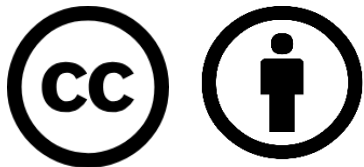


Electrical Distribution System Power Characteristics

Ship Electrical Distribution System Design

Revision of September 23, 2026

Dr. Norbert Doerry



<http://doerry.org/norbert/MarineElectricalPowerSystems/index.htm>

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Essential Questions

What are the principal features of a primary bus, distribution bus, secondary bus, and special bus?	Understand
What are the sources of power quality requirements?	Understand
What is Quality of Service?	Understand
What terms (and what do they mean) are used to describe power quality and quality of service?	Understand

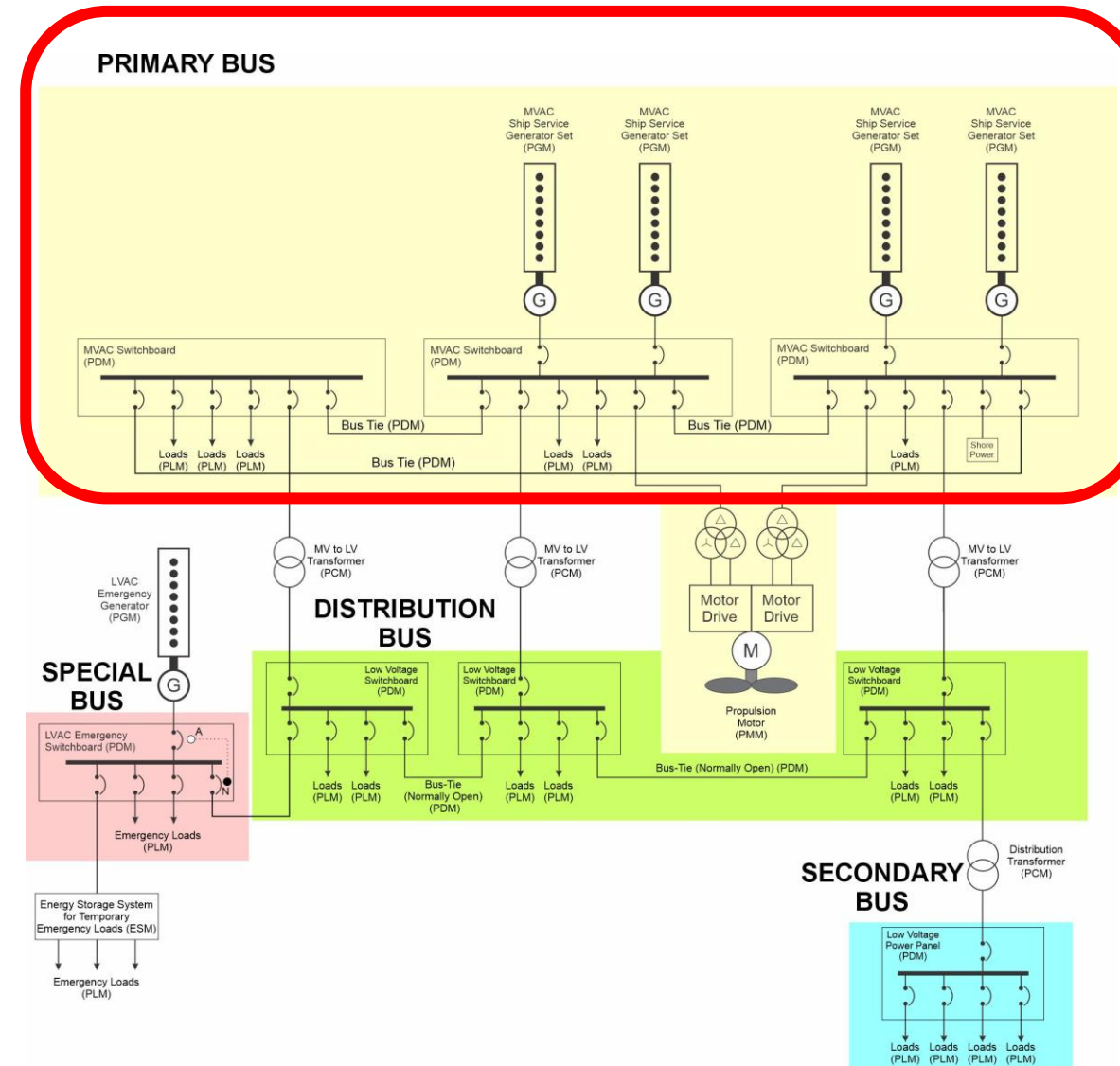
Characteristics of shipboard power systems (As compared to terrestrial systems)

- Frequency is not a constant
- Lack of time scale separation
- Load sharing instead of power scheduling
- Short electrical distances
- Load dynamics may be important
- Tighter control
- Ungrounded or high-resistance grounded systems
- Physical environment

Primary Bus

IEEE Std 45.1

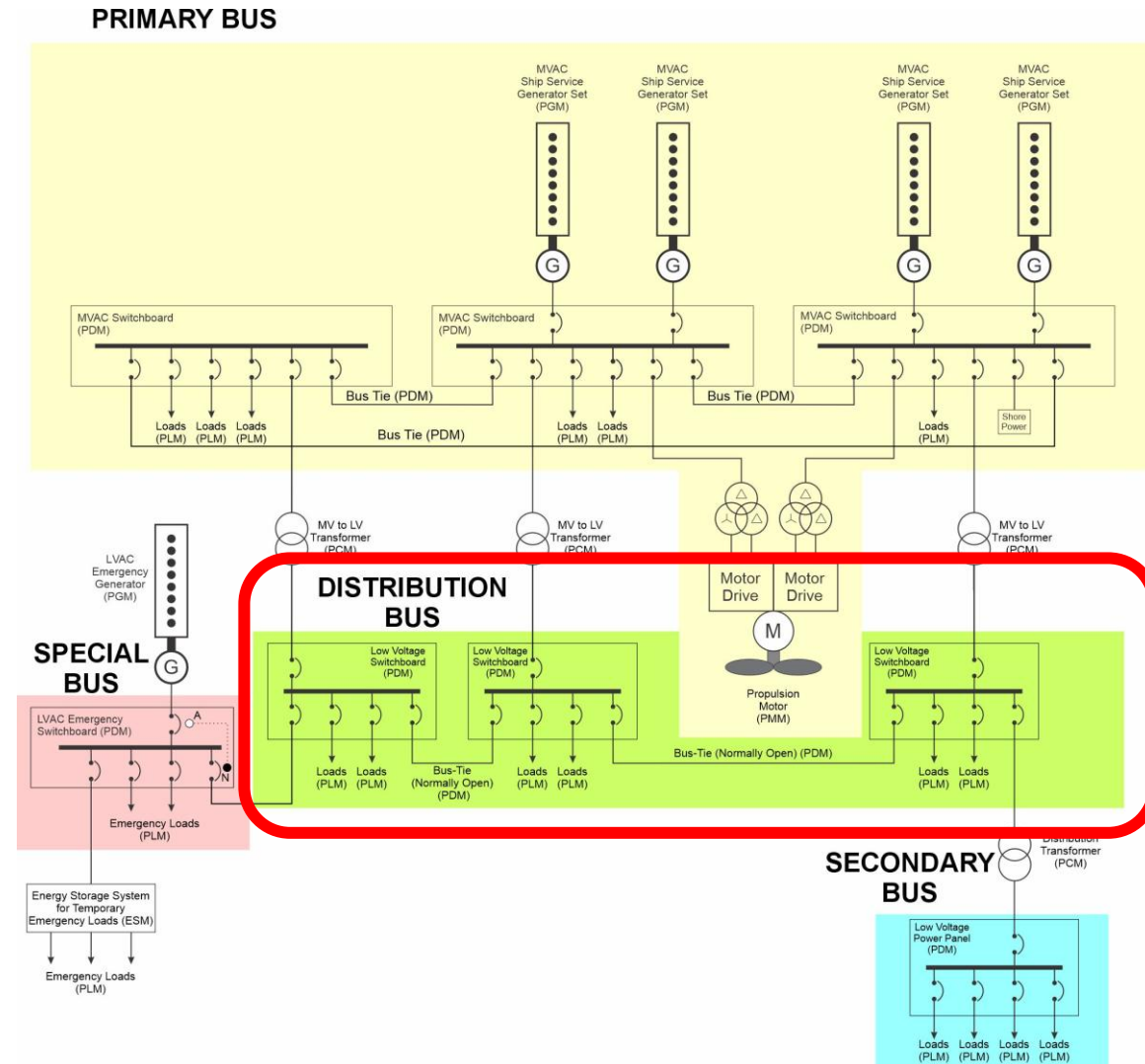
- A primary bus is a term reserved for an ac or dc bus with a nominal system voltage greater than 1000 V
- A primary bus may be implemented as multiple buses for redundancy, criticality, or safety.
- A primary bus usually is only directly connected to a few large loads; the majority of the loads are powered from other buses that connect to the primary bus via power conversion equipment (e.g., transformers, solid-state power converters)
- Standard nominal system voltages
 - AC: 3.3 kV; 4.16 kV; **6.6 kV**; **11 kV**; 13.8 kV
 - Shore power connections defined for 6.6 kV and 11 kV
 - DC: 1.5 kV; 3 kV; 6 kV; 12 kV; 18 kV; 24 kV; 30 kV



Distribution Bus

IEEE Std 45.1

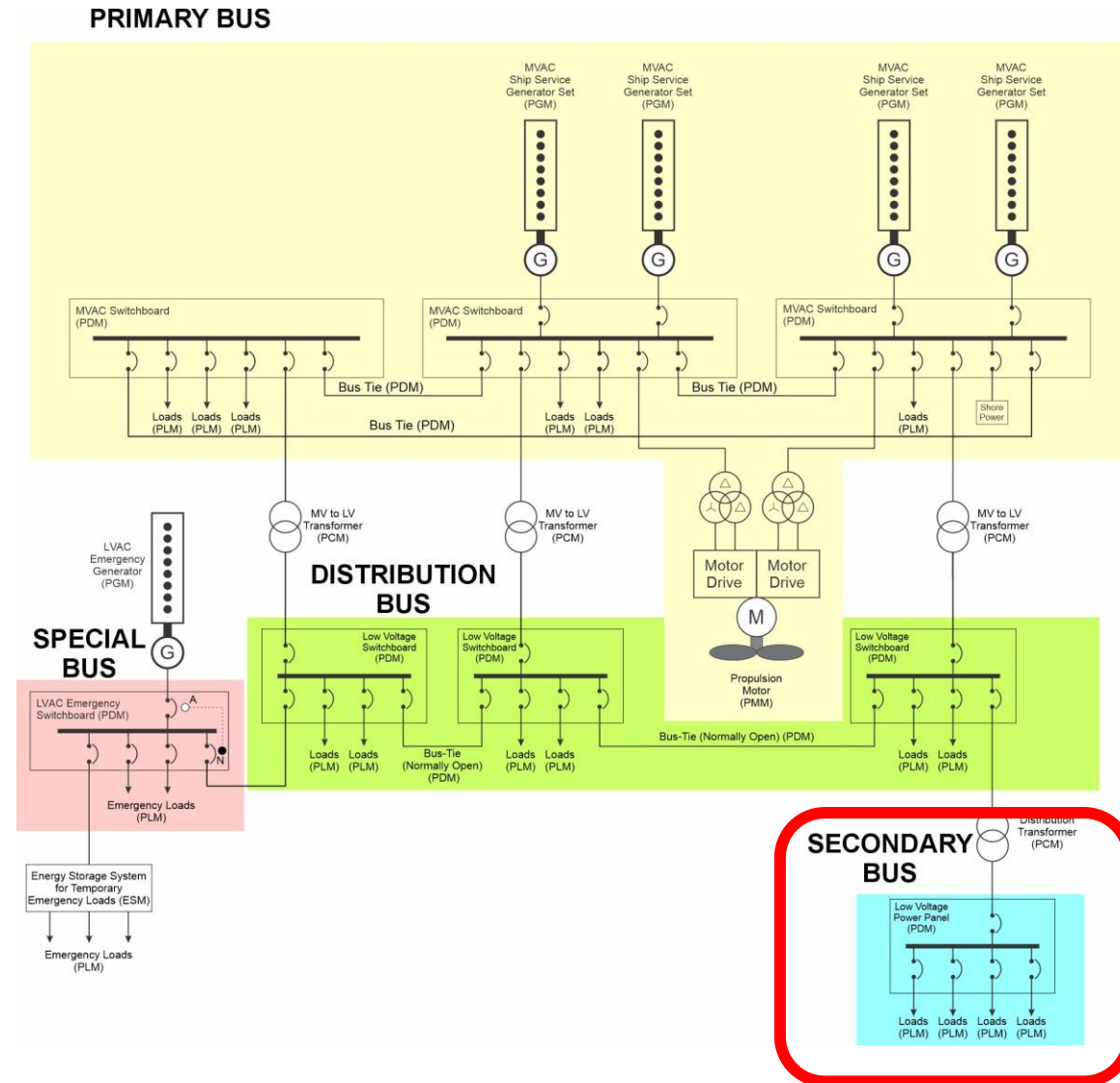
- A distribution bus provides power to loads throughout a ship or a zone.
- Multiple distribution buses may be utilized as necessary for the vessel design.
- Distribution buses typically support nominal system voltages between 400 V and 1000 V
- Standard nominal system voltages
 - AC: 400 V; 450 V; 480 V; 600 V; 690 V.
 - DC: 600 V; 650 V; 700 V; 750 V; 1000
 - USN: AC 440 V; DC 850 V



Secondary Bus

IEEE Std 45.1

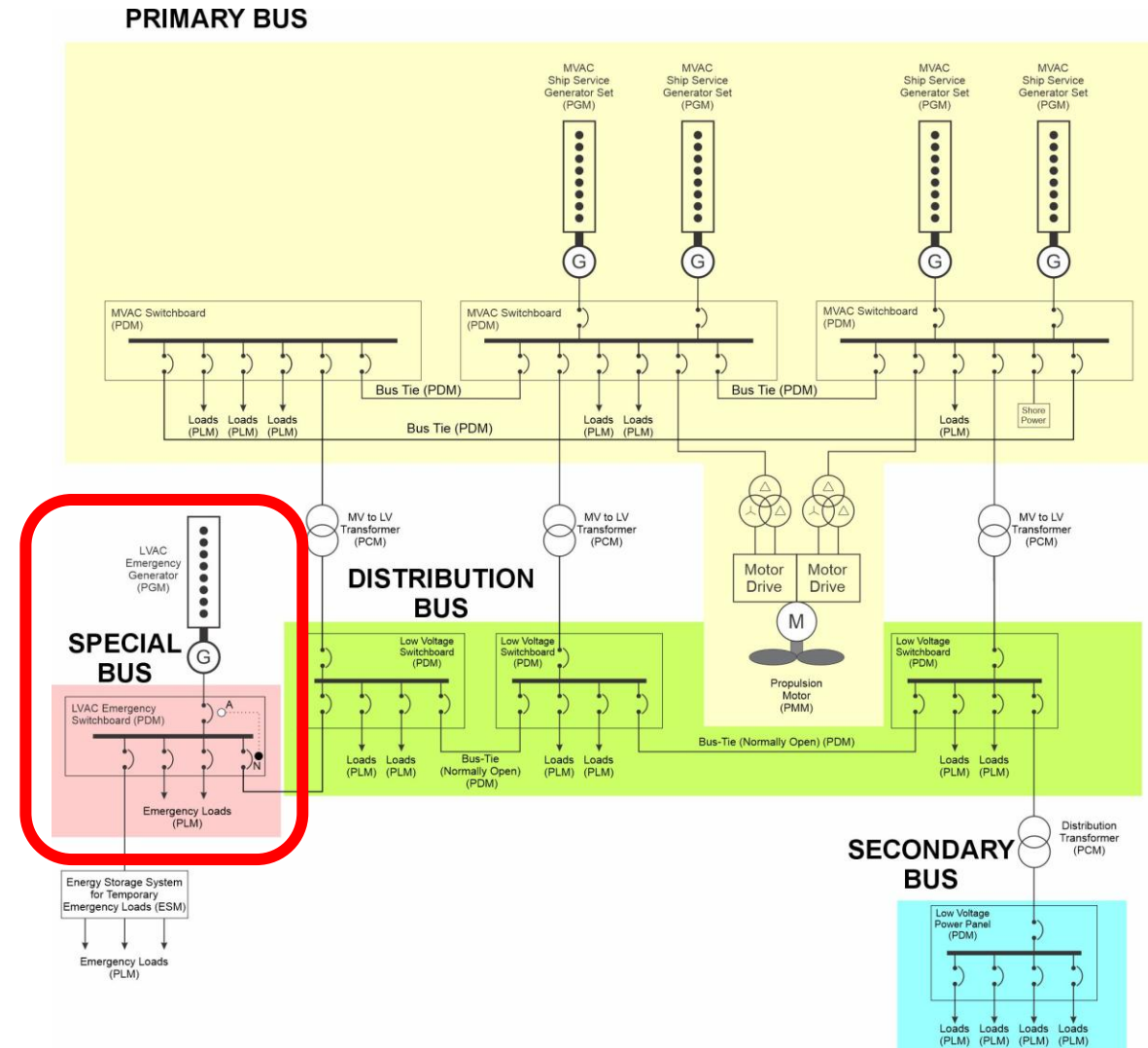
- A secondary bus provides electrical power with a nominal system voltage typically no greater than 400 V directly to
 - equipment,
 - appliances, or
 - appliance outlets.
- Standard nominal system voltages
 - AC: 120 V; 208 V; 230 V; 240 V; 400 V
 - DC: 110 V, 220 V, 375 V
 - USN: AC 115 V; 200 V



Special Bus

IEEE Std 45.1

- A special bus provides power for unique purposes such as medical use, control system power, special control, or propulsion.



IEEE 45.1 Power Quality

- Provides definitions for every term
- Additional ac requirements
 - “The total waveform distortion (TWD) of the voltage at the switchboard, load center, or power panel directly connected to a load should not exceed 8% and any single frequency component of the voltage waveform should not exceed 5%.”
 - “If the TWD of the voltage waveform exceeds 5% or any single frequency component exceeds 3%, equipment specifications should include the expected maximum values for TWD and the equipment vendors should be made aware of this requirement.”
 - “Load equipment should limit current distortion in accordance with IEEE Std 519”

AC Power

Characteristics	Limits
Frequency (reference system frequency)	
a) Frequency tolerance	±5%
b) Frequency transient	
1) Frequency transient tolerance	±10%
2) Frequency transient recovery time	5 s
c) Frequency modulation	0.5%
Voltage (reference nominal system voltage)	
a) Voltage tolerance	+6%/−10%
b) Voltage transient	
1) Voltage transient tolerance	±20%
2) Voltage transient recovery time	1.5 s
c) Line voltage unbalance (three-phase systems only)	3%
Combined	
a) Sum of frequency tolerance (%) and voltage tolerance (%)	+6%/−10

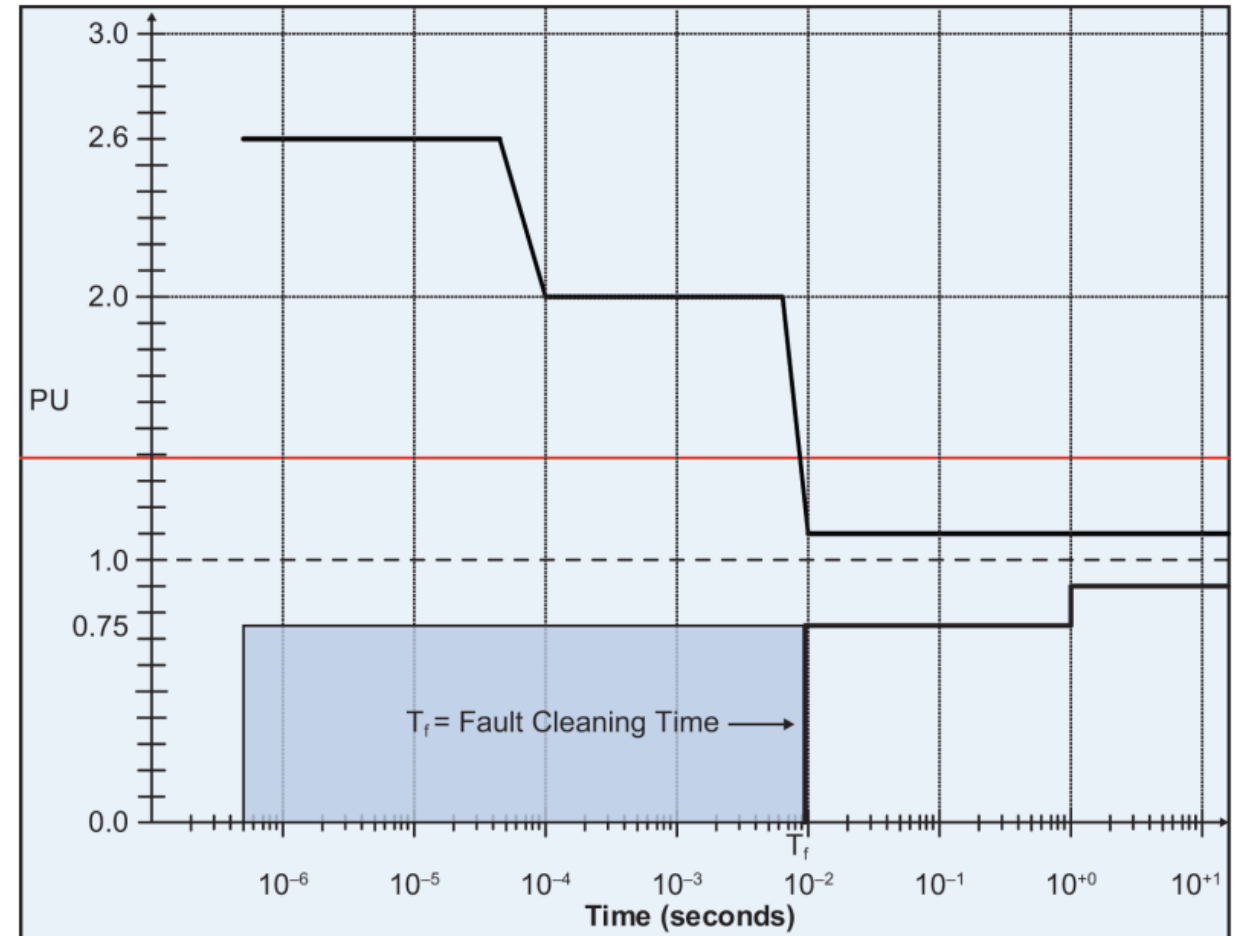
DC Power

Characteristics	Limits
Voltage (references nominal system voltage)	
a) Steady state	
1) Steady-state voltage tolerance (rms)	±1.5%
2) Steady-state voltage range (rms) (0 to rated power)	±4%
3) Steady-state voltage ripple (rms)	4%
4) Steady-state peak-to-peak voltage deviation	18%
b) Transient	
1) Voltage transient tolerance	±20%
2) Voltage transient recovery time	1.5 s

IEEE Std. 1709

- Also adds ripple requirement
 - “The acceptable rms value of ripple voltage and load induced noise should not exceed 5% per unit.”

IEEE Std 1709 DC Power (1 kV and above)
MVDC voltage tolerance



MIL-STD-1399-300-1

- Low voltage ac
- Provides definitions for every term
- Provides additional guidance for load current waveforms
 - Unbalance
 - Power factor
 - Ramp loads
 - Pulsed loads

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

MIL-STD-1399-300-2

- Medium voltage ac
- Definitions consistent with MIL-STD-1399-300-1

Frequency	
1. Nominal Frequency	60 Hz
2. Frequency Modulation	0.5%
3. Frequency Tolerance	±3%
4. Frequency Transient Tolerance	±4%
5. Worst Case Frequency Steady-State and Transient Excursion	±5.5%
6. Recovery Time from Item 4 or 5	2 seconds
Voltage	
7. Designated Nominal User Voltage	4,160 V _{rms} 6,600 V _{rms} 13,800 V _{rms}
8. Line-to-Line Voltage Unbalance	3%
9. Voltage Modulation	2%
10. Average Line-to-Line Voltage from Nominal Tolerance	±1%
11. Single Line-to-Line Voltage from Nominal Tolerance	±3%
12. Maximum Voltage Steady-State Departure	±4%
13. Voltage Transient Tolerance	±16%
14. Worst Case Voltage Steady-State and Transient Excursion	±18%
15. Recovery Time from Item 13 or 14	3 seconds
16. Voltage Spike	30 kV _p (4,160 V _{rms}) 75 kV _p (6,600 V _{rms}) 95 kV _p (13,800 V _{rms})
Waveform (Voltage)	
17. Maximum THD	5%
18. Maximum Single Harmonic	3%
19. Maximum Deviation Factor	5%
Emergency Conditions	
20. Frequency Excursion	-100% to +12%
21. Duration of Frequency Excursion	2 minutes
22. Voltage Excursion	-100% to +35%
23. Duration of Voltage Excursion:	
a. Upper Limit (+35%)	2 minutes
b. Lower Limit (-100%)	2 minutes
NOTE: Characteristics are defined in Section 3.	

MIL-STD-1399-300-3

- Low voltage dc
- Provides definitions for every term
- Provides additional requirements for current waveforms

Characteristic	Value: Type I (interface without energy storage)	Value: Type III (interface with regulated energy storage)	Verification Method
Voltage			
Nominal system voltage	850 VDC	850 VDC	N/A
User equipment normal service steady-state voltage range	773 to 918 VDC (-9 to +8%)	790 to 884 VDC (-7 to +4%)	5.3.1
User equipment voltage transient tolerance (includes steady-state range plus transient variations)	646 to 1046 VDC (-24 to +23%)	714 to 926 VDC (-16 to +9%)	5.3.2
User equipment voltage transient recovery time	2 seconds	0.25 second	5.3.2
User equipment maximum steady-state voltage ripple (peak-to-peak percent of nominal system voltage) ^{1/} , ^{2/}	14% up to 20 kHz then rolling off as shown on figure 4	14% up to 20 kHz then rolling off as shown on figure 4	5.3.1
User equipment voltage spike (spikes may be line-to-line or line-to-ground)	2500 V total including system voltage	2500 V total including system voltage	5.3.5
Emergency Conditions			
User equipment voltage positive excursion	+38% (220% for systems with symmetric auctioneering diodes)	+16% (220% for systems with symmetric auctioneering diodes)	5.3.2
User equipment voltage positive excursion duration	2 minutes	2 minutes	5.3.2
User equipment interruption voltage	-100%	-100%	5.3.4
User equipment power interruption duration, t _p	2 minutes Default value, see 5.2.2.1	2 minutes Default value, see 5.2.2.1	5.3.4
User equipment power interruption duration, t _r	0 millisecond (ms) (no-break supply) 150 ms (not on no-break supply) Default value, see 5.2.2.1	0 ms (no-break supply) 150 ms (not on no-break supply) Default value, see 5.2.2.1	5.3.4
NOTES: ^{1/} Unless otherwise specified (see 6.2), the individual narrowband components of the voltage ripple shall be limited on a frequency-specific basis as specified on figure 4 . ^{2/} User equipment maximum steady-state voltage ripple is due to the ripple created by the source combined with ripple caused by pulsed loads on the power system.			

Characteristic	Value: Type II (battery-based)	Verification Method
Voltage		
Nominal user equipment voltage	875 VDC Open-circuit unloaded	N/A
User equipment normal service voltage range, overcharged to discharged	680 to 1000 VDC (-22 to +14%)	5.3.1
User equipment voltage transient tolerance (includes steady state range plus transient variations)	650 to 1060 VDC (-25 to +21%)	5.3.2
User equipment voltage transient recovery time	2 seconds at 650 VDC 30 seconds at 1060 VDC	5.3.2
User equipment maximum voltage ripple (peak-to-peak percentage of nominal system voltage) ^{1/} , ^{2/}	14% up to 20 kHz then rolling off as shown on figure 4	5.3.1
User equipment voltage spike (spikes may be line-to-line or line-to-ground)	2500 V total including system voltage	5.3.5
Emergency Conditions		
User equipment voltage positive excursion	1060 VDC	5.3.2
User equipment voltage positive excursion duration	2 minutes	5.3.2
User equipment interruption voltage	-100%	5.3.4
User equipment power interruption duration, t _p	2 minutes Default value, see 5.2.2.1	5.3.4
User equipment power interruption duration, t _r	0 ms (no-break supply) 150 ms (not on no-break supply) Default value, see 5.2.2.1	5.3.4
NOTES: ^{1/} Unless otherwise specified (see 6.2), the individual narrowband components of the voltage ripple shall be limited on a frequency-specific basis as specified on figure 4 . ^{2/} User equipment maximum steady-state voltage ripple is due to the ripple created by the source combined with ripple caused by pulsed loads on the power system.		

ABS Marine Vessel Rules (MVR)

- Does not provide definition for terms

<i>Voltage and Frequency Variations for AC Distribution Systems</i>		
<i>Quantity in Operation</i>	<i>Permanent Variation</i>	<i>Transient Variation (Recovery Time)</i>
Frequency	±5%	±10% (5 s)
Voltage	+6%, -10%	±20% (1.5 s)

<i>Voltage Variations for DC Distribution Systems (such as systems supplied by DC generators or rectifiers)</i>	
<i>Parameters</i>	<i>Variations</i>
Voltage Tolerance (continuous)	±10%
Voltage cyclic variation deviation	5%
Voltage ripple (AC r.m.s over steady DC voltage)	10%

<i>Voltage Variations for Battery Systems</i>	
<i>Type of System</i>	<i>Variations</i>
Components connected to the battery during charging (see note)	+30%, -25%
Components not connected to the battery during charging	+20%, -25%

Quality of Service

- Quality of Service is a reliability metric for the electrical power system
 - Measured at the interface for each load
 - Key metric is the Mean time between service interruption
 - A Service interruption is a service disruption with duration greater than a load can tolerate
- Service interruptions and disruptions are compared to two system metrics
 - T1 = Reconfiguration time – based on choice of circuit protection
 - T2 = Generator start time – based on choice of generator sets

Causes of service disruption (service interruption)

- Fault within user equipment causing voltage to fall below its minimum value before the applicable circuit breaker trips.
- Generator sets tripping off line
- Power distribution equipment failures

Quality of Service categories

- Uninterruptible load
 - Cannot tolerate service disruptions of duration t_1
 - Power system designed to minimize service disruptions
 - Usually powered by an uninterruptible power supply (UPS)
- Short-term interrupt load
 - Can tolerate service disruptions of duration t_1
 - Cannot tolerate service disruptions of duration t_2
 - Power system designed to limit service disruptions to duration t_1
- Long-term interrupt load
 - Can tolerate service disruptions of duration t_2
 - Power system designed to limit service disruptions to duration t_2
- Exempt load
 - Subcategory of long-term interrupt load
 - Need not be restored if surviving generation capacity is insufficient to power all loads