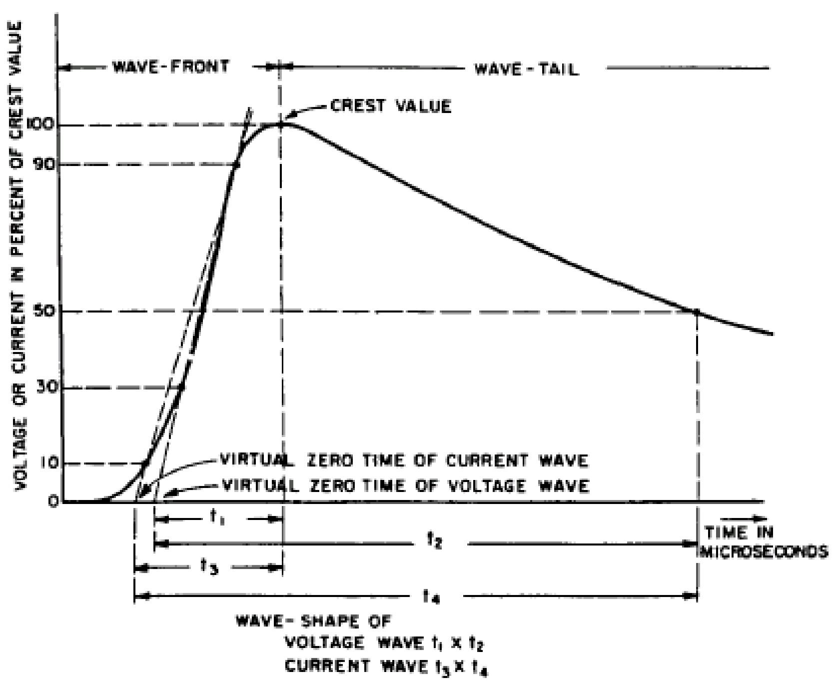

FIGURE 12. Voltage and current waves.

5.3.3.1 Procedure. Electrical power and distribution apparatus assigned a given insulation class shall be subjected to high-potential and BIL test voltages as specified in 5.3.3. Test equipment and procedures commercially approved for similar testing may be used.

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5.3.4 Emergency condition test. The emergency condition test shall be used to evaluate the user equipment performance under the following conditions:

a. Power system sudden interruptions
b. Rapid re-application of power after an interruption
c. Power source voltage and frequency decay test
d. Emergency condition voltage and frequency tolerances

The operation of the user equipment shall be within the manufacturer's defined operating parameters when tested to the emergency conditions of 5.3.4.

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) - ±0.5 percent accuracy
c. Frequency meter - ±0.5 Hz accuracy
d. Storage oscilloscope having 500 kHz response
e. Current and potential transformers as required
f. Frequency to voltage transducer
g. Temperature meter - ±0.5 °C accuracy

5.3.4.2 Procedure. The user equipment shall be operated in a normal operating mode within the frequency and applicable voltage tolerance envelopes shown on Figures 6 through 10 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 30 minutes. Power source frequency, line voltage (one-phase), and line current shall be measured at the user equipment power input terminals and recorded before the start and during each test. The input power shall be suddenly interrupted. After an interval between 40 msec to 60 msec, the input power shall be suddenly reapplied. After the equipment has been operated long enough to detect any major performance degradation and to include equipment recycling time, the power to the user equipment shall be interrupted for an interval of 2 minutes followed by the sudden reapplication of input power to the user equipment. This test shall be repeated in all operating modes. The user equipment shall be subjected to the emergency condition positive excursion tolerances specified in Table II, items 19 through 22. The user equipment shall be operated in a normal operating mode with the power input voltage and frequency in the applicable tolerance band. The power input voltage and frequency shall be varied in accordance with the positive excursion limits and time durations specified in Table VI. One line voltage, one line current, and frequency shall be measured and recorded before and during each of the emergency condition tests. Repeat the test for each operating mode.

TABLE VI. Emergency condition test.

Emergency Condition	Voltage Tolerance	Frequency Tolerance
Maximum excursion:	+35% of nominal	+12% of nominal
Duration:	2 minutes	2 minutes

5.3.5 User equipment power profile test. User equipment shall be tested to determine the following items in all operating modes. If the user equipment requires more than one input from the electric power system, the data shall be provided for each power input required. The power profile data shall include the applicable data listed below for each operating mode and shall be in accordance with the associated procedure.

a. Type of power
b. Number of phases
c. Voltage
d. Line current magnitudes (rms)

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e. Power factor (leading or lagging)

f. Power kilowatt (kW) rated and typical operating power profile

g. Pulsed loading

h. Load unbalance

i. Spike generation

The operation of the user equipment shall be within the manufacturer's defined operating parameters or requirements specified herein, as appropriate, for all operating modes.

5.3.5.1 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. Ammeters

e. Power factor meter

f. Storage oscilloscope having 500 kHz response

g. Current and potential transformers and probes as required

5.3.5.2 Procedure. The user equipment shall be operated in accordance with the equipment operating procedure in a normal mode of operation. Power input voltage and frequency shall be within the frequency and applicable voltage tolerance envelopes shown in Figures 6 through 10. Measure and record power input voltages (each phase), each line current, power factor for each phase, and power (kW). These measurements shall be made for each power input required from the electric power system. From the data collected during these tests, calculate and record the data elements specified in 5.3.5 for each user equipment power input. The power profile test shall be repeated for each normal operating mode and for each user equipment 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 reported in order to assist in analyzing the impact the equipment may have on a shipboard power system. The power source rating and its source impedance, as well as the length and type of connecting cable used, shall be included.

5.3.6 Current waveform test. The harmonic content from nominal input line frequency up to 20 kHz of the current waveform in the user equipment power input lines shall be determined for each operating mode. The harmonic current of the user equipment shall be in compliance with the requirements in 5.2.9.

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

c. Frequency meter - ±0.5 Hz accuracy

d. Ammeters

e. Wide-band current probe or shunt

f. Potential transformers as required

g. Harmonic analyzer with a better than 3 percent of measured frequency band width below 2.5 kHz and a less than 75 Hz bandwidth at frequencies between 2.5 and 200 kHz

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5.3.6.2 Procedure. The user equipment shall be energized in accordance with the equipment procedure and operated in a normal mode of operation. The power source voltage and frequency shall be within the frequency and applicable voltage tolerance envelopes shown in Figures 6 through 10. The power input current harmonics shall be determined for each operating mode. The current harmonics shall be measured by means of a wide-band current probe or shunt in each power input line. The fundamental and harmonics of each line current shall be measured by means of a harmonic analyzer. The current harmonics shall be determined for each normal operating mode and shall not exceed the values specified in 5.2.9. If it is suspected that the power source has sufficient voltage harmonic distortion to affect current harmonic measurements, to determine the baseline harmonic currents due to the source, connect a linear load (no larger than the user equipment load and having the same fundamental frequency leading or lagging power factor as the user equipment to be tested) at the power interface where the user equipment would be connected. The harmonic currents shall be measured. These measured harmonic current values from the linear load may then be subtracted from the harmonic current values measured from the normally operated user equipment to provide an approximation of the equipment's harmonic current content.

5.3.7 Voltage and frequency modulation test. User equipment performance shall be evaluated under the voltage modulation and frequency modulation conditions specified in Table II, items 3 and 10. The operation of the user equipment shall be within the manufacturer's defined operating parameters when tested to the voltage modulation and frequency modulation conditions specified in Table II, items 3 and 10.

5.3.7.1 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
e. Current and potential transformers and probes as required
f. Temperature meter - ±0.5 °C accuracy

5.3.7.2 Procedure. The user equipment shall be operated in a normal operating mode within the frequency and applicable voltage tolerance envelopes shown in Figures 6 through 10 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 30 minutes. 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 II, items 3 and 10 for the applicable voltage class. 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.

a. Voltage modulation test: With the frequency held constant at nominal, vary the voltage from minimum to maximum for periods of 17 msec, 75 msec, 250 msec, 500 msec, 1 second, 5 seconds, and 10 seconds. Repeat each cycle of modulation ten consecutive times before moving to the next modulation period, starting at 17 msec 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 17 msec, 75 msec, 250 msec, 500 msec, 1 second, 5 seconds, and 10 seconds. Repeat each cycle of modulation ten consecutive times before moving to the next modulation period, starting at 17 msec 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 17 msec, 75 msec, 250 msec, 500 msec, 1 second, 5 seconds, and 10 seconds. Repeat each cycle of modulation ten consecutive times before moving to the next modulation period, starting at 17 msec and ending at 10 seconds.

The user equipment 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.

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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 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 the standard.

b. Deviations (see 4.3)

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 requests. Requests for deviation are to be submitted for approval to the Naval Sea Systems Command (NAVSEA 05Z3).

Custodians:
Navy – SH
Air Force – 99

Preparing activity:
Navy – SH
(Project 1990-2008-002)

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