# Designing Electrical Power Systems for Survivability and Quality of Service

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***ASNE DAY***

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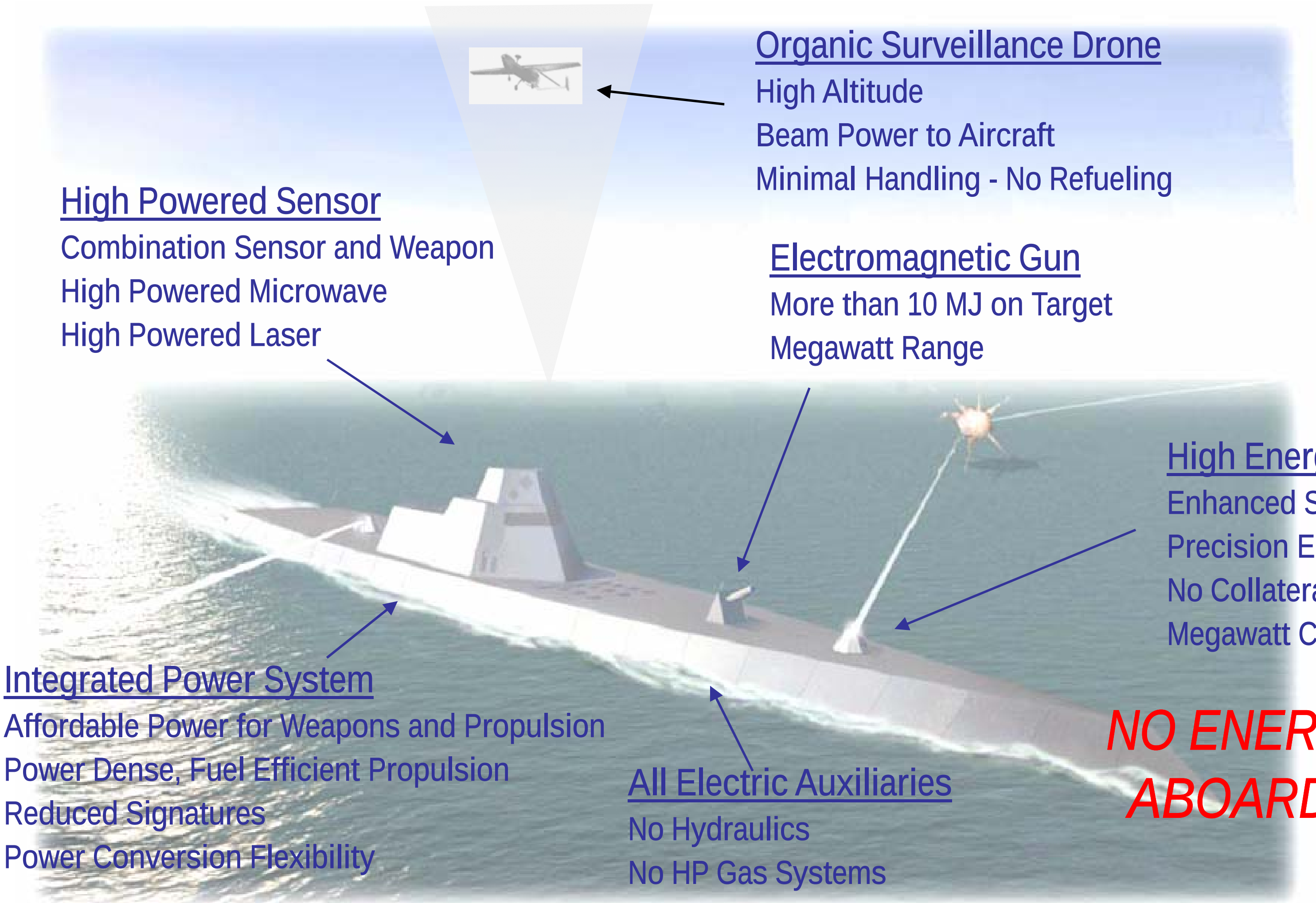
# All-Electric Warship Vision



**Organic Surveillance Drone**
- High Altitude
- Beam Power to Aircraft
- Minimal Handling - No Refueling

**High Powered Sensor**
- Combination Sensor and Weapon
- High Powered Microwave
- High Powered Laser

**Electromagnetic Gun**
- More than 10 MJ on Target
- Megawatt Range

**High Energy Laser**
- Enhanced Self Defense
- Precision Engagement
- No Collateral Damage
- Megawatt Class Laser

**Integrated Power System**
- Affordable Power for Weapons and Propulsion
- Power Dense, Fuel Efficient Propulsion
- Reduced Signatures
- Power Conversion Flexibility

**All Electric Auxiliaries**
- No Hydraulics
- No HP Gas Systems
- Reduced Sailor Workload

*NO ENERGETICS ABOARD SHIP!*

# Agenda

- Evolving Naval Power System Design
- Definitions
  - Survivability
  - Quality of Service
- Issues associated with Quality of Service
- Relationship of Quality of Service to Survivability

# Naval Electric Power System Design

**The primary aim of the electric power system design will be for survivability and continuity of the electrical power supply**. To insure continuity of service, consideration shall be given to the number, size and location of generators, switchboards, and to the type of electrical distribution systems to be installed and the suitability for segregating or isolating damaged sections of the system.

\- *NAVSEA DESIGN PRACTICES and CRITERIA MANUAL, ELECTRICAL SYSTEMS for SURFACE SHIPS*, CHAPTER 300
NAVSEA T9300-AF-PRO-020

# Naval Electric Plant Design References for Early Stages of Design

- Naval Vessel Rules
  - ABS Guide for Building and Classing Naval Vessels 2004
- NAVSEA Design Practices and Criteria Manual, Electrical Systems for Surface Ships, Chapter 300, NAVSEA T9300-AF-PRO-020
- Electrical System Load and Power Analysis for Surface Ships, Design Data Sheet 310-1, Mil-STD-2189-DDS310-1
- Interface Standard for Shipboard System, Electric Power, Alternating Current, MIL-STD-1399, Section 300A
- IEEE Standard 45; Recommended Practice for Electrical Installations on Shipboard

# Current Electric Plant Design Practice

- Electric plant design is currently centered on providing sufficient total ship generation capacity to service loads while avoiding fault current limitations.
  - Load Factors: Ratio of the average load to the peak load of the equipment – Standby Equipment are assumed to be “off”.
- Reliability and survivability issues addressed by invoking (n-1) rule and providing redundant paths of power to vital loads.
  - Over time, more and more loads have been classified as “Vital”
- No consensus in method for sizing zonal distribution and conversion equipment for zonal electrical distribution systems.
  - Some advocate using Load Factors
  - Others advocate Demand Factors
  - Still others advocate variations of load factors and demand factors.

# Impact of Power System Design Evolution

- Zonal Distribution Systems
  - Reduces amount of cabling required as compared to radial systems.
  - Design Practices have not been formalized
- Elimination of steam plants and introduction of electric heating and auxiliaries
  - 10° F operating condition now is the design condition (vice 100° F operating condition)
- Integrated Power Systems
  - Power Quality on Medium Voltage Bus often does not meet MIL-STD-1399
  - Rules for sizing generation plant not clear
    - Propulsion Plant and Electrical Plant sizing criteria are different.
- Use of large diesel generator sets and multi-spool aero-derived gas turbines
  - Reduced Inertia – Lack of time scale separation between speed regulation and protection dynamics.
  - Inability to sustain overload conditions (110% vice 150%)
    - Potential for cascading loss of power – Dark Ship
  - Frequency regulation for Gas Turbine in some cases is not sufficient to meet MIL-STD-1399
- Constant Power Loads
  - Potential sources of system instabilities
- Use of Commercial (COTS) equipment in Ungrounded Systems
  - Potential for line to ground voltages exceeding insulation system ratings
  - Transition to high-impedance ground systems in low voltage systems.

**LEGACY DESIGN METHODS NO LONGER ASSURE A GOOD DESIGN**

# New Technology is Available

- Smart and Fast Circuit Breakers
  - Machinery Control system has more monitoring points.
  - Time of power quality disturbances shortened.
- Affordable Power Conversion Equipment
  - Provide high power quality.
  - Prevent disturbances from propagating outside a zone.
  - Limits Fault Current.
- Computer based Machinery Control Systems
  - Ability to manage loads based on operational context.
  - Ability to manage generation based on operational context.

# More Changes are Coming …

- Pulse Power Loads
  - Weapons: rail-guns and directed energy
  - Sensors: High power radars
  - Launchers: EMALS (ElectroMagnetic Aircraft Launch System)
- Energy Storage
  - Flywheels
  - Superconducting Magnetic Energy Storage (SMES)
  - Batteries
  - Ultra-capacitors
- Fuel Cells
- Alternate Fuels

# Definition: Survivability

## *As applied to Distributed Systems*

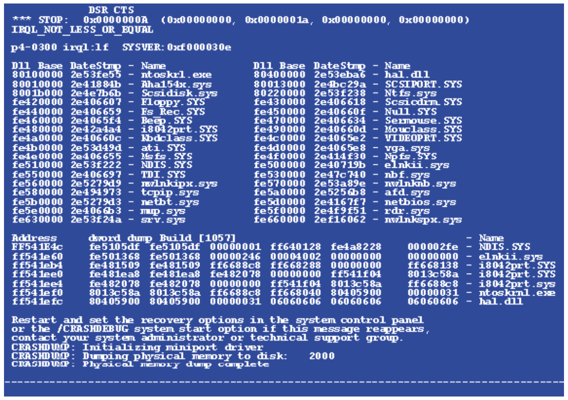
- Zonal Survivability
  - Zonal Survivability is the ability of the distributed system, when experiencing internal faults due to damage or equipment failure confined to adjacent zones, to ensure loads in undamaged zones do not experience an interruption in service or commodity parameters outside of normal parameters
    - Sometimes only applied to "Vital Loads"

- Compartment Survivability
  - Even though a zone is damaged, some important loads within the damaged zone may survive. For critical non-redundant mission system equipment and loads supporting in-zone damage control efforts, an increase level of survivability beyond zonal survivability is warranted.
  - For these loads, two sources of power should be provided, such that if the load is expected to survive, at least one of the sources of power should also be expected to survive.

**SURVIVABILITY DEALS WITH PREVENTING FAULT PROPOGATION AND WITH RESTORATION OF SERVICE UNDER DAMAGE CONDITIONS**

# Definition: Quality of Service

- Quality of Service is a metric of how reliable a distributed system provides its commodity (electricity) to the standards required by its users (loads).
- Calculated as a Mean Time Between Failure as viewed from the loads.
- A failure is any interruption in service, or commodity parameters outside of normal parameters, that results in the load not being capable of performing its function.
  - Interruptions in service shorter than a specified amount for a given load are NOT a failure for QOS calculations.
- Time is usually measured over an operating cycle or Design Reference Mission.



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Dll Base DateStmp - Name                Dll Base DateStmp - Name
80100000 2e53fe55 - ntoskrl.exe         80400000 2e53eba6 - hal.dll
80010000 2e41884b - Aha154x.sys         80013000 2e4bc29a - SCSIPORT.SYS
8001b000 2e4e7b6b - Scsidisk.sys        80220000 2e53f238 - Ntfs.sys
fe420000 2e406607 - Floppy.SYS          fe430000 2e406618 - Scsicdrm.SYS
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fe460000 2e4065f4 - Beep.SYS            fe470000 2e406634 - Sermouse.SYS
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fe510000 2e53f222 - NDIS.SYS            fe500000 2e40719b - elnkii.sys
fe550000 2e406697 - TDI.SYS             fe530000 2e47c740 - nbf.sys
fe560000 2e5279d9 - nwlnkipx.sys        fe570000 2e53a89e - nwlnknb.sys
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fe5b0000 2e5279d3 - netbt.sys           fe5d0000 2e4167f7 - netbios.sys
fe5e0000 2e4066b3 - mup.sys             fe5f0000 2e4f9f51 - rdr.sys
fe630000 2e53f24a - srv.sys             fe660000 2ef16062 - nwlnkspx.sys

Address    dword dump Build [1057]                               - Name
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ff541efc   80405900 80405900 00000031 06060606 06060606   06060606 - hal.dll

Restart and set the recovery options in the system control panel
or the /CRASHDEBUG system start option if this message reappears,
contact your system administrator or technical support group.
CRASHDUMP: Initializing miniport driver
CRASHDUMP: Dumping physical memory to disk:   2000
CRASHDUMP: Physical memory dump complete

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**QUALITY OF SERVICE DEALS WITH ENSURING LOADS RECEIVE A RELIABLE SOURCE OF POWER UNDER NORMAL OPERATING CONDITIONS**

# Quality of Service:

## *Modes of System Failures*

- Loss of Prime Mover
  - Most likely cause of power interruption under “normal” conditions.
  - Typically results in generation under capacity until standby generators brought on line.
    - Usually results in Load Shedding
  - System generally takes 2 to 5 minutes to bring a standby generator on line.
- Failure within Load Equipment
  - Can take from 10 ms to 2 seconds to isolate faulted loads using fuses, solid state or electromechanical circuit breakers.
  - Loads “electrically near” the faulted equipment will see power disturbance until protection devices clear the fault.
- Failure within Power Conversion Equipment
  - Depending on system architecture and design choices, may or may not result in inability to provide sufficient power to all loads.
- Failure in distribution system (cables and switchgear)
  - Generally infrequent occurrence under “normal” conditions

# Quality of Service:

## *Current Thoughts on Classification of Loads*

- “Un-Interruptible” Loads
  - Loads that can tolerate between 10 ms and 2 seconds of power interruption.
  - System designed to provide with high reliability no more than 10 ms of power interruption.
  - Loads must have sufficient hold up time to accept a 10 ms interruption.
- “Short Term Interrupt” Loads
  - Loads that can tolerate between 2 seconds and 5 minutes of power interruption.
  - System designed to provide with high reliability no more than 2 seconds of power interruption.
- “Long Term Interrupt” Loads
  - Loads that can tolerate more than 5 minutes of power interruption.
  - System designed to provide with high reliability no more than 5 minutes of power interruption.

# Quality of Service:

## *Classification of Loads: Examples*

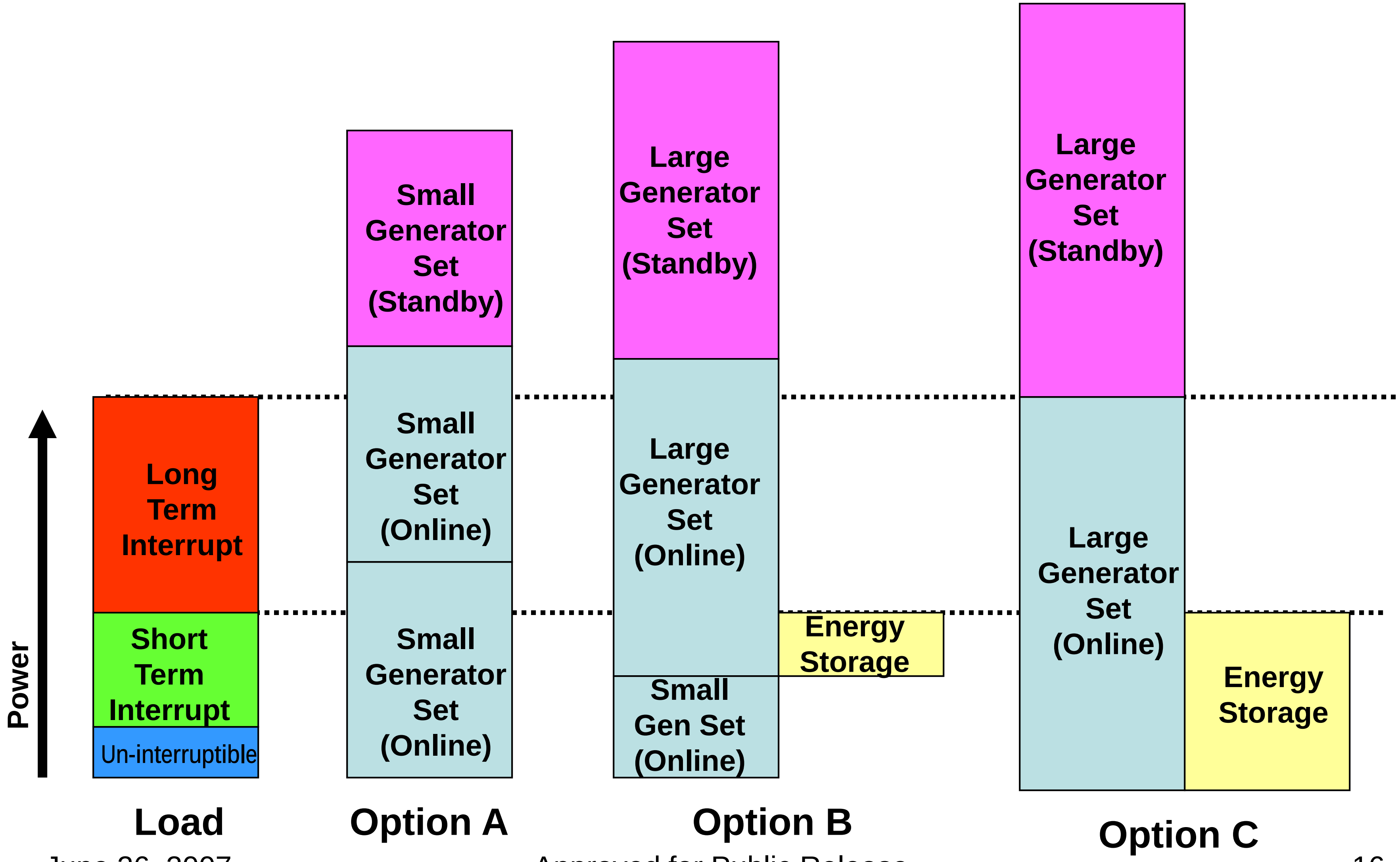
- “Un-Interruptible” Loads
  - Critical Electronic Systems
  - Fast Reaction time Self Defense Weapons Systems
- “Short Term Interrupt” Loads
  - Most Motor Driven equipment (pumps, winches, elevators)
  - AC Plants
  - Lights (non-NEALS)
- “Long Term Interrupt” Loads
  - Lights (NEALS)
  - Resistive Heaters
  - HVAC
  - Chill Boxes

# Quality of Service:
## *Design Implementation*

- “Un-interruptible” Loads:
  - Provided with un-interruptible transfer of power from independent power sources.
  - Alternate Power source could be an Independent Generator Set or an Energy Storage Module.
    - Energy Storage should have sufficient energy for at least 5 minutes for QOS considerations.
- “Short Term Interrupt” Loads
  - Use traditional electromechanical breakers to reconfigure the plant to restore power to “Short Term Interrupt” loads within 2 seconds.
  - If shedding of “Long Term Interrupt” loads not sufficient to prevent overload of online generation capacity, initially shed “Short Term Interrupt” loads using mission prioritization.
    - Shedding of Short Tem Interrupt Loads for longer than 2 seconds under non-combat failures constitutes a QOS failure in MTBF calculations.
- “Long Term Interrupt” Loads
  - Initially shed sufficient “Long Term Interrupt” loads if remaining online generation capacity insufficient.  Use mission prioritization to determine which loads to shed.
    - Shedding of Short Tem Interrupt Loads for longer than 2 seconds under non-combat failures constitutes a QOS failure in MTBF calculations.

**QOS DESIGN ASSUMES SUFFICIENT GENERATION CAPACITY CAN BE RESTORED WITHIN 5 MINUTES.  IF NOT, THEN AT 5 MINUTES TRANSITION TO SURVIVABILITY BASED LOAD SHEDDING**

# Power Generation Sizing



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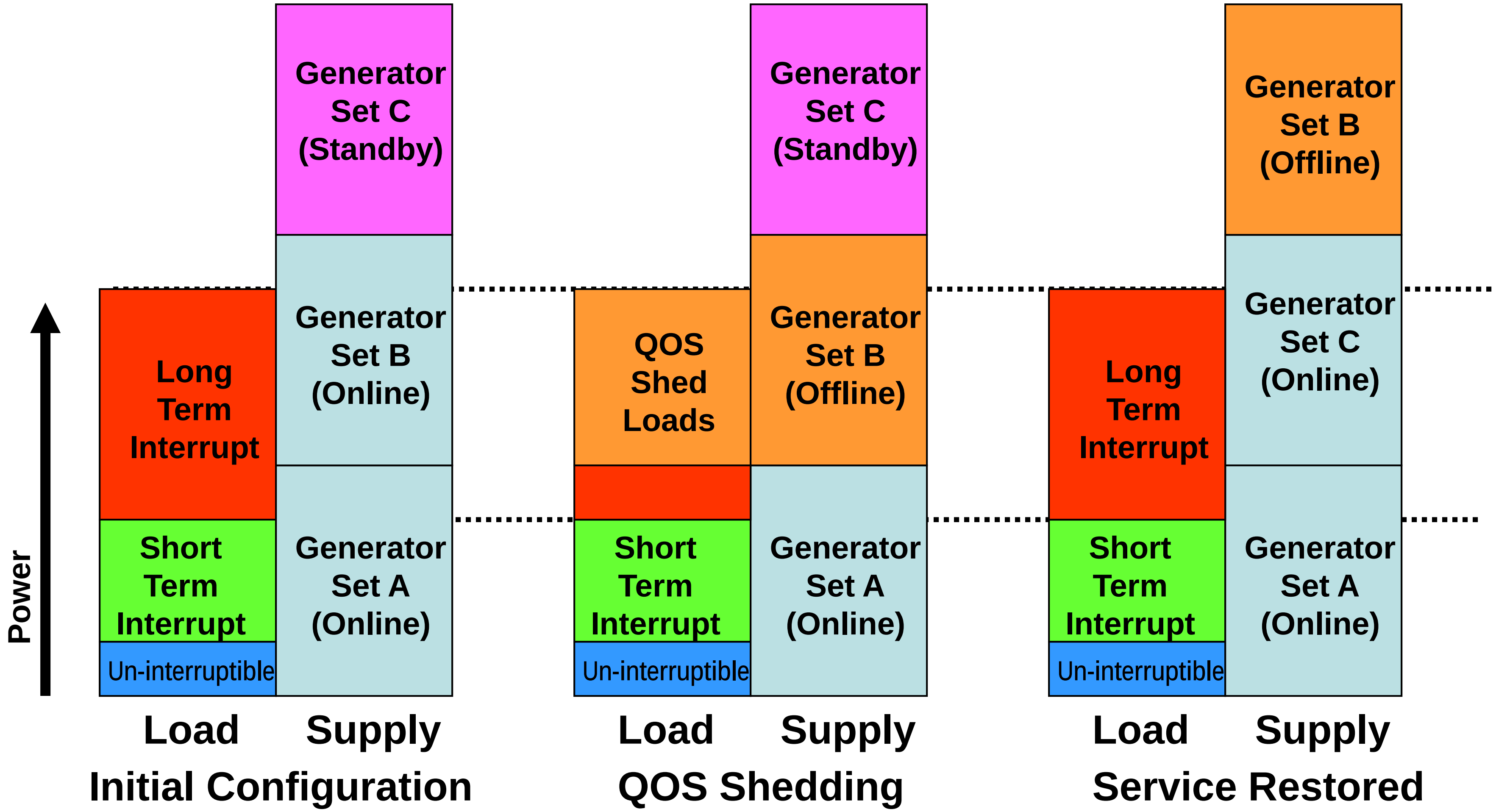
# Quality of Service:

## *Design Issues*

- Un-interruptible Loads
  - Aggregation of Loads enables cheaper and more reliable power conversion, but increases probability that failure of one load will impact QOS to another load.
    - Desire to aggregate enough loads so that load failures are not the driver for QOS MTBF calculations (while still having a high QOS)
  - Failure Modes of loads typically not known during early stage design (if at all)
- Short Term Interrupt and Long Term Interrupt Loads
  - Typically require highly reliable paths to two independent sources of power.
  - The routing of the paths is not critical for QOS considerations.
- Electric Plant Controls
  - Treats first 5 minutes of an outage as a QOS problem.
  - At 5 minutes transitions to a Survivability problem.
    - Possible if standby generators do not start, or extensive damage to distribution system.
    - May result in shedding of Short Term Interrupt loads at 5 minutes in order to restore power to higher mission prioritized Long Term Interrupt loads.
    - Must provide sufficient controllability of loads to differentiate between QOS and Survivability load shedding.

# Example: Machinery Plant Controls (Loss of First Generator Set)



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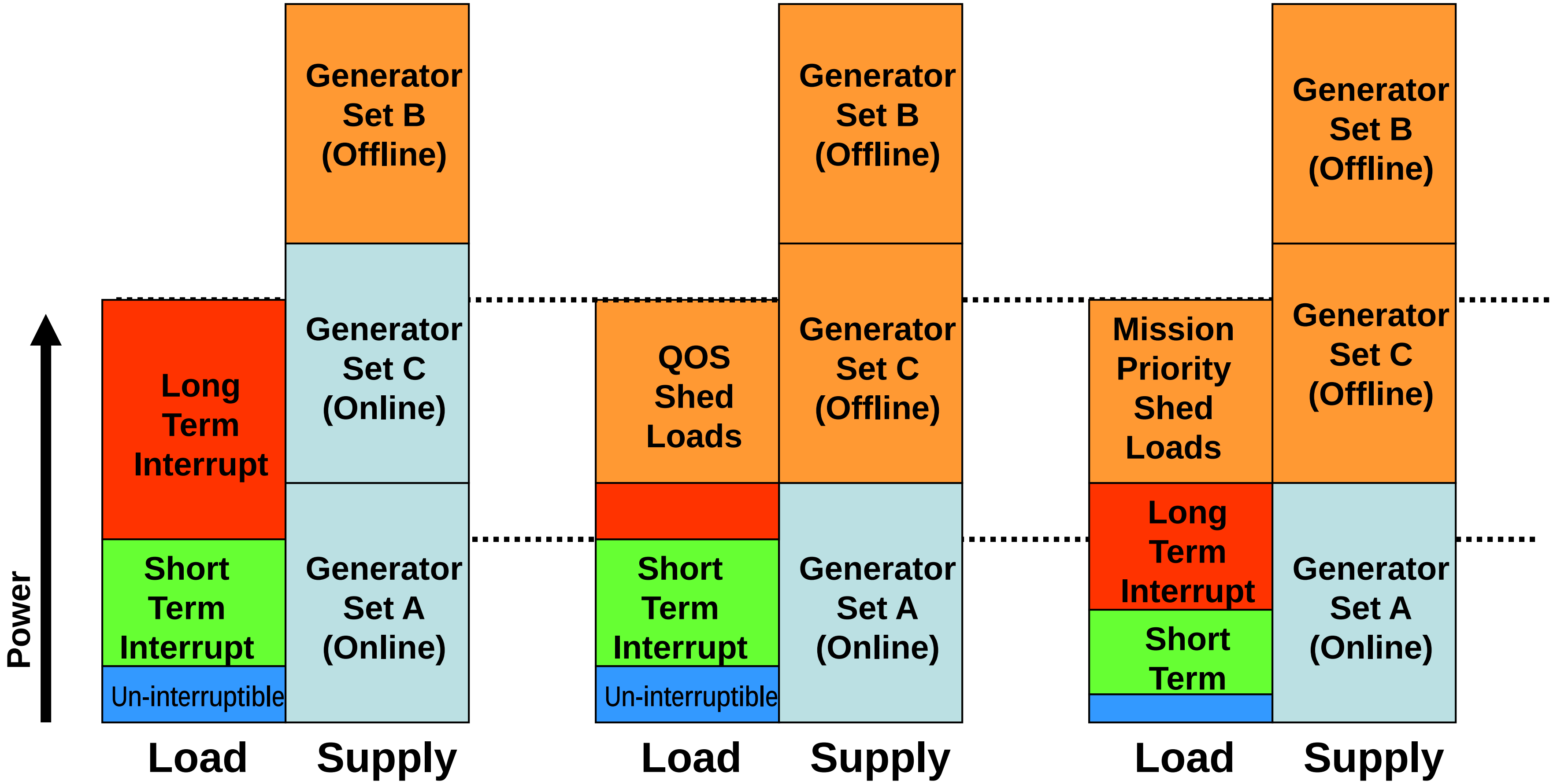
# Example: Machinery Plant Controls (Loss of Second Generator Set)



**Initial Configuration** **QOS Shedding** **Mission Priority Load Shed**

# Quality of Service:
## *Design Issues (continued)*

- Sizing of Distribution Equipment in Zonal Electrical Distribution Systems
  - Capacity for Un-interruptible loads must be accounted for in capacity of port and starboard power conversion and distribution system equipment.
  - Capacity for “Short Term Interrupt” and “Long Term Interrupt” loads can be split between port and starboard power conversion and distribution system equipment for QOS considerations.
    - Assumes Electric Plant controls can reconfigure Medium Voltage Bus or Port and Starboard buses to restore power to these loads.
    - Survivability considerations may lead to higher required capacity.
  - Capacity should be calculated using “Zonal Load Factors”
    - Differ from total ship Load Factors in that stand-by loads are assumed “on” rather than “off”.
    - Worse case condition (Design point) for a given zone may differ from the worse case condition for other zones or the entire ship.

# Survivability:

## *Design Considerations as compared to QOS*

- Failure Modes are Different
  - Shock Damage to multiple components at same time
  - Failure of highly reliable devices due to direct damage
- Control Strategy based on restoration of service vice continuity of service
  - Restore power to higher mission priority loads first
  - Time table for restoration of service may stretch into hours or days. Specified as a “Design Threat Outcome” for specific “Design Threats”.
- Minimum rating of zonal electrical distribution system equipment for Survivability reasons established by sum of loads provided compartment level survivability.
  - Both Port and Starboard distribution nodes must be individually capable of supporting all compartment level survivability loads.
- Geography extremely important
  - Routing of cabling and location of equipment extremely important to Survivability – not so with QOS.
    - Alternate sources of power should “split” within expected damage envelope of the load.
  - Survivability of alternate paths generally more important than speed of switching to alternate path
    - Exception: High Priority Loads with long “reboot” times

# Energy Storage:
## *QOS vs Survivability Applications*

- QOS Applications
  - Support “Un-interruptible” and “Short Term Interrupt” loads for up to 5 minutes.
    - Must support “Long Term Interrupt” loads until they can be shed (0 to 100 milliseconds).
  - Enables “Single Engine” cruise operation for fuel economy
    - Provides alternate source of power until standby generator sets come online.
    - Standby generator sets must be self-starting
  - Grade A shock not required;  Grade B sufficient
  - Centralized Energy Storage likely most economical solution.
    - “Un-interruptible” support may need distributed energy storage.
- Survivability Applications
  - Support critical “compartment level” survivability loads for 30 minutes or longer and power generation module starting.
  - Grade A shock required.
  - Distributed Energy Storage co-located with served equipment most effective solution.

# Take-Aways

- Quality of Service and Survivability should both be taken into account in the design of Naval Electrical Power Systems.
  - Although many design features impact both survivability and quality of service, some features only impact one or the other.
- Accurately Predicting Quality of Service during early stage design is difficult because of lack of data and techniques.
  - Currently we can at best do qualitative assessments.
  - Ideally with time our capability to predict QOS will improve.
- Incorporating Quality of Service into Design References and Naval Vessel Rules still needs to happen.