Pulsed load analysis

Electric Power Load Analysis (EPLA)

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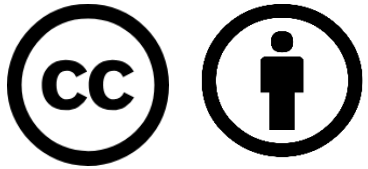
Dr. Norbert Doerry

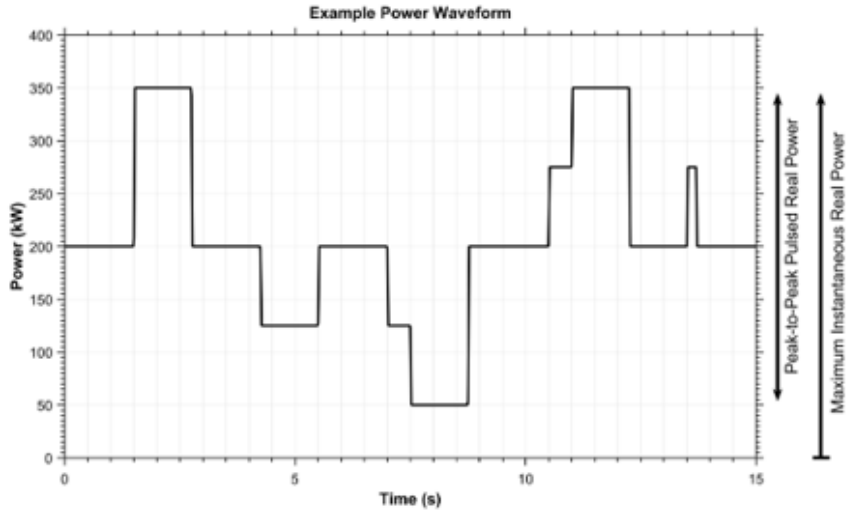


Essential Questions

What are the characteristics of pulsed loads?	Understand
What are system implications of pulsed loads on ac systems powered by generators? Powered by transformers?	Understand
What are system implications of pulsed loads on systems powered by power electronic converters?	Understand
What can be done to mitigate the impact of pulsed loads on system performance?	Understand
How is pulsed load analysis performed?	Apply

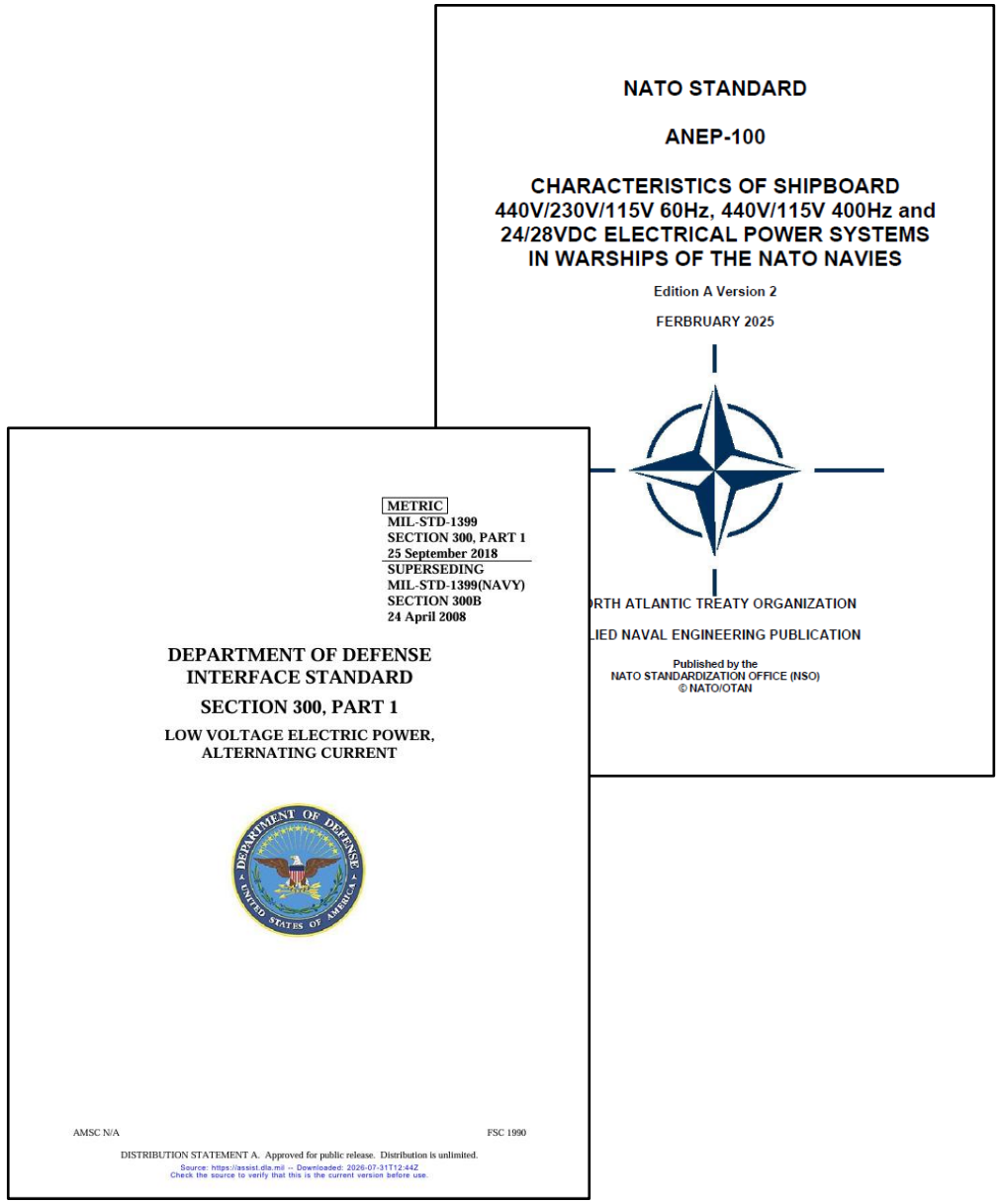
Introduction

- A pulse is a power excursion with a short rise time, short fall time, and a duration of at least one cycle and less than 10 seconds (per MIL-STD-1399-300-1)
- Infrequent pulsed loads – occur no often than once every 120 seconds
- Repetitive Pulse loads – occur more often and may have multiple levels



Standards

- MIL-STD-1399-300-1
  - Low Voltage a.c. Power
- MIL-STD-1399-300-2
  - Medium Voltage a.c. Power
- NATO ANEP-100 (STANAG 1008)
  - NATO Standard
  - 440V/230V/115V 60Hz
  - 440V/115V 400 Hz
  - 24/28VDC



Infrequent Pulsed Loads

- Present a pulse no more than once every 120 seconds
  - Most pulsed loads can present a pulse more often under normal operations
- MIL-STD-1399-300-1 and MIL-STD-1399-300-2
  - Limited by ramp rate of 30% of the online source rating (VA) per second

Repetitive Pulsed Loads (MIL-STD-1399-300-1)

- Should meet the following
  - Pulsed power deviation limit in the time domain
  - Pulsed power magnitude/frequency in the frequency domain
  - Pulsed Power total signal distortion limit.
- Also subject to inrush current requirements

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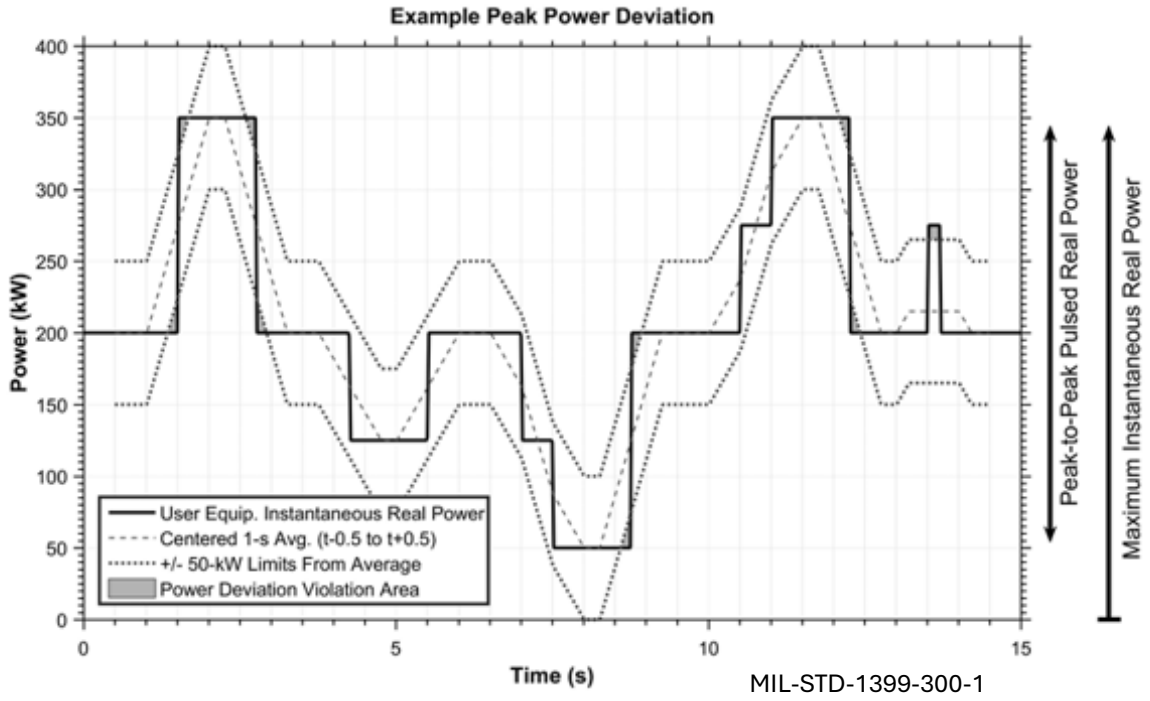
Pulsed Power Deviation Limit in the Time Domain

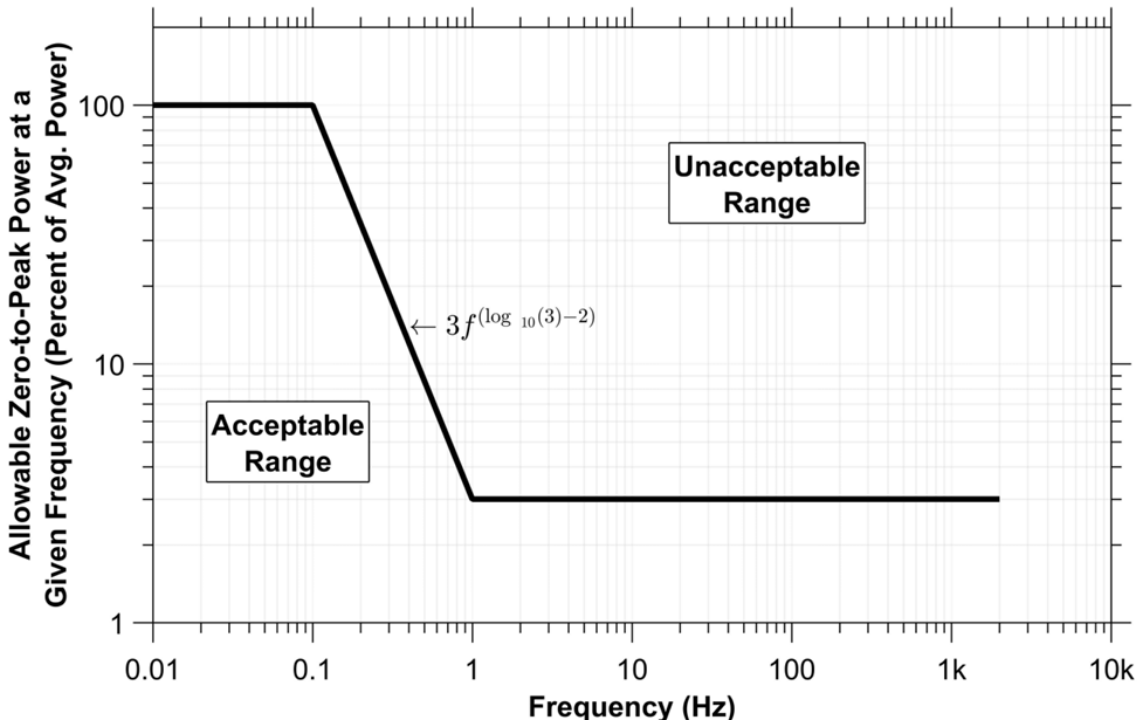
- Real power deviation from the average power level
  - No more than ±50 kW
  - Over 1 second integration limit
- Applies to load with maximum instantaneous real power
  - Greater than 100 kW
  - Less than 2 MW
- Implications
  - Step load change less than 100 kW
  - Maximum ramp rate for load change of magnitude M between 100 kW and 200 kW: $\frac{M^2}{M-100}$ kW/s
  - Maximum ramp rate for load changes with magnitude *M* greater than 200 kW is 400 kW/s



Load change has a constant ramp rate
Load has a constant value before and after ramp for .5 seconds

Pulsed Power Magnitude/Frequency in the Frequency Domain

- Applies to pulsed power loads > 100 kW
- Peak to Peak real pulsed power ≤ 25% of prime mover real power rating.
- The frequency content of the real power waveform minus the average power over a 100 second average is determined using a Discrete Fourier Transform (DFT)
  - Long Window is 100 seconds (< 1 Hz)
  - Short sliding window is 4 seconds with each window having a 3 second overlap with the previous window (≥ 1 Hz)
  - Resulting frequency content should fall within the Acceptable Range



MIL-STD-1399-300-1

Pulsed Power total signal distortion limit

- Power total signal distortion (TSD)
  - < 5% for frequencies between 1 Hz to 2 kHz.
  - Average real power calculated over 100 seconds
  - TSD calculated over 4 second rolling window
  - Maximum TSD for all windows used

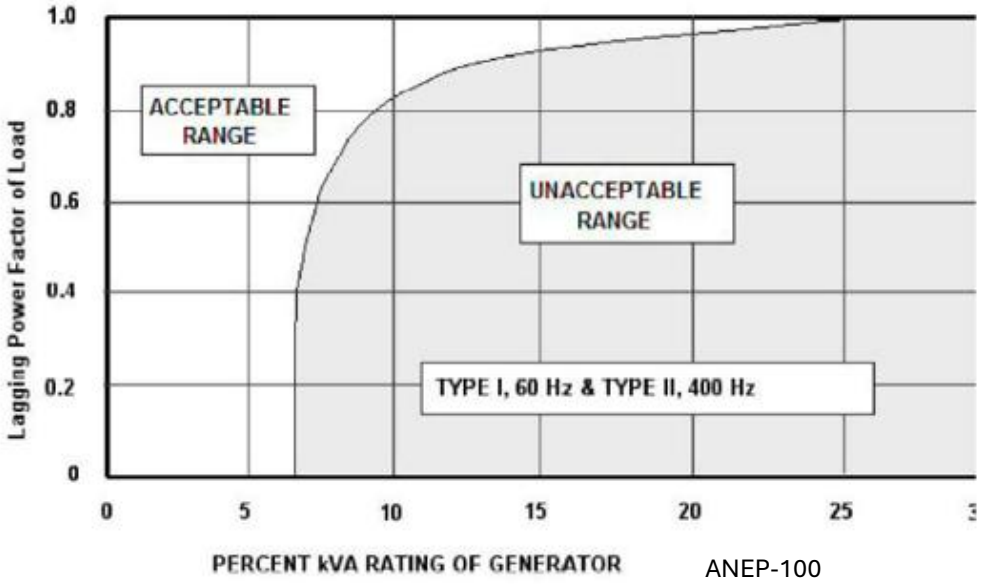
$$\text{Power TSD (percent)} = 100 \times \sqrt{\sum_{s} \left(\frac{P_s}{\sqrt{2}} \cdot \frac{1}{P_{av}} \right)^2}$$

Where:

- P_s = Zero-to-peak real power amplitude at individual signal frequency s
- 1 Hz ≤ s ≤ 2 kHz
- P_{av} = Average real power over a specified time period determined by the application

ANEP-100 (STANAG 1008) Pulsed load limit

- The ANEP-100 limit for pulsed load is based on the graph to the right
  - X-axis is the ratio of the apparent power rating of the pulsed load to the apparent power rating of online generator sets expressed as a percentage.
  - Y-axis is the power factor of the pulsed load.
- Pulsed loads limited to 25% of the rated apparent power of online generator sets.



ANEP-100

Impact of Pulsed Loads on Generator Sets

- Metal fatigue and throttle wear
  - Torque Pulsations
  - Rapid Thermal Cycling
  - Steel Lamination Losses
- Paralleled generators of different type
  - Smaller genset transiently takes on more load and could trip off line if too much
- May be unable to meet frequency and voltage power quality requirements

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Impact of Pulsed loads on Transformers

- Degradation of insulation
  - Rapid thermal cycling
  - High transient Electromagnetic forces
  - High core losses
- Transformer inductances and resistances may interact with pulses such that voltage power quality requirements are not met.

Impact of Pulsed Loads on Power Electronic Converters

- Should be able to maintain voltage power quality at the converter output
  - Fast switching times
  - Sufficient internal energy storage
- Should be able to maintain current power quality at the converter input
  - Fast switching times
  - Sufficient internal energy storage

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Pulsed Load Mitigation

- Energy storage
  - Fulfilling ESM-F4 functionality
  - UPS style may be effective, but limits ability to share energy storage among multiple pulsed power loads
  - Pulsed power bus enables sharing, but requires circuit protection and significant cabling
  - Energy storage systems at switchboards enable power sharing
    - Can also be used for power factor correction and harmonic current cancelation
- Power redirection
  - Use propulsion motor (or other large loads) as a virtual energy storage system
    - Ship speed not significantly impacts by lower propulsion power during the pulse
  - Propulsion motor must be operating at a minimum speed such that sufficient power may be redirected
  - When used, can extend life of energy storage systems and prime movers.
- Control negotiations
  - Enables power system and pulsed loads to negotiate values of the interface
- DC distribution systems
  - Enables higher ramp rates
  - Reduces risk associated with paralleling multiple generator sets of different sizes
  - Currently no existing standards cover pulsed loads with MVDC systems..

Pulsed load analysis – Pulsed load meeting interface requirements

- Original Equipment Manufacturer (OEM) usually performs analysis and testing to demonstrate conformance to interface requirements
- Some interface requirements depend on ratings of online generator sets
  - Ship designer has role in ensuring successful pulsed load integration
- If interface requirements are not easily met, recommend allocating space, weight, power and cooling (SWAP-C) for mitigation equipment

Pulsed load analysis – determining if power quality is maintained

- Usually starts in Preliminary / Contract Design
  - May be earlier if required
- Requires detailed transient analysis
  - Waveform level models
  - Incorporate actual inductances, capacitances, and resistances
    - Time periods can be shorter than the period of the fundamental frequency.
- Should cover a series of scenarios to cover various operational situations the ship may encounter
- Initially used to bound values for SWAP-C
- As system models become more representative of actual hardware:
  - Determine whether SWAP-C should be used for mitigation efforts
  - Determine which mitigation efforts should be used

Pulsed load analysis – determining impact on prime movers

- Generally insufficient information on prime mover data sheets
- May need to contract with OEM to determine impact
- Alternately could perform tests in a test site.