NATO STANDARD

ANEP-100

CHARACTERISTICS OF SHIPBOARD 440V/230V/115V 60Hz, 440V/115V 400Hz and 24/28VDC ELECTRICAL POWER SYSTEMS IN WARSHIPS OF THE NATO NAVIES

Edition A, Version 1

OCTOBER 2021

NORTH ATLANTIC TREATY ORGANIZATION

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NATO LETTER OF PROMULGATION

12 October 2021

1. The enclosed Allied Naval Engineering Publication ANEP-100, Edition A, version 1, CHARACTERISTICS OF SHIPBOARD 440V/230V/115V 60Hz, 440V/115V 400Hz and 24/28VDC ELECTRICAL POWER SYSTEMS IN WARSHIPS OF THE NATO NAVIES, which has been approved by the nations in the CNAD, is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 1008.

2. ANEP-100, Edition A, version 1, is effective upon receipt.

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4. This publication shall be handled in accordance with C-M(2002)60.

Dimitrios SIGOULAKIS
Major General, GRC (A)
Director, NATO Standardization Office

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS
Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.	

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RECORD OF SPECIFIC RESERVATIONS

[nation]	[detail of reservation]
GRC	Definition and Limits of Harmonics, Extend content of ANEP-100 to include not only integer harmonics effect on voltage/current distortion but also subharmonics, inter-harmonics and notches.

Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.

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CHAPTER 1 INTRODUCTION

1.1. GENERAL STATEMENT

1. This ANEP is divided into five parts: Annex A – Definitions, Annex B – User Information and Constraints, Annex C – Characteristics of Standard Electrical Power Supplies, Annex D – List of References for ANEP-100 and Annex E – National Specifications of Member Countries. The section covering user information and constraints contains guidance on certain aspects of power systems in Warships and on restrictions that would be typically imposed on user equipment to ensure compatibility with power systems and to minimize interference with other user equipment. Three types of power supplies, operating at 440V/230V/115V 60Hz, 440V/115V 400Hz and 24/28VDC are specified in this ANEP and it should be noted that not all these supplies may be present in a particular ship.

2. The definitions, user information and characteristics in this ANEP refer essentially to a healthy electrical power supply system and include transient conditions that result from normal system operations, such as motor starts and switching events. The ANEP does not describe system behaviour under abnormal conditions, e.g. short circuit faults, excluding loss of generator sets or malfunction of associated controls, as this behaviour depends heavily on the design characteristics of individual systems.

1.2. IMPLEMENTATION OF THE AGREEMENT

This ANEP is considered to be implemented when nations ensure that warships are equipped with electrical power supplies and electrical/electronic systems having characteristics according to this ANEP.

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ANNEX A LEXICON

The following definitions are to be used for the purpose of this agreement only. Other terms used in this agreement and which are not defined herein are as defined in IEC Publication 60050.

A.1. GENERAL DEFINITIONS

a. Naval Administration

As per ANEP-77 the Naval Administration is defined as:
"The Department of Government of the State responsible for providing safety regulation for naval ships. The Naval Administration may be assisted or supported by other government departments or agencies who, by mutual agreement of the Naval Administration and the department or agency concerned, have agreed to enact this Code for specified ships of that department or agency."
A Naval Administration is typically established by a navy.

b. Electrical Power System Designer

The organization charged with the responsibility of designing the ship power generation and distribution system.

c. User Equipment

Any system or equipment which uses electrical power from power supplies covered by this ANEP.

d. Ship Service Power Supply System

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

e. Power Supply Interface

For user equipment contained within a single enclosure, the terminals in the equipment to which the cables from the distribution system are connected. For user equipment consisting of interconnected independent enclosures, the terminals, designated by mutual agreement between the Electrical Power System Designer and the Naval Administration, at which the provisions of this ANEP apply.

f. Unearthed Electrical System

An unearthed electric power system is a system that its neutral and line conductors are intentionally not connected to the metal structure of the ship. An unearthed electric power system can continue to perform normally if one line conductor becomes solidly earthed.

g. Limited Break Supply

A power supply, provided by one or two or more independent power sources, incorporating means for transferring the user equipment load from a power source to another power source within a specified time.

h. Maintained Supply

A no break supply such that supply characteristics are continuously held within the specified limits for a specified limited time. This specified time duration can be from a short break during the transfer over from one power source to another, to time to recovery from a total loss of supply.

i. Pulsed Load

A repetitive random or cyclic load that imposes time-varying power requirements on the system that result in amplitude modulation in voltage and frequency, for example, a SONAR or a RADAR.

A.2. VOLTAGE DEFINITIONS

All AC voltages are root mean square (rms) and all DC voltages are mean values unless otherwise indicated in the text. (All voltage tolerances are expressed as a percentage of the nominal user voltage).

a. Nominal User Voltage Level

The designated line-to-line voltage (line voltage) at the power supply interface (as defined in paragraph A.1.e).

b. User Voltage Tolerance

The maximum permitted departure from nominal user voltage during normal shipboard operations, excluding transient conditions and modulation. User voltage tolerance includes variations as a result of system design (AVR droop, cable losses and drift etc.) and variation caused by the environment (temperature, humidity, vibration, inclination).

c. Line Voltage Unbalance Tolerance

The maximum permitted ratio, expressed as a percentage, between the root mean squares of the negative sequence component and the positive sequence component of the voltage. The line voltage unbalance ratio may be calculated by use of the following formula:

$$\mathbf{K_1^2} = \frac{\mathbf{U_{12}^2 + U_{23}^2 + U_{31}^2 - \sqrt{3\left(U_{12}^2 + U_{23}^2 + U_{31}^2\right)^2 - 6(U_{12}^4 + U_{23}^4 + U_{31}^4)}}}{\mathbf{U_{12}^2 + U_{23}^2 + U_{31}^2 + \sqrt{3\left(U_{12}^2 + U_{23}^2 + U_{31}^2\right)^2 - 6(U_{12}^4 + U_{23}^4 + U_{31}^4)}}}$$

Where U_{12}, U_{23} , U_{31} are the line voltages and K_1 is the voltage unbalance ratio. For an approximation to the true voltage unbalance ratio the following will give good results:

$$\mathbf{K_1} = \frac{\textbf{Maximum deviation of any of the three line voltages from the average line voltage}}{\textbf{Average line voltage}}$$

d. Voltage Modulation

The periodic variation of the user voltage (see Figure 1), such as might be caused by regularly or randomly repeated pulsed loading. For the purposes of measurement the periodicity of voltage modulation is considered to be longer than one cycle time on an AC system.

$$\textbf{Voltage Modulation } (\%) = \frac{\mathbf{(E_{max} - E_{min}) \times 100}}{\mathbf{2 \times E_{nominal}}}$$

Voltages in this formula are to be <u>all</u> rms values, <u>all</u> peak values or <u>all</u> mean values in accordance with Figure 1, <u>never</u> a combination of these values.

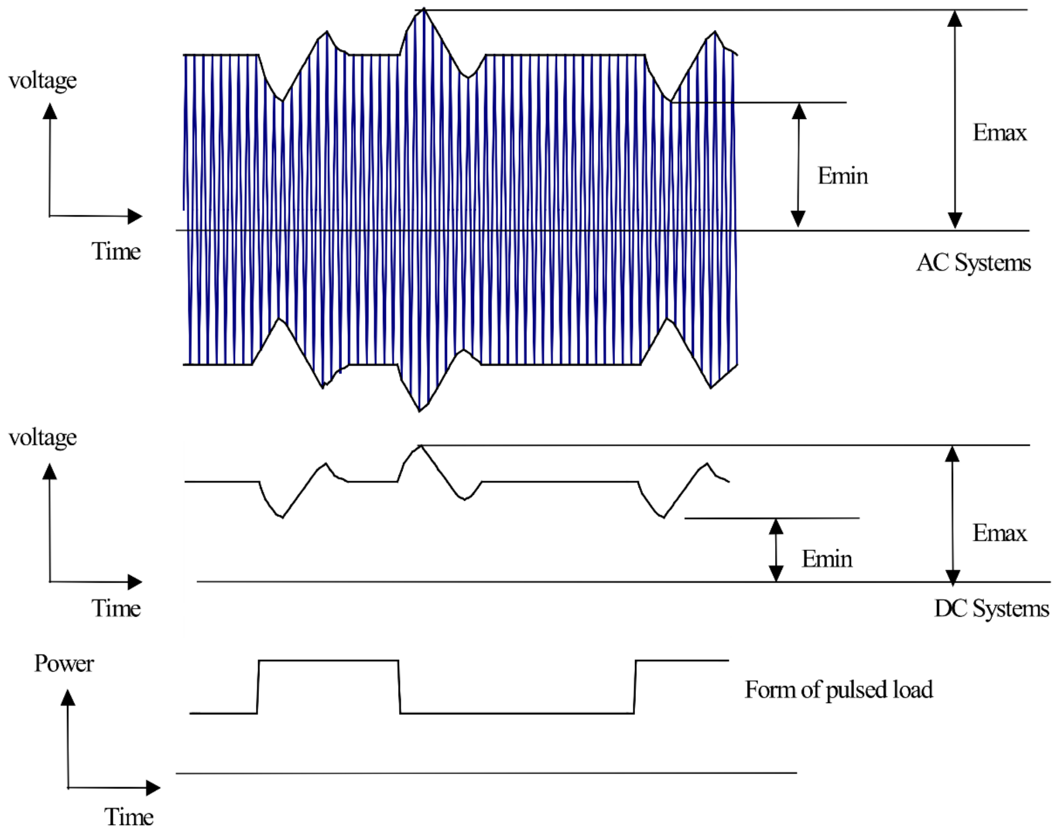

Figure 1: Voltage Modulation

e. Voltage Transient and Voltage Transient Tolerance

A voltage transient (excluding voltage spikes) is a sudden but temporary change in the peak amplitude of the voltage (see Figure 2), which exceeds the user voltage tolerance limits. Typical time duration for voltage transients is between 1ms and 2 seconds for both 60Hz and 400Hz systems.
Transient effects are usually the result of changes in load. The reaction of the prime mover, alternator and associated controls to that change defines the recovery time. Voltage recovery times can be shorter than the original disturbance that caused the transient. A typical example of this is voltage recovery during the start of a large motor load.

f. Voltage Transient Recovery Time

The time elapsed from when the voltage first goes outside the steady state user voltage tolerance limits to when it recovers and remains within the steady state user voltage tolerance limits (see Figure 2 and 8).

g. Voltage Spike

A voltage spike is a disturbance of the voltage waveform with high frequency components and fast rise and decay times which results in the instantaneous value of the voltage departing above or below the instantaneous value of the fundamental component. The amplitude and waveform of voltage spikes will vary greatly, depending on circuit parameters. A voltage spike is usually less than 1ms in duration. Spikes may be individual events or repetitive and are generally of an oscillatory nature and not unidirectional as those often used in testing (see Figure 2). Voltage spikes are the result of all types of switching actions of inductive loads.

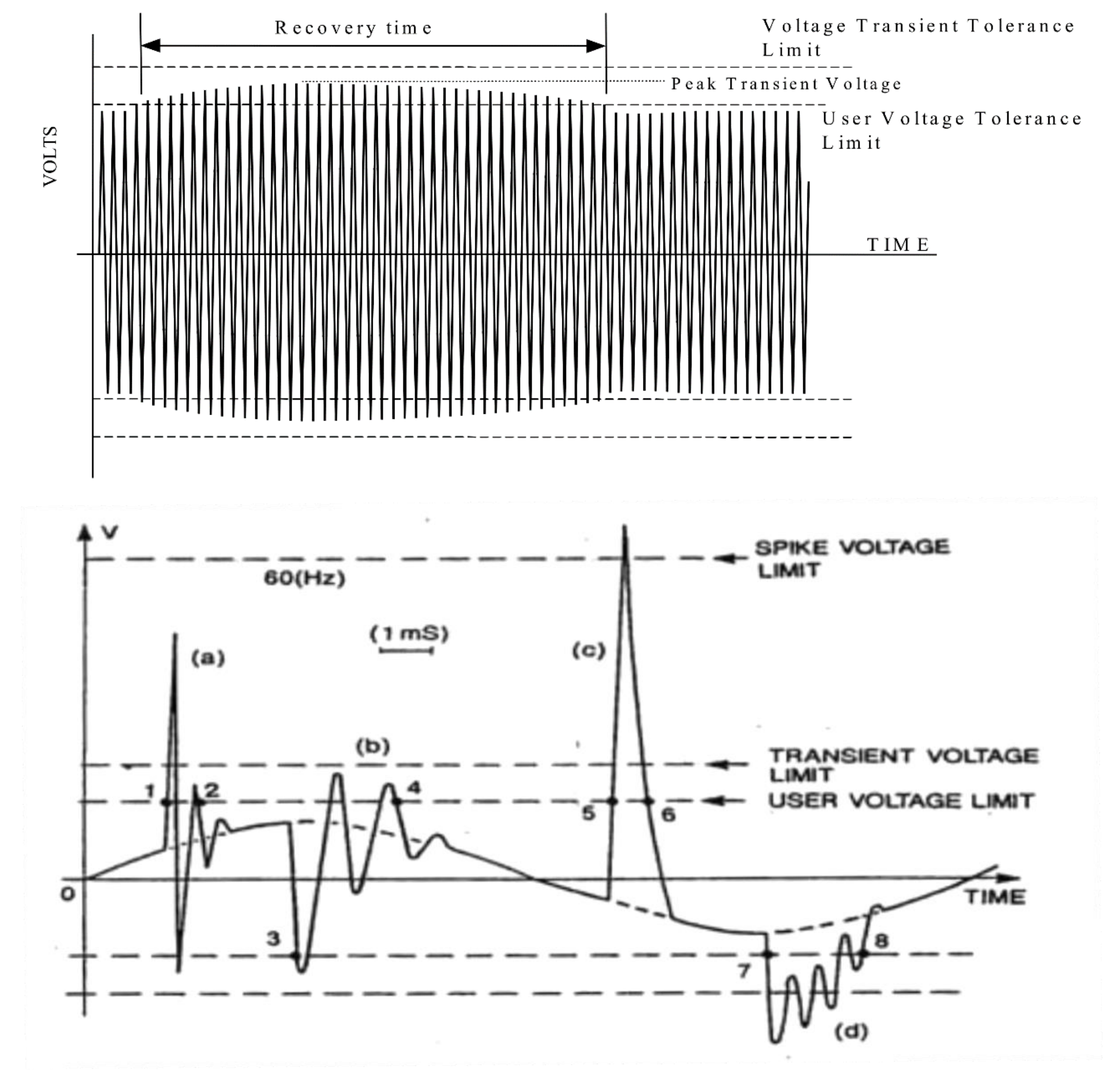

Figure 2: Voltage Transients and Spikes,
(a) Acceptable Spike, (b) Acceptable Transients, (c) Unacceptable Spike, (d) Unacceptable Transient, t(1,2) and t(5,6) < 1msec. t(3,4) and t(7,8) > 1msec

h. **Voltage Waveform**

(1) **Harmonic Content.** A function obtained by subtracting the fundamental waveform from a non-sinusoidal periodic function.

(2) **Total Harmonic Distortion.** The ratio of the rms value of the harmonic content to the rms value of the fundamental component of an alternating quantity (voltage) expressed in percent.

(3) **Harmonic Components.** The terms in the Fourier series for a periodic function excluding the fundamental and DC terms.

(4) **Individual Harmonic.** The value of the individual harmonic of a voltage wave is the ratio of the rms value of the individual harmonic component to the rms value of the fundamental, expressed in percent.

(5) **Deviation Factor** (see Figure 3). The maximum difference between corresponding ordinates of the wave and an equivalent sine wave (same rms value, frequency and having a phase relationship such as to make the difference as small as possible) expressed as a percent of the maximum ordinate of the equivalent sine wave (see Ref. [01], [02], [03]).

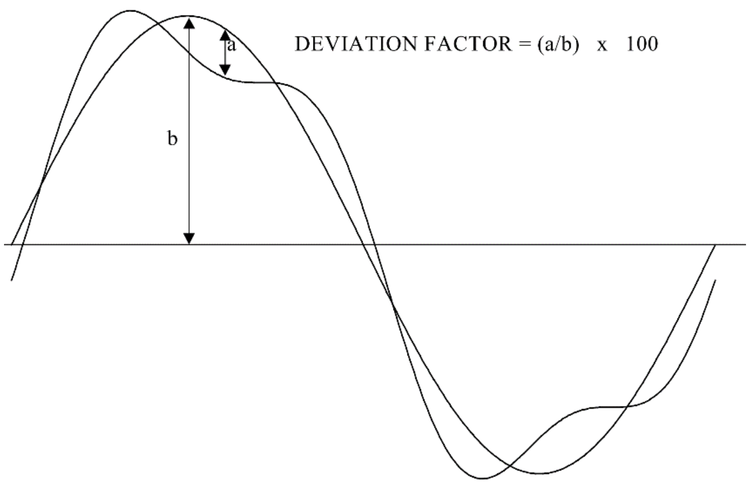

Figure 3: Deviation Factor

(6) **Ripple Voltage** (see Figure 4). The alternating voltage component of the uni-directional voltage from a direct current power supply. The frequency of the ripple voltage is always greater than or equal to the input power supply frequency.

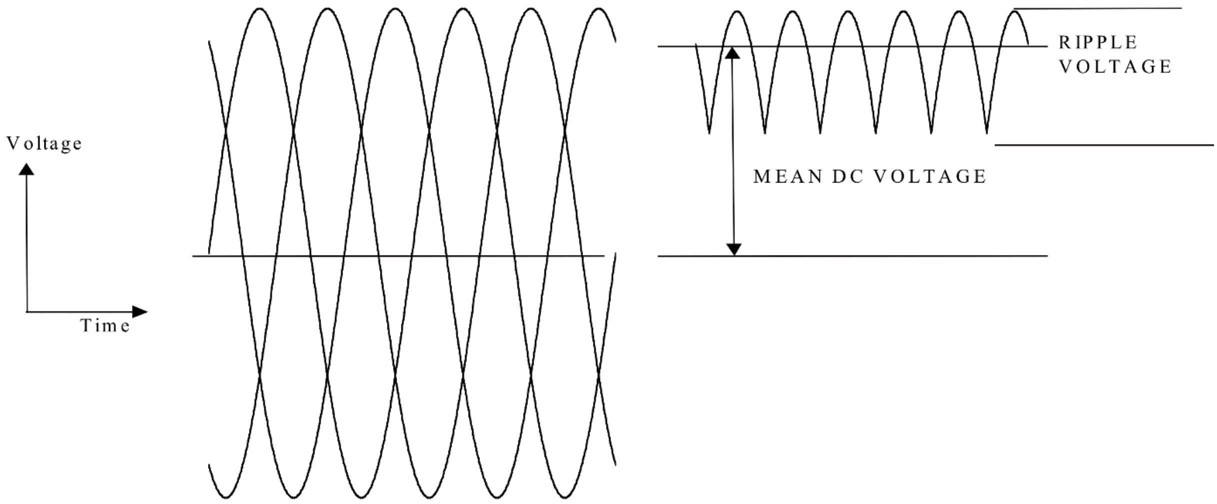

Figure 4: Voltage Ripple of a Rectified AC Supply

A.3. FREQUENCY DEFINITIONS

All frequencies are expressed in Hertz and all tolerances are expressed in percentage of the nominal frequency.

a. **Nominal Frequency**

The designated frequency in Hertz of the alternating current system.

b. **Frequency Tolerance**

The maximum permitted departure from nominal frequency during normal operation, excluding transient and frequency modulation. This includes variations as a result of system design (Governor droop, drift etc.) and variation caused by the environment (temperature, humidity, vibration, inclination etc.).

c. **Frequency Modulation**

The periodic variation of the frequency such as might be caused by regularly or randomly repeated loading (see Figure 5). For purposes of measurement the periodicity of Frequency Modulation is considered to be longer than 1 cycle time.

$$\textbf{Frequency Modulation}\ (\%) = \frac{(\mathbf{F_{max}} - \mathbf{F_{min}}) \times \mathbf{100}}{\mathbf{2} \times \mathbf{F_{nominal}}}$$

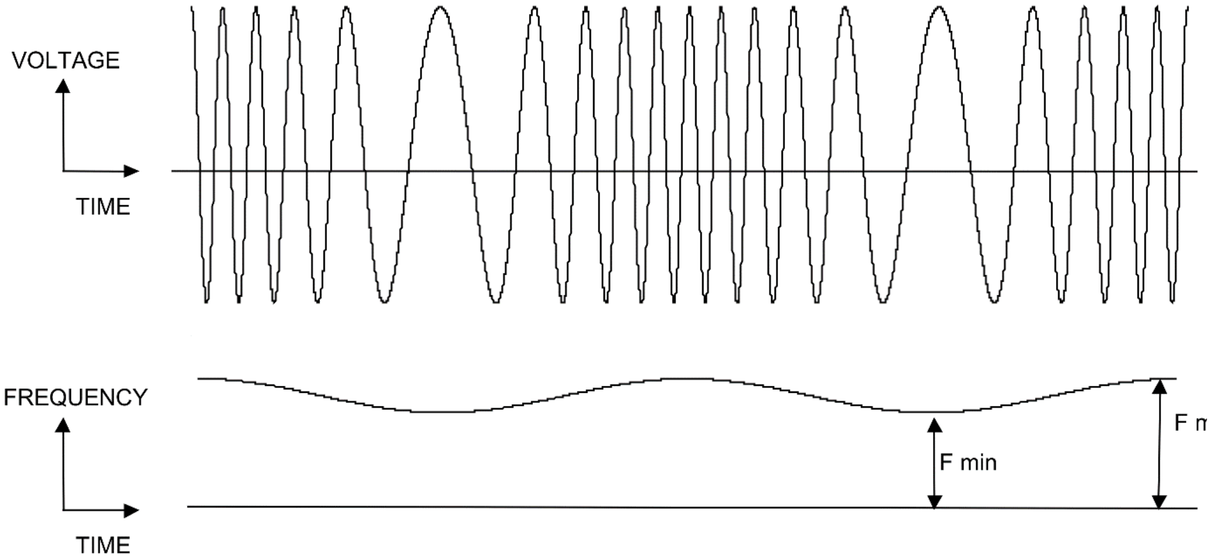

Figure 5: Frequency Modulation

d. **Frequency Transient and Frequency Transient Tolerance**

A sudden change in frequency which goes outside the frequency tolerance limits and returns to and remains inside these limits within a specified recovery time after the initiation of the disturbance. The frequency transient tolerance is in addition to the frequency tolerance limits.

e. **Frequency Transient Recovery Time**

The time elapsed from when the frequency first goes outside the frequency tolerance limits and when the frequency recovers and remains within the frequency tolerance limits.

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ANNEX B USER INFORMATION AND CONSTRAINS

B.1. GENERAL

a. In order to prevent the need for conversion equipment, the ships should be provided with a 440V 60Hz 3-phase electrical distribution system in order to supply directly user equipment requiring such electrical supply source. The only permitted exception to this policy are vessels such as hovercraft etc., employing aircraft practice. 440V 60 Hz system can be either the main distribution and generation system of the ship or can be derived from it if this is operated at different voltage (and/or frequency) values.

b. Where existing weapon systems designated for other supplies, must be fitted in new ships, local limited supply systems derived from the main supply may be provided if it is not cost-effective for the whole ship to modify equipment to operate on 440V 60Hz 3-phase.

c. Where a supply at higher frequency must be provided for the above reasons it is preferred to be at 400Hz, to the requirements of this ANEP.

d. Similarly, where low-voltage DC supplies must be provided they are preferred to be at 24V, to the requirements of this ANEP.

e. This ANEP does not apply to user equipment directly connected to special purpose power sources such as electrical propulsion system buses and submarine batteries.

f. All loads of 5kVA and above should be 3-phase and supplied at 440V 60Hz. This is also preferred for loads of less than 5kVA, but where this is either undesirable or not practicable, the following shall be the order of preference:

(1) 115V 60Hz 3 phase 3 wire, Unearthed

(2) 115V 60Hz 1 phase 2 wire, Unearthed

(3) 230V 60Hz 1 phase 2 wire, Unearthed

(4) 440V 60Hz 1 phase 2 wire, Unearthed

g. Equipment conditioning devices, e.g. anti-condensation heaters, should be designed for connection to 115V supplies.

B.2. EARTHING

a. The ship's supply system covered by this ANEP are unearthed and user equipment must not introduce direct or indirect connections between supply lines and earth, except for electro-magnetic interference suppression, insulation monitoring devices (IMD), surge suppression or for occasional test or maintenance purposes. Only capacitive earthing for EMI suppression is allowed, however this must remain within the limits of paragraph B.9.b. Where greater values are considered or where earthed circuits are considered essential, then the equipment must be isolated from the ship's supply system, e.g. using transformers or motor-generator sets.

b. Designers should note that the magnitude of individual phase voltages to earth will vary and are not necessarily equal:

(1) Each phase to earth may be subjected to full system voltage during low resistance earth faults on the power system.

(2) Voltage spikes up to 2.5kV amplitude may be experienced between a line and earth.

(3) Full phase voltage may occur between earth and any artificially created neutral point.

(4) Voltage waveform to earth may contain appreciable triple harmonic distortion.

(5) Earth faults on directly coupled (i.e. not transformer isolated) DC conversion systems may be reflected and rotated around each phase of the AC system at harmonic frequencies equivalent to the rectifier pulse number. This condition may result in AC lines carrying DC voltage levels of up to 300V to earth.

c. Power system conductors will normally have some capacitance to earth, and earth faults having inductance in the fault path can result in sustained phase-to-earth voltages exceeding the full system line-to-line voltage. For balanced systems the maximum voltage can be 105% of the line to line voltage, and for unbalance systems this can be 115%.

B.3. LIMITED BREAK AND MAINTAINED SUPPLIES

Limited break and maintained supplies may be provided for user equipment. For limited break supplies, time for which power is interrupted will be typically greater than a quarter electrical cycle but less than 30 seconds, depending on whether the changeover switch is a mechanical transfer switch (MTS), static transfer switch (STS) or manual switch. For user equipment requiring maintained supplies the preferred approach is for the equipment supplier to provide the alternative source of power (an energy storage device) and the power conditioning equipment required to maintain power to the equipment during loss of ship's power. Where the energy storage device has an impact on the electrical system or installation, then the equipment supplier must ensure early coordination with Naval Administration and the Electrical Power System Designer.

B.4. NON-STANDARD SUPPLIES

The provision of non-standard supplies will be strongly resisted and requests for such supplies shall be notified to the relevant Electrical Power System Designer and Naval Administration at an early state of the design. Approval is to be obtained before entering into any commitment.

B.5. LOAD UNBALANCE

If a three-phase load is composed of single-phase loads or three-phase loads or both single-phase and three-phase loads it is necessary to limit the resulting difference between the highest and lowest line currents under normal operating conditions in order to prevent the limitation on line voltage unbalance being violated. A useful practical guideline to apply to equipment line currents has been found to be that the difference between the highest and lowest line currents under normal operating conditions should not exceed 5% of the arithmetic sum of the three full-load line currents for that equipment.

B.6. WAVEFORM DISTORTION

User equipment specifications, or early consultation with the Electrical Power System Designer and Naval Administration, should ensure that the consuming equipment will not cause distortion in the voltage waveform of the power supply to levels sufficient to exceed the voltage waveform tolerances of the power supply system. This would normally be achieved by designing equipment to draw alternating current that is closely sinusoidal. If non-sinusoidal current demand is essential, the effects on the power supply system should be minimized by:

a. Provision of filters in the consuming equipment or sub-system.

b. Other suitable means, such as appropriate power converters.

c. Consultation with the Electrical Power System Designer and Naval

Administration, if the limit of the specified values will be exceeded.

The above applies particularly to equipment employing electronic switches operating once, or more than once, per-cycle of the power supply voltage.

B.7. PULSE LOADS

User equipment which demands frequent or regular repeated power input shall have such demands restricted in relation to the normal generating capacity of the system, to avoid exceeding the specified system modulation tolerances for frequency and voltage. This will be achieved by:

a. Limiting the rating of pulse load equipment,

b. Provision of kinetic or electrical energy storage and re-emission,

c. Early consultation with the Electrical Power System Designer and Naval Administration,

d. Other suitable means.

B.8. VOLTAGE SPIKES

On AC systems, line-to-line and line-to-earth spikes should not exceed 2500V (440V), 1400V (230V) or 1000V (115V) in amplitude. A standard lightning-impulse voltage, as defined in IEC publication 60060 – 1 (see Ref. [04]), with a crest (peak) level of 2500V (440V), 1400V (230V) or 1000V (115V) is recommended for test purposes. This test waveform has been calculated to give an energy level of approximately 100 Joules into a 2 ohm load. The standard lightning impulse shown in Figure 6a is the characteristic voltage spike used for test purposes. The Ring Wave 0.5μsec-100kHz, shown in Fig. 6b may also be used according to the IEEE "Surge-Trilogy" (see Ref. [05]).

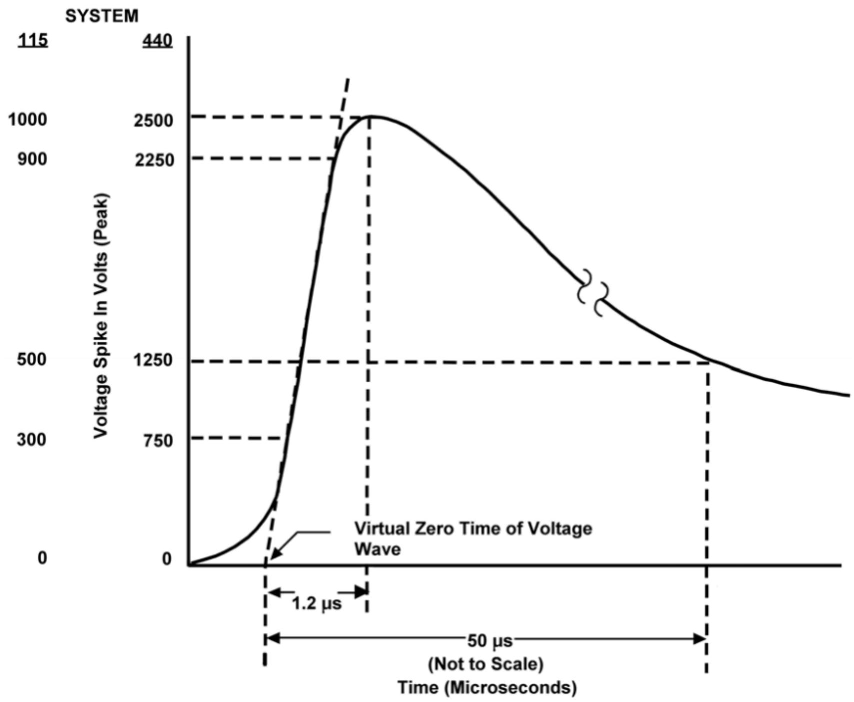


Figure 6a: Voltage Spike Test Waveform

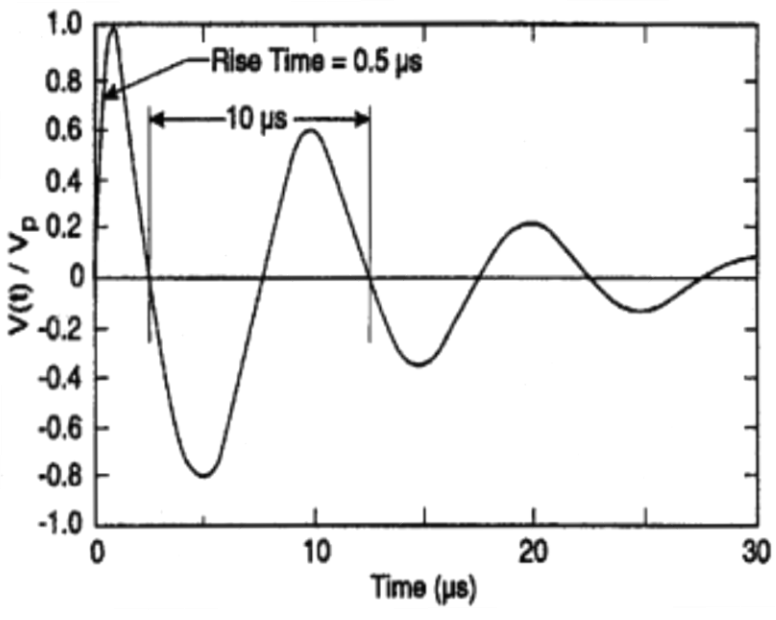


Figure 6b: Voltage Spike Test Waveform

B.9. DESIGN CONSTRAINS

The following illustrate the principles which are both necessary and sensible to avoid one user creating disturbances which adversely affect other users. Equipment conforming to the following specific constraints will normally be acceptable for all ships of the NATO navies. Equipment designers should, as early as possible, notify the Electrical Power System Designer and Naval Administration if their equipment exceeds these design constraints.

a. User equipment shall be constructed to limit the ratio of surge current to normal operating current. The crest (peak) value of any inrush/starting current on a circuit is normally to be less than 10 times its full load rms current. For 60Hz transformers rated at 10kVA or greater 25x rated full load rms current is acceptable. For transformers of smaller rating inrush currents higher than 25x rated full load current is acceptable. Furthermore, starting currents on 440V motor circuits are to be limited as follows:

Motor Starting Current (% of Generator Rated Current)	Generator Size [kVA]
50	<800
45	800 to 1600
40	>1600

b. Capacitance is introduced in the power system either by means of stray capacitance (i.e. leakage capacitance of power cables) as capacitance intended to provide EMI/RFI suppression to sensitive equipment, etc. Filters utilized by devices establish low impedance paths for common-mode currents through the ground plane and can be a major cause of interference in systems, platforms, or installations because the currents can couple into other equipment using the same ground plane. Furthermore, increased values of capacitance could potentially cause disruptions in the operation of insulation monitor devices. If such equipment must be employed, the line-to-ground capacitance for each line shall not exceed 0.1 microfarads (μF) for 60 Hertz (Hz) equipment or 0.02 μF for 400 Hz equipment. For DC-powered equipment, the filter capacitance from each line-to-ground at the user interface shall not exceed 0.075 μF/kW of connected load. For DC loads less than 0.5 kW, the filter capacitance shall not exceed 0.03μF. The above limits are not to be exceeded without previous notification and approval of the Electrical Power System Designer and Naval Administration who may require the isolation of such capacitance by means of isolation transformers.

c. The operation of user equipment should have the minimum harmonic distortion effect on the electrical system. If the sum of the power of all loads which distort the current waveform (power electronic converters etc.) connected to the supply system is less than 1% of the short circuit power of the generation capacity, with the largest single distorting load less than 0.5%, normally no measures are necessary to reduce the current harmonics (e.g..12-pulse rectifiers, filters etc.). This limit can be further extended to 2% of the short circuit power of the generation

capacity without additional measures for reduction of current harmonics, if this load is due to the sum of only small distorting equipment, each less than 0.1% of the short circuit power of the generation capacity.
If any of these limits will be reached or exceeded by the distorting load, analyses to whether the ANEP-100 requirements are still met with respect to voltage harmonics and an early co-ordination between the Electrical Power System Designer, Naval Administration and the equipment manufacturer should be undertaken. A minimum of six-pulse rectification is preferred for individual distorting loads. As a useful approximation of the short circuit the following equation may be taken:

$$S_{sc} = 100 \times \frac{S_n}{x''_d\%}$$

Where,

S_{sc}= equivalent short circuit apparent power of the supply system in kVA,
S_n = equivalent nominal apparent power of the feeding generators, in kVA and
$x''_d\%$ = equivalent subtransient reactance of the feeding generators in percent.

$\sum P_{distort} < 1\% \, S_{sc}$ with $P_{distort} < 0.5\% \, S_{sc}$	No measures to be taken.
$\sum P_{distort} < 2\% \, S_{sc}$ with $P_{distort} < 0.1\% \, S_{sc}$	No measures to be taken.
$P_{distort} \geq 0.5\% \, S_{sc}$ Or $\sum P_{distort} \geq 2\% \, S_{sc}$ Or $1\% \, S_{sc} < \sum P_{distort} < 2\% \, S_{sc}$ but $P_{distort} \geq 0.1 \, \% \, S_{sc}$	Conduct analysis to ensure ANEP-100 requirements are still met with respect to Voltage Harmonics. Early co-ordination between Electrical Power System Designer, equipment designer/manufacturer and Naval Administration is required to determine methods of distortion reduction i.e. 12 pulse rectification, filters etc.

This guideline may be applied to 230V or 115V 3-phase systems fed by transformers as well. In this case the short circuit power provided by the transformer is to be used.

For systems operating parallel generators the system design should take account of the worst case – e.g. minimum number of generators able to sustain the loads, according to the vessel electric load balance reference document - normal operating configuration of generators, and not for extreme or abnormal operating conditions.

d. Pulse loads should not exceed the limits specified in subparagraphs d.(1) and d.(2) below since that will cause voltage and frequency modulations exceeding the limits of this power supply standard. These limits remain applicable to all power factors of the pulsed load.
If such a load, as limited in d.(1) and d.(2), cannot be avoided, the Electrical Power System Designer and Naval Administration is to be consulted so corrective action can be determined.

(1) In case that insufficient information of system's parameters exist the pulsed loads should not exceed the limits specified in the equations below. Figure 7 is a graphical representation of them.

$$Q_{pulse} < 6.5\% \text{ of } S_{supply} \text{ and } P_{pulse} < 25\% \text{ of } S_{supply}$$

Or (see Ref. [06]),

$$\cos\varphi > \sqrt{1 - \left(\frac{a}{S_{pulse}}\right)^2}, a = 0.065 \text{ and } \cos\varphi < \frac{\beta}{S_{pulse}}, \beta = 0.25$$

Where,

Q_{pulse}= Reactive power (kVar) of the pulsed load,
P_{pulse} = Real Power (kW) of the pulsed load and
S_{pulse} = Full Rated Apparent Power (kVA) of the supply at the occurrence of the pulse.

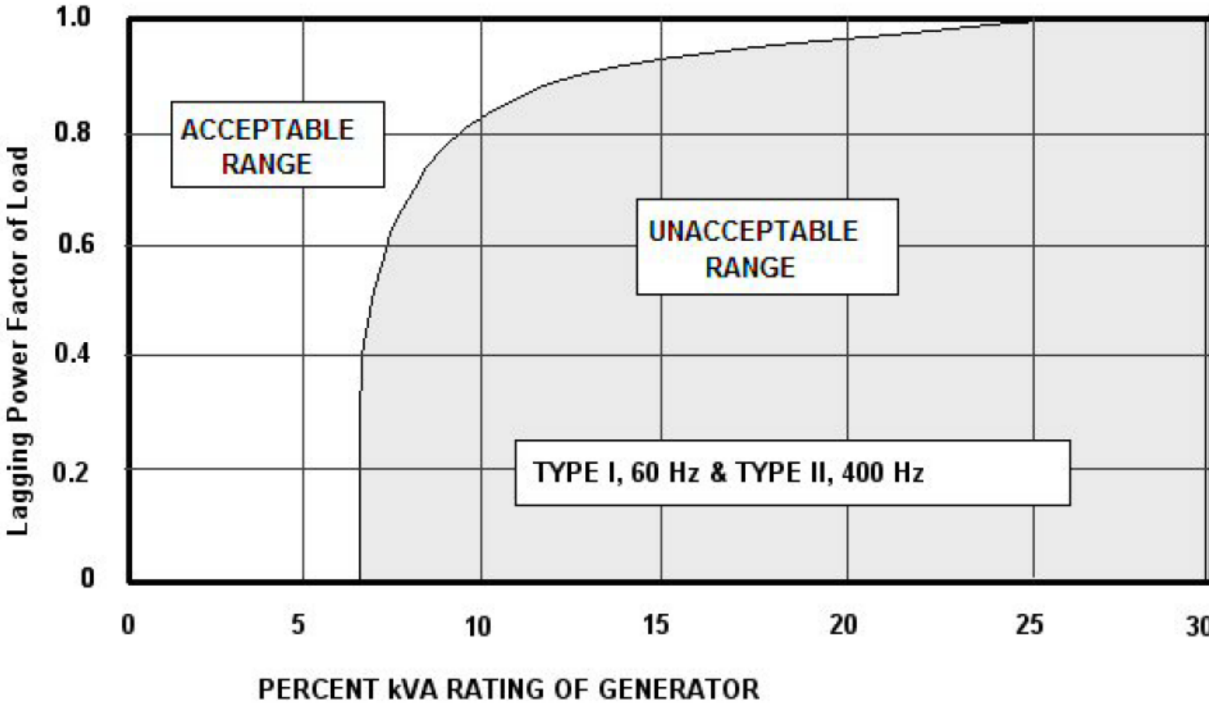


Figure 7: Pulsed Load Limitations

(2) Whereas the equations and the diagram of paragraph d.(1) provide a good approximation of pulse load limitations, a more detailed description of pulsed loads' limitations can be obtained in case that sufficient information of electrical system's parameters exist (see Ref. [07]).
The parameters of the system that determine system's response on pulse loads are shown in the following table, while associated equations for accurate calculations can be found in the literature. (see Ref. [08]).

$\mathbf{R + j \cdot X_c}$	Equivalent cable impedance between generator output and load (p.u.)
$\mathbf{X'}$	Electric generator reactance, respectively. (p.u.)
$\mathbf{X = X' + X_c}$	
$\mathbf{J'}$	Rotor inertia (sec)
$\mathbf{f_n}$	Nominal frequency (p.u.)
$\mathbf{S_{L0}}$	System load apparent power before the occurrence of the pulsed load (p.u.)
$\mathbf{T}$	Pulsed load period
$\mathbf{dc}$	Pulsed load duty cycle (-)
$\mathbf{\cos\varphi}$	Pulsed load power factor (-)
$\mathbf{V_{G0}}$	Voltage at the generator ends before the occurrence of the pulsed load
$\mathbf{V_{L0}}$	Voltage at pulsed load connection point before the occurrence of the pulsed load
$\mathbf{K, K_I}$	Proportional and integral gain of automatic voltage regulator

$\mathbf{R_f, K_{fI}}$	Proportional and integral gain of automatic frequency regulator
$\mathbf{Q_{pulse}}$	Reactive power of the pulsed load (p.u)
$\mathbf{P_{pulse}}$	Real power of the pulsed load (p.u)
$\mathbf{S_{pulse}}$	Apparent power of the pulsed load (p.u)
$\mathbf{S_{supply}}$	Full Rated Apparent power of the supply at the occurrence of the pulse(p.u)
$\mathbf{M_V^{lim}}$	Voltage modulation limit.
$\mathbf{M_f^{lim}}$	Frequency modulation limit.
	All quantities are referred to p.u. system. S_{supply} is used as base power.

e. Where more than one ship supply input to user equipment is provided then:

(1) Paralleling of the AC system at the user equipment is expressly forbidden.

(2) Paralleling after a DC conversion stage is only permitted with transformer isolation on the AC input.

ANNEX C CHARACTERISTICS OF STANDARD ELECTRICAL POWER SUPPLIES

C.1. PHASE SEQUENCE

Terminals of electrical power supplies should be designated in accordance with IEC 60445 by using an alphanumeric notation.

C.2. CHARACTERISTICS OF STANDARD 60Hz SUPPLIES

Voltage	Nominal User Voltage	440Vac 230Vac or 115Vac
	Steady State User Voltage Tolerances	
	Average of three line-to-line voltages (1)	± 5%
	Any one line-to-line voltage including (1) above and (2) below.	± 7%
	Line voltage unbalance tolerance (2)	2%
	Voltage Modulation (3)	2%
	Maximum departure for the average of three line to line voltages due to combined effects of (1), (2) and (3)	± 6%
	Maximum departure for any line to line voltage due to combined effects of (1), (2) and (3)	± 8%
	Voltage Transient Excursions*	
	Voltage Transient tolerance	± 16%
	Maximum excursion due to the combined effects of these transients and (1), (2) and (3) for the average of three line to line voltages	± 20%
	Maximum excursion due to the combined effects of these transients and (1), (2) and (3) for any line to line voltage	± 22%
	Voltage transient recovery time (see Figure 8)	2 seconds
	Voltage spike (peak value, includes fundamental) (see Ref. [01], [09])	2.5kV (440 V) 1.4kV (230V) 1kV (115V)
Voltage Waveform	Total Harmonic Distortion**(Maximum)	5%
	Individual Harmonic (Maximum)	3%
	Deviation Factor	5%
Frequency	Nominal Frequency	60Hz
	Frequency Tolerance (4)	± 3%
	Frequency Modulation (5)	0.5%
	Frequency Transient Tolerance (6)	± 4%
	Maximum Departure from the Nominal Frequency due to the combined effects of (4), (5) and (6)	± 5.5%
	Frequency Transient Recovery Time	2 seconds

*** Transient duration between 1m-second and 1 cycle see Figure 8 (see Ref. [10]).**
**** Calculation of voltage waveform THD should include all frequencies up to 50 times the supply frequency.**

C.3. CHARACTERISTICS OF STANDARD 400Hz SUPPLIES

Voltage	Nominal User Voltage	440Vac or 115Vac
	Steady State User Voltage Tolerances	
	Average of three line-to-line voltages (1)	± 5%
	Any one line-to-line voltage including (1) above and (2) below.	± 7%
	Line voltage unbalance tolerance (2)	2%
	Voltage Modulation (3)	2%
	Maximum departure for the average of three line to line voltages due to combined effects of (1), (2) and (3)	± 6%
	Maximum departure for any line to line voltage due to combined effects of (1), (2) and (3)	± 8%
	Voltage Transient Excursions*	
	Voltage Transient tolerance	± 16%
	Maximum excursion due to the combined effects of these transients and (1), (2) and (3) for the average of three line to line voltages	± 20%
	Maximum excursion due to the combined effects of these transients and (1), (2) and (3) for any line to line voltage	± 22%
	Voltage transient recovery time (see Figure 8)	2 seconds
	Voltage spike (peak value, includes fundamental) (see Ref. [01], [09])	2.5kV (440V) 1 kV (115V)
Voltage Waveform	Total Harmonic Distortion**(Maximum)	5%
	Individual Harmonic (Maximum)	3%
	Deviation Factor	5%
Frequency	Nominal Frequency	400Hz
	Frequency Tolerance (4)	±5%
	Frequency Modulation (5)	0.5%
	Frequency Transient Tolerance (6)	±4%
	Maximum Departure from the Nominal Frequency due to the combined effects of (4), (5) and (6)	±6.5%
	Frequency Transient Recovery Time	2 seconds

*** Transient duration between 1m-second and 1 cycle see Figure 8 (see Ref. [10]).**
**** Calculation of voltage waveform THD should include all frequencies up to 50 times the supply frequency.**

C.4. CHARACTERISTICS OF STANDARD LOW VOLTAGE DC SUPPLIES (EXCLUDING AIRCRAFT SUPPLIES)

The table below describes the standard for centralized 24/28V DC systems and not equipment that is supplied from dedicated power supplies. In this latter application the standard of the power supply should meet the requirements of the equipment it is supplying. Minimum voltage in these cases is usually 20V. In centralised systems, the power system Electrical Power System Designer should take account of the cable voltage drop in order to guarantee the voltage supplied at the equipment terminals. This may enable equipment, not essential to ship operation, to be connected directly to a centralised system although they only operate down to 20V. In these cases the equipment should isolate itself from the system when the voltage falls below 20V.

Nominal User Voltage	24/28 V
User voltage limits (see Note A)	
a. Normal	22 - 30 V
b. Emergency (see Note B)	18 - 30 V
c. Abnormal (see Note C)	32V
Voltage Modulation (see Figure 1)	2%
Ripple Peak-to-Peak (see Figure 4)	2.5V
Voltage Transient Upper Limit Lower Limit	 35V 18V
Voltage Spike (Peak Value)	600V
Voltage transient recovery time (see Figure 9)	2 seconds

Note A Voltage modulation and ripple variations are additional to nominal user voltage and transient limits.

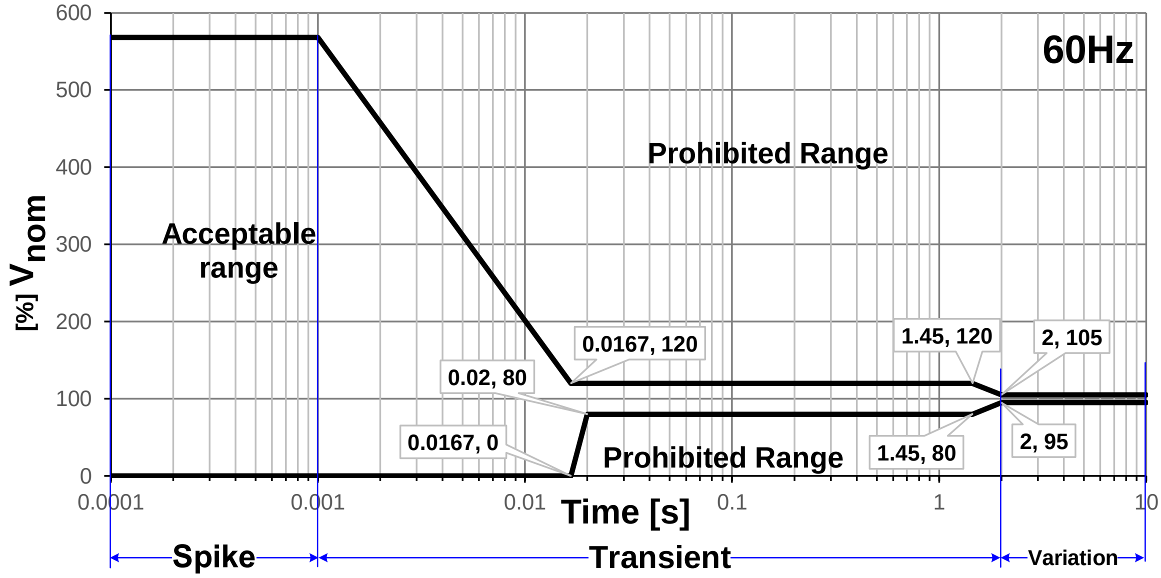
Note B "Emergency" is the condition existing when the battery charger has ceased to function. It also relates to the condition where through excessive discharge, battery voltage is collapsing down to 0 volts. Under this condition equipment must not suffer damage.

Note C "Abnormal" is the condition existing when, through fault or other reasons, the battery is at top of charge. This is a rare condition for which equipment designated as vital must maintain its operational efficiency without deterioration for periods of at least 2 hours.

C.5. CHARACTERISTICS OF ELECTRICAL SUPPLY DURING ABNORMAL SUPPLY CONDITIONS

Characteristics of electrical supply (for protection purposes) during abnormal supply conditions, due to malfunctions within power generation system such as the automatic voltage regulator or the driving engine speed governor:

Nominal Voltage Nominal Frequency	440V, 230V or 115V 60Hz	Time Duration
Voltage	+50%	2 minutes
Frequency	-10% to +17%	2 minutes



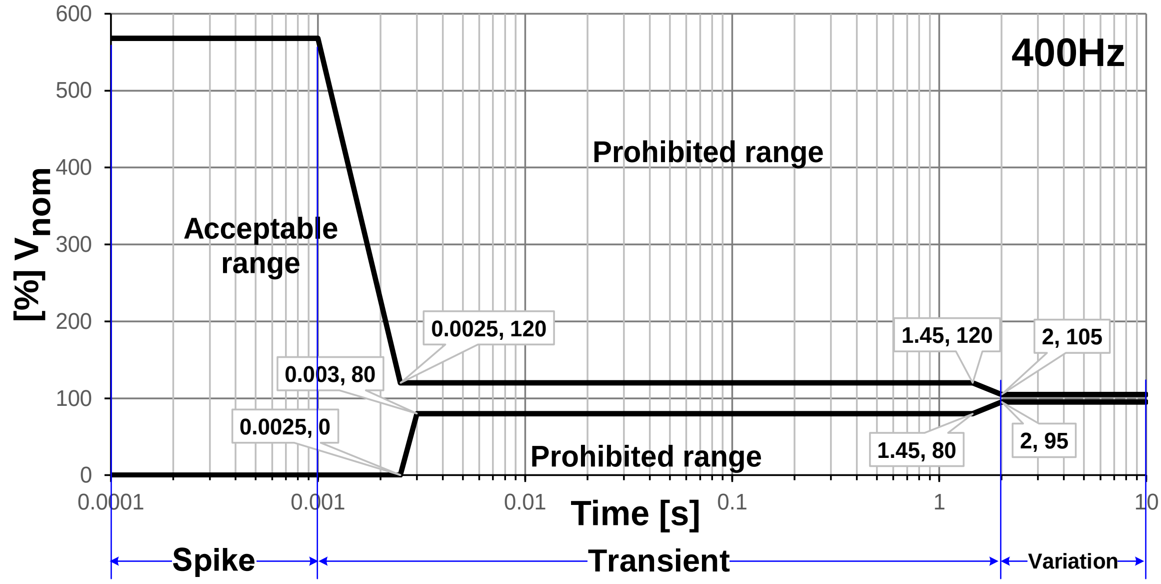


Figure 8: Voltage Spike, Transient & Variation Characteristics of 60 Hz & 400Hz Supplies

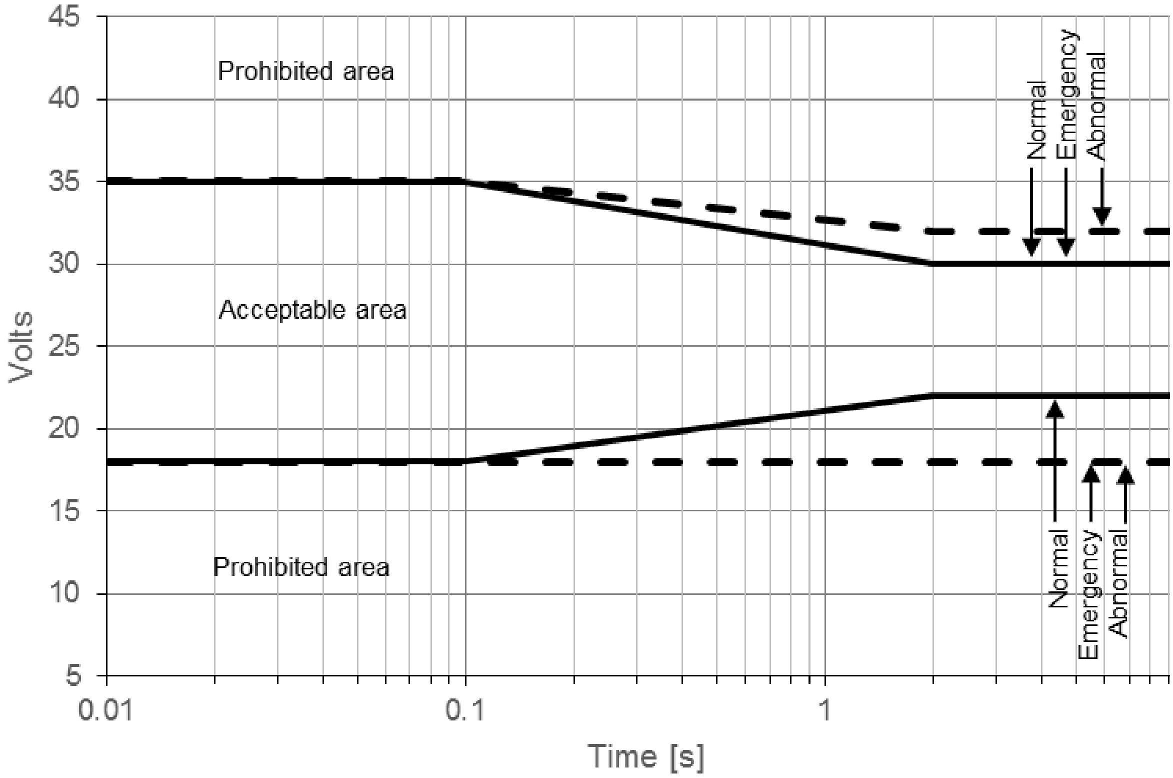


Figure 9: DC Voltage Transient Envelope

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ANNEX D LIST OF REFERENCES FOR ANEP-100

[01] – U.S. MIL-STD-1399 (NAVY) – Section 300B, 24 April 2008, “ELECTRIC POWER, ALTERNATING CURRENT”.

[02] – F. Scuiller, B. Keruel and M. Richard, "Voltage deviation factor analysis and meaning for warship electric power system," 2011 IEEE Electric Ship Technologies Symposium, Alexandria, VA, 2011, pp. 434-438.doi: 10.1109/ESTS.2011.5770911.

[03] – MIL-STD-705C, ‘GENERATOR SETS, ENGINE DRIVEN, METHODS OF TESTS AND INSTRUCTIONS’, part 601.5 (voltage waveform test, deviation factor), 24 April 1989.

[04] – IEC publication 60060 – 1 High-voltage test techniques - Part 1: General definitions and test requirements

[05] – IEEE “Surge-Trilogy” (Std C62.41.1TM-2002, Std C62.41.2TM-2002 and Std C62.45-2002).”

[06] – 35(US)12.04- 06Sep2012 : STANAG 1008 Pulsed Loads / Modulation.

[07] – F. Kanellos, I.K. Hatzilau, J. Prousalidis“ Investigation of Voltage/Frequency Modulation in Ship Electric Networks with Pulsed Loads according to STANAG 1008 Design Constraints ”Proceedings of“AES 2007 , The Vision Redrawn“, All Electric Ship 2007 International Conference and Exhibition, IMarEST & SEE, 25,26 September 2007, London/U.K.

[08] – G.J. Tsekouras, F.D. Kanellos, J.M. Prousalidis, I.K. Hatzilau, “Implementation Limitations of STANAG 1008 Design Constraints for Pulsed Loads”, Nausivios Chora, A Journal in Naval Sciences and Technology, pp. 110-135, ISSN: 1791-4469, 2012 Hellenic Naval Academy.

[09] – S. F. Cannova, "Short-Time Voltage Transients in Shipboard Electrical Systems," in IEEE Transactions on Industry Applications, vol. IA-9, no. 5, pp. 533-538, Sept. 1973.doi: 10.1109/TIA.1973.349926.

[10] – UK DEF STAN 61-5 Part 4-Issue 4-19 May 2006 (“Low Voltage Electrical Power Supply Systems - Quality of Electrical Power Systems in HM Ships”).

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ANNEX E NATIONAL SPECIFICATIONS OF MEMBER COUNTRIES

Belgium	-
Canada	D-03-003-005/SF-000, General Electrical Specification for Canadian Forces Ships
France	Marine Nationale – Constructions Et Armes Navales – Fascicule E509
Federal Republic Of Germany	Bauvorschrift Fur Schiffe Der Bundeswehr Marine • Heft 3000-1 E-Anlagen, Planung Und Allgemeine Richtlinien • Heft 3400 E-Anlagen Kabelanlagen ▪ Vol 3000-1 Electricity Systems, Planning And General Guidelines ▪ Vol 3400 Electricity Systems, Cable Systems
Greece	-
Italy	• General specification for Italian Navy Ships electrical plants, NAV-80-6160-0024-14-00B000
Netherlands	-
Norway	The Royal Norwegian Standard Requirement and Regulation (NRAR)
Portugal	-
Spain	-
United Kingdom	Defence Standard 61/5 Part 4 – 14
United States	Mil-Std-1399 (Navy) Section 300B – 24 April 2008

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