Implementing Quality of Service in Shipboard Power System Design

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Topics

- Definitions
  - Survivability
  - Quality of Service
- Relationship of Quality of Service to Survivability
- Design Issues associated with Quality of Service
- Energy Storage

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

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Definition: Survivability

As applied to Distributed Systems

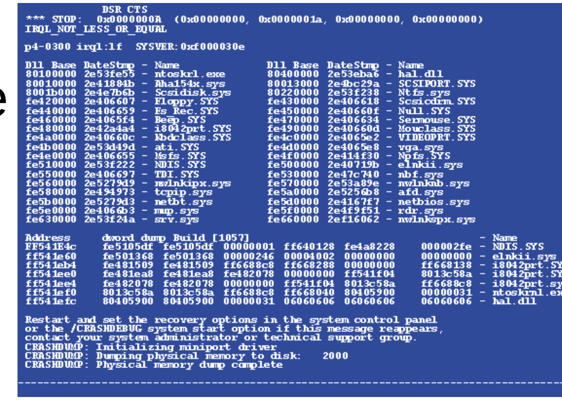
- Zonal Survivability
  - Zonal Survivability is the ability of the distributed system, when experiencing internal faults due to damage or equipment failure confined to adjacent zones, to ensure loads in undamaged zones do not experience an interruption in service or commodity parameters outside of normal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

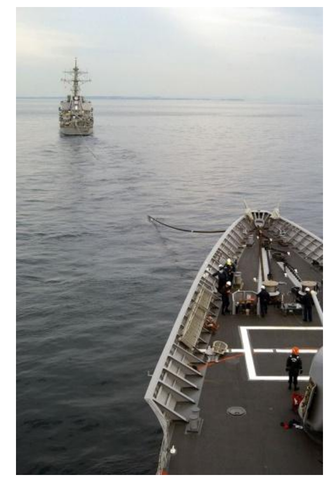
- Compartment Survivability
  - Even though a zone is damaged, some important loads within the damaged zone may survive. For critical non-redundant mission system equipment and loads supporting in-zone damage control efforts, an increase level of survivability beyond zonal survivability is warranted.
  - 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 the electrical systems provides power with the continuity required by its users (loads).
- Calculated as a Mean Time Between Service Interruption as viewed from the loads.
- A Service Interruption is any interruption in power, or degradation in power quality, 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 service interruption for QOS calculations.
- Time is usually measured over an operating cycle or Design Reference Mission.

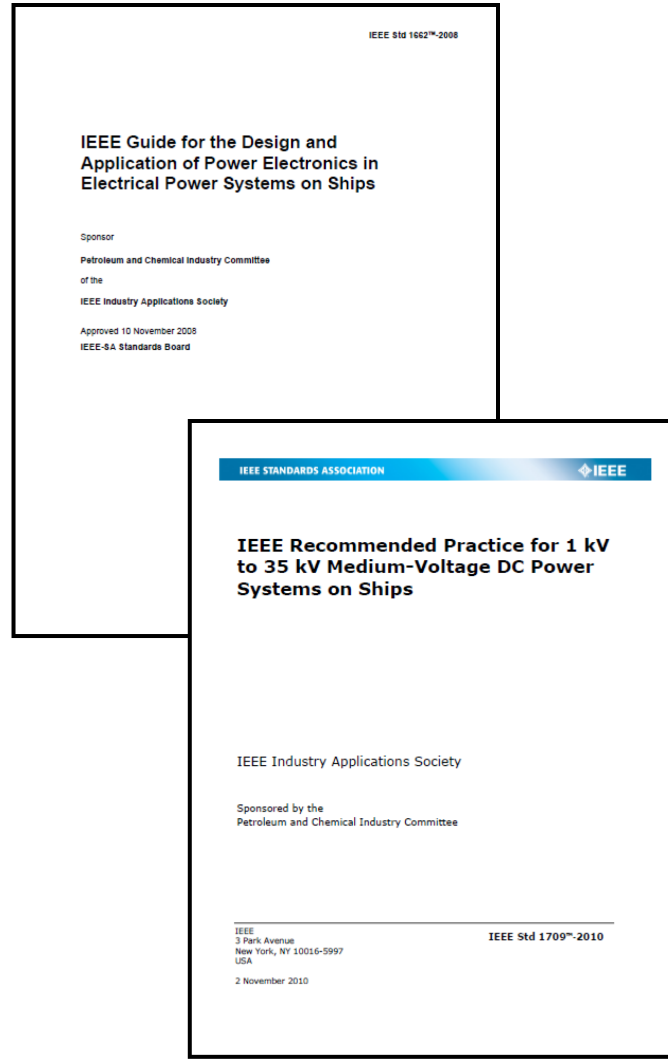




QUALITY OF SERVICE DEALS WITH ENSURING LOADS RECEIVE A RELIABLE SOURCE OF POWER UNDER NORMAL OPERATING CONDITIONS

IEEE Standards implementing QOS

- Existing Standards
  - IEEE 1662-2008 “IEEE Guide for the Design and Application of Power Electronics in Electrical Power Systems”
  - IEEE 1709-2010 “IEEE Recommended Practice for 1 to 35 kV Medium Voltage DC Power Systems on Ships”
- Standards under development
  - IEEE Standard P45 “Recommended Practice for Electrical Installations on Shipboard”
  - IEEE Standard P1826 “Standard for Power Electronics Open System Interfaces in Zonal Electrical Distribution Systems Rated Above 100 kW”


IEEE Std 1662™-2008

IEEE Guide for the Design and Application of Power Electronics in Electrical Power Systems on Ships

Sponsor

Petroleum and Chemical Industry Committee

of the

IEEE Industry Applications Society

Approved 10 November 2008

IEEE-SA Standards Board

IEEE STANDARDS ASSOCIATION IEEE

IEEE Recommended Practice for 1 kV to 35 kV Medium-Voltage DC Power Systems on Ships

IEEE Industry Applications Society

Sponsored by the
Petroleum and Chemical Industry Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1709™-2010

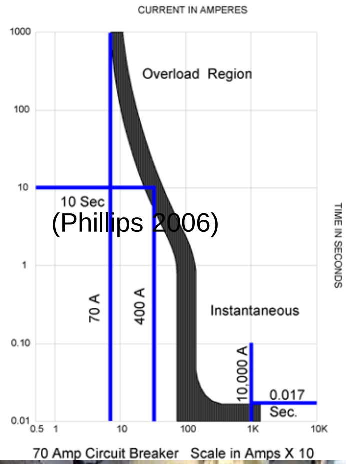
2 November 2010

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

QOS time reference values

- **Reconfiguration time (t1)**
  - The maximum time to reconfigure the distribution system without bringing on additional generation capacity. For a system employing conventional circuit breakers, t1 is on the order of two seconds.
  - T1 is a function of power distribution system technology
- **Generator start time (t2)**
  - The maximum time to bring the slowest power generation module online. Generator start time is typically on the order of one to five minutes.
  - T2 is a function of Power Generation Module technology.



Quality of Service:
Classification of Loads

- "Un-Interruptible" Loads
  - Loads that cannot tolerate power interruptions of duration t1.
  - The power system is designed to provide power with the minimum achievable power interruption with the reliability as defined by the customer specified Mean Time Between Service Interruption (MTBSI).
- "Short Term Interrupt" Loads
  - Loads that can tolerate power interruptions of duration t1, but cannot tolerate power interruptions of duration t2.
  - The power system is designed to provide power with interruptions exceeding time t1 with the reliability as defined by the customer specified MTBSI.
- "Long Term Interrupt" Loads
  - Loads that can tolerate power interruption greater than t2 in duration.
  - The power system is designed to provide power with interruptions exceeding time t2 with the reliability as defined by the customer specified MTBSI.
- "Exempt" Loads
  - Loads that can tolerate power interruption greater than t2 in duration.
  - The power system is designed to provide power to these loads under normal conditions, but does not guarantee any level of MTBSI
  - Normally applied only to a portion of Propulsion Power in Integrated Power System (IPS) configurations. Avoids installing too much redundant capacity.
  - In operation, "Exempt" loads are treated like "Long Term Interrupt" loads.

Quality of Service:
Classification of Loads: Examples

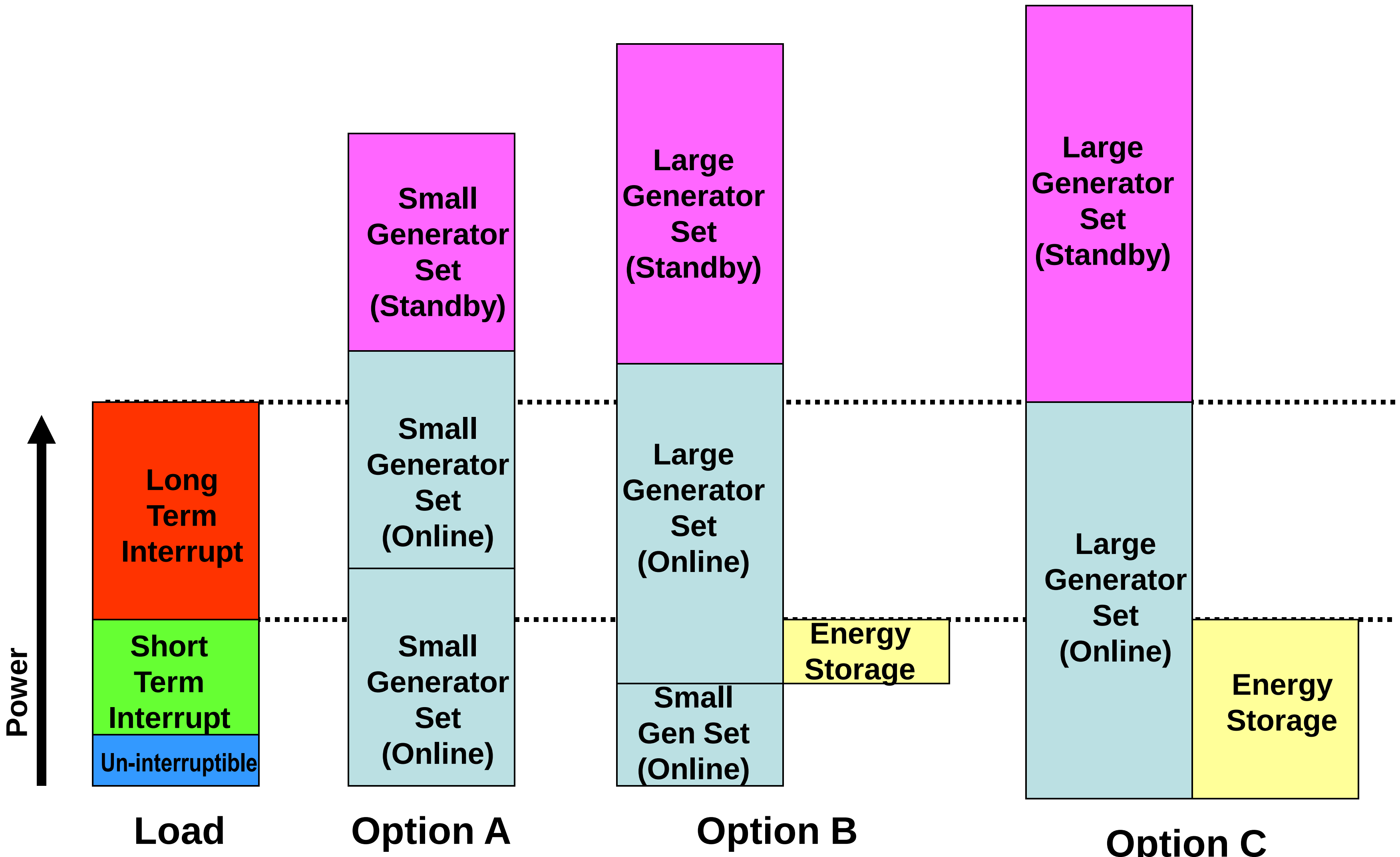
- “Un-Interruptible” Loads
  - Critical Electronic Systems
  - Fast Reaction time Self Defense Weapons Systems
- “Short Term Interrupt” Loads
  - Most Motor Driven equipment (pumps, winches, elevators)
  - AC Plants
  - Lights
- “Long Term Interrupt” Loads
  - Resistive Heaters
  - Heating, Ventilation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

Quality of Service: *Design Implementation*

- "Reconfiguration time" t1:
  - Making t1 shorter by using power electronics and other fast isolation strategies, can limit the number of un-interruptible loads (and potentially the amount of energy storage) on the ship.
- "Generator start time" t2:
  - Making t2 shorter through careful selection of Power Generation Modules can move loads from the "Short Term Interrupt" category to the "Long Term Interrupt" category which can reduce the amount of combined rolling reserve and energy storage needed.
- "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.
- "Short Term Interrupt" Loads
  - Online power generation and energy storage capability should be sufficient to power all Un-interruptible and short-term interrupt loads in the event that the largest online power generation module trips off line.
- "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.

QOS DESIGN ASSUMES SUFFICIENT GENERATION CAPACITY CAN BE RESTORED WITHIN TIME T2. IF NOT, THEN AT TIME T2 TRANSITION TO SURVIVABILITY BASED LOAD SHEDDING

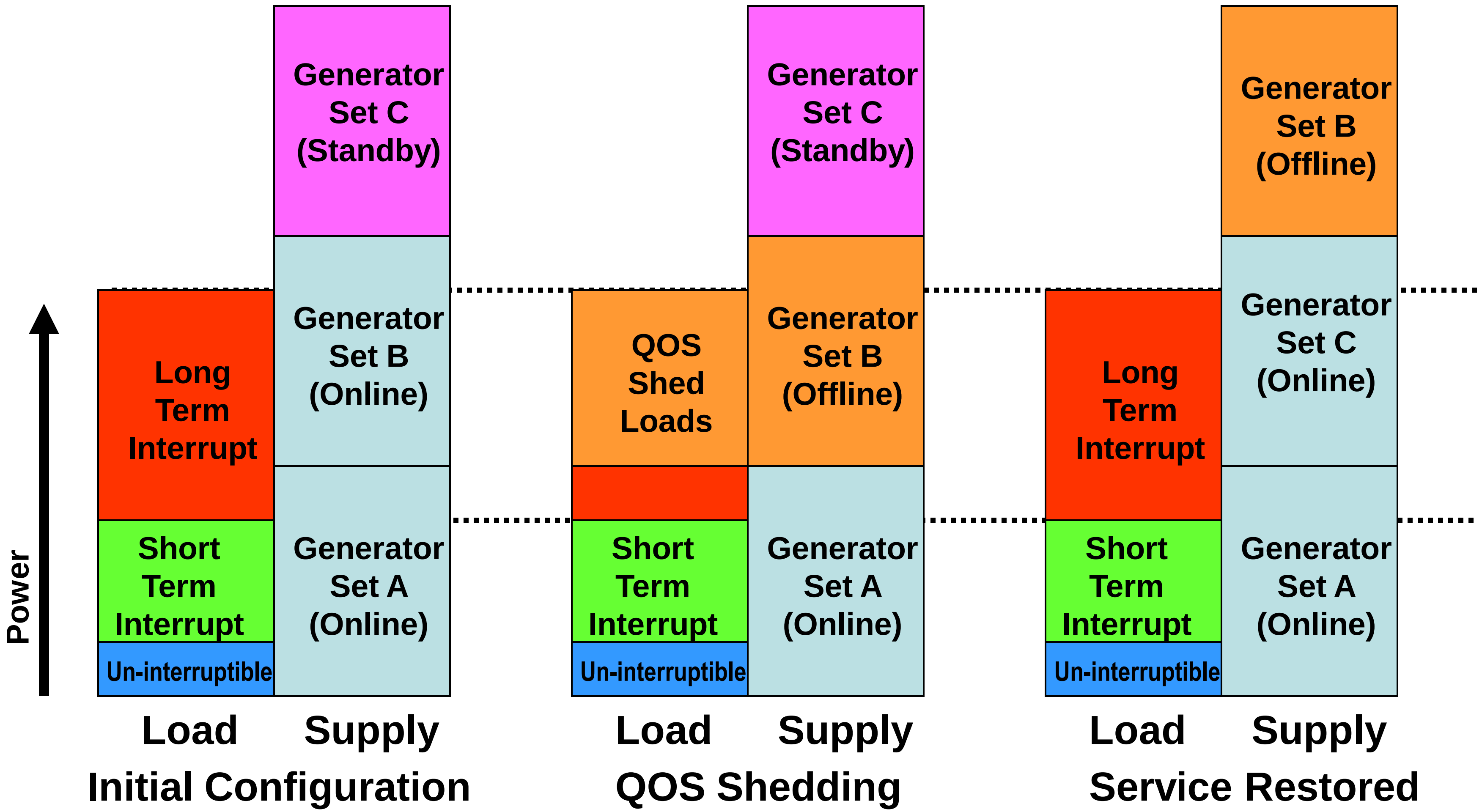
Power Generation Sizing



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.
  - 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 up to time t2 of an outage as a QOS problem.
  - At time t2 transition 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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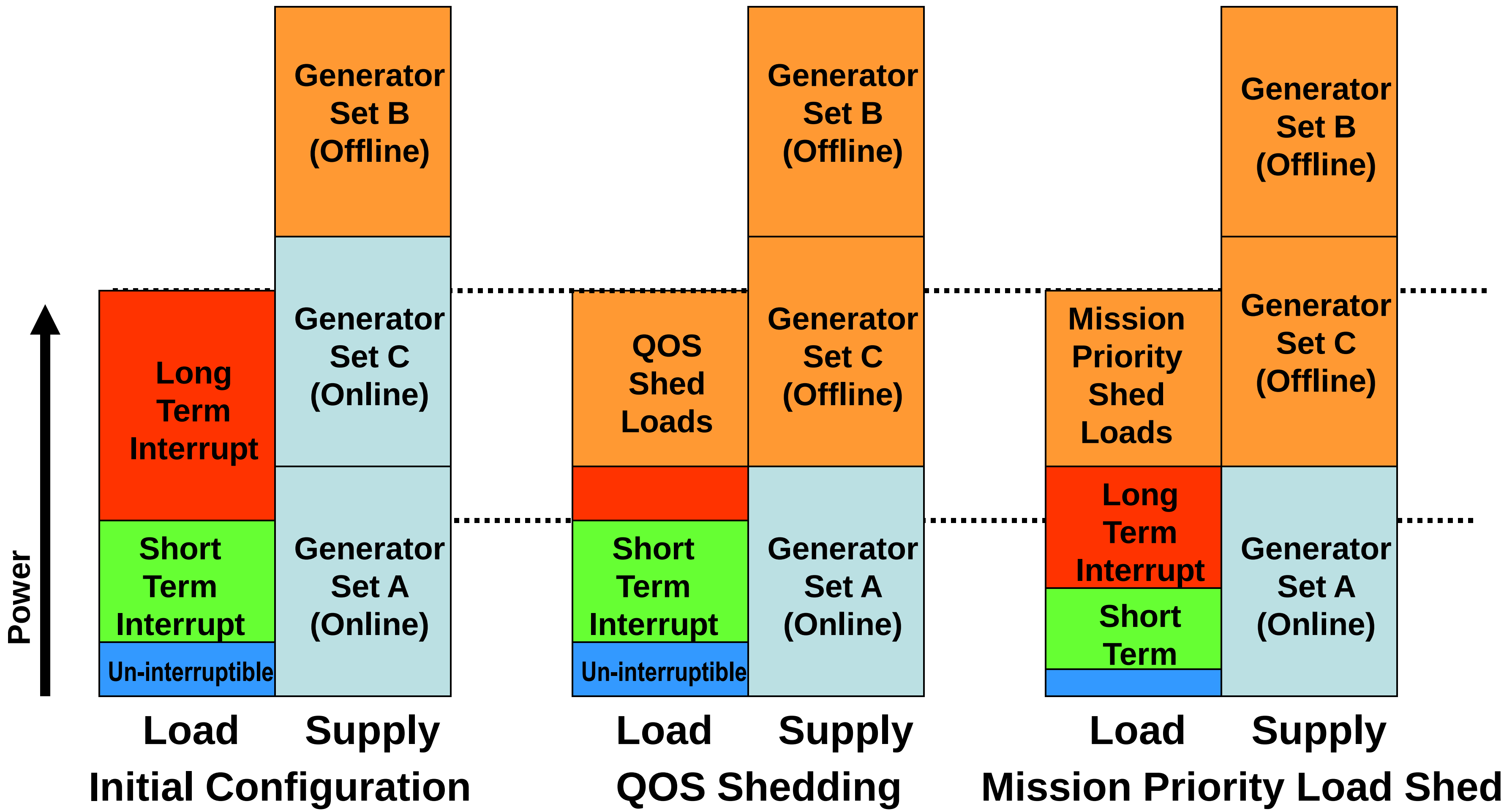
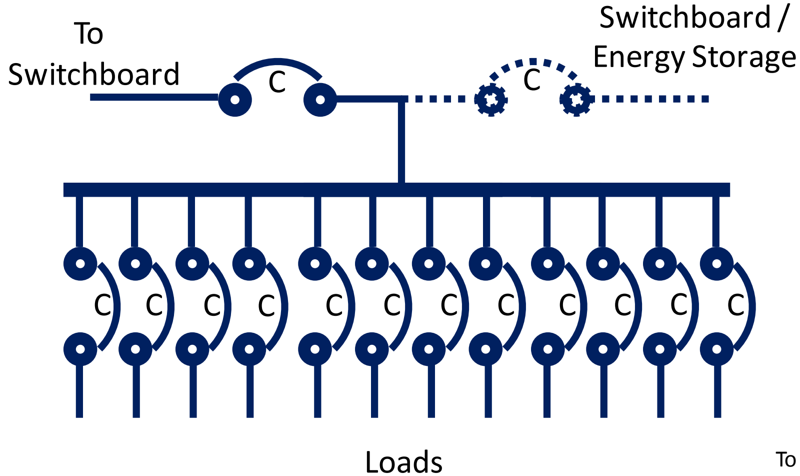
Example: Machinery Plant Controls (Loss of Second Generator Set)

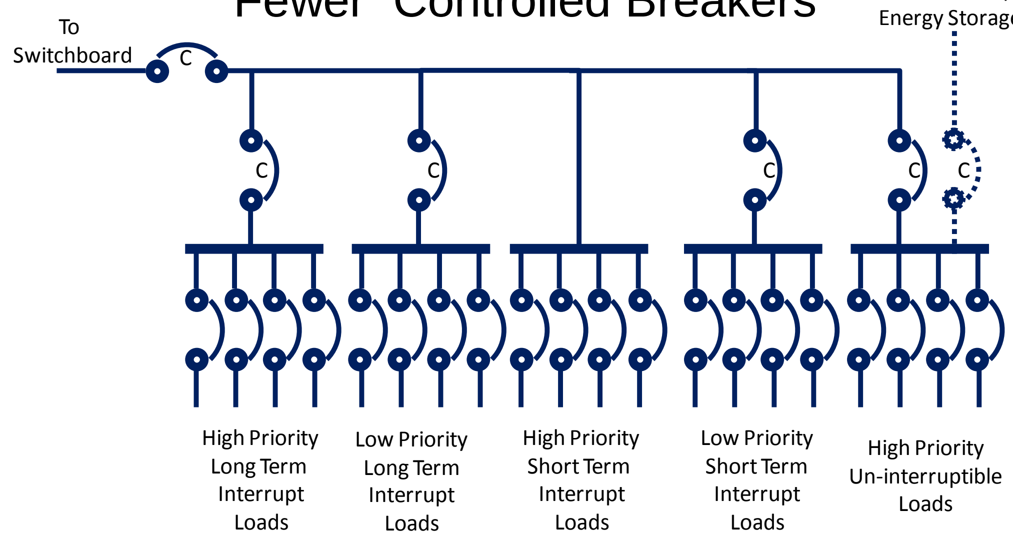


Quality of Service:
Controlling Loads

Many Controlled Breakers



Fewer Controlled Breakers



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”.
- Zonal electrical distribution system must enable both Port and Starboard distribution nodes to individually support all compartment level survivability loads.
- Geography extremely important
  - Unlike QOS, routing of cabling and location of equipment extremely important
    - 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
    - Only energize equipment when “safe” to do so
    - Possible Exception: High Priority Loads with long “reboot” times

Energy Storage Functions

- ESM-F1
  - Isolate un-interruptible loads from short term power interruptions
  - Generally ratings of 10’s to 100;s of kW and run time on order of 10 seconds
  - Few charge-discharge cycles
- ESM-F2
  - Provide backup power to un-interruptible and short term interrupt loads on the failure of a PGM or unanticipated addition of load.
  - Provide standby power until additional PGMs can be brought online for pulse power loads or other large mission loads.
  - Generally ratings of 100’s of kW to 10’s of MW for a duration of 1.5 to 6 times t2.
  - Few charge-discharge cycles
- ESM-F3
  - Provide Emergency Starting for PGM
  - Generally ratings of 100’s of kW for a duration of 15 to 30 minutes
  - Few charge-discharge cycles
- ESM-F4
  - Provide Load Leveling for pulse power loads and for PGMS with slow dynamics (such as fuel cells)
  - Generally ratings of 100’s of kW to 10’s of MW with run times on order of 10 seconds
  - Many charge-discharge cycles

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Take-Aways

- Quality of Service is now part of electrical system design
- Quality of Service provides a means for ensuring continuity of electrical power
- Quality of Service enables trade-offs in implementation that can be used to minimize cost
  - Leverage technology where it makes sense.
- Quality of Service provides sizing guidance for Energy Storage