



# Implementing Quality of Service in Shipboard Power System Design

IEEE ESTS 2011  
April 11-13, 2011

Dr. Norbert Doerry

Technical Director, Technology Group  
Naval Sea Systems Command

SEA 05TD

(202) 781-2520

[norbert.doerry@navy.mil](mailto:norbert.doerry@navy.mil)

Dr. John Amy Jr.

Office of the Assistant Secretary of the Navy  
for Research, Development and Acquisition (ASN(RDA))

(202) 781-0714

[john.amy@navy.mil](mailto:john.amy@navy.mil)

Approved for Public Release

# Report Documentation Page

*Form Approved  
OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>APR 2011</b>	2. REPORT TYPE	3. DATES COVERED <b>00-00-2011 to 00-00-2011</b>			
4. TITLE AND SUBTITLE <b>Implementing Quality Of Service In Shipboard Power System Design (Presentation)</b>		5a. CONTRACT NUMBER			
		5b. GRANT NUMBER			
		5c. PROGRAM ELEMENT NUMBER			
6. AUTHOR(S)		5d. PROJECT NUMBER			
		5e. TASK NUMBER			
		5f. WORK UNIT NUMBER			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Sea Systems Command, Washington, DC, 20376</b>		8. PERFORMING ORGANIZATION REPORT NUMBER			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)			
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)			
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>IEEE ESTS 2011, April 11-13, 2011, Alexandria, VA</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>	<b>Same as Report (SAR)</b>	<b>20</b>	

- 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

# 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**

- 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.

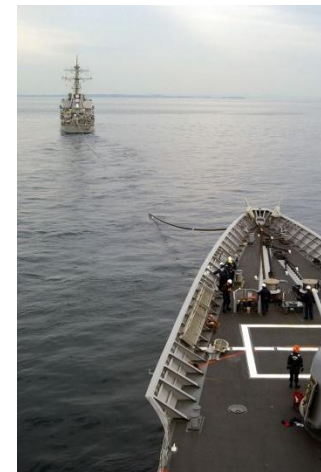
```

*** STOP: 0x0000000A (0x00000000, 0x0000001a, 0x00000000, 0x00000000)
IRQ1 NOT LESS OR EQUAL
p4-0300 irq1-1if SYSWER: 0xc000039e

D11 Base DateStrap - Name D11 Base DateStrap - Name
80100000 2e534e55 - mconkrl.exe 80400000 2e534e55 - hal_dll
80010000 2e51294b - Rha354r.sys 80130000 2e58c28a - SC31PKT.SYS
8001b000 2e4e7b6b - SesiDisk.sys 80220000 2e53f238 - RtFs.sys
fe240000 2e486007 - Floppy.SYS fe340000 2e406618 - ScsiCtrl.SYS
fe440000 2e406e59 - Fx loc.SYS fe340000 2e40660f - Null.SYS
fe440000 2e4065f4 - Bsp.SYS fe470000 2e406634 - Semouse.SYS
fe480000 2e524844 - I386prt.SYS fe340000 2e40660d - LowClass.SYS
fe4a0000 2e40660c - MdkLass.SYS fe4c0000 2e4065e2 - VIBOPRT.SYS
fe4b0000 2e534921 - all.SYS fe4d0000 2e4065e9 - sys.sys
fe4b0000 2e406650 - Mifs.SYS fe4f0000 2e414f30 - Npfs.SYS
fe510000 2e534722 - NDIS.SYS fe500000 2e407f5b - elink.sys
fe550000 2e406e57 - TDI.SYS fe530000 2e47c740 - sbt.sys
fe560000 2e5279d9 - mnlkpkp.sys fe570000 2e53a89e - mnlknb.sys
fe580000 2e534773 - tcpip.sys fe5a0000 2e526e68 - atd.sys
fe5b0000 2e5279d3 - netbt.sys fe5d0000 2e4167f7 - netbios.sys
fe5e0000 2e406623 - map.sys fe5f0000 2e443f51 - rdx.sys
fe630000 2e53421a - sev.sys fe660000 2e1f6062 - nurlkpkp.sys

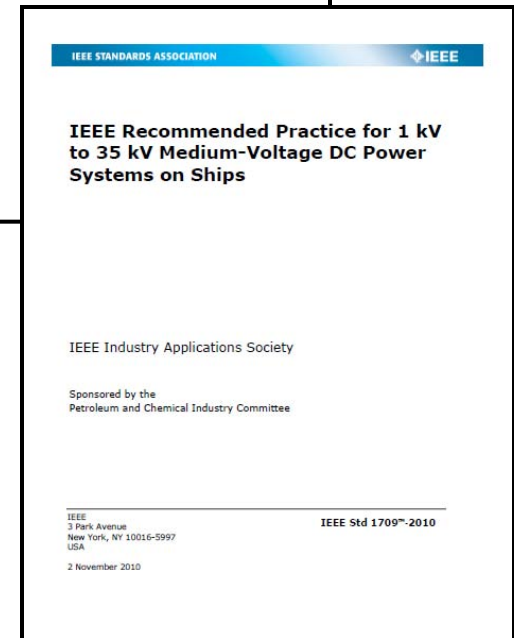
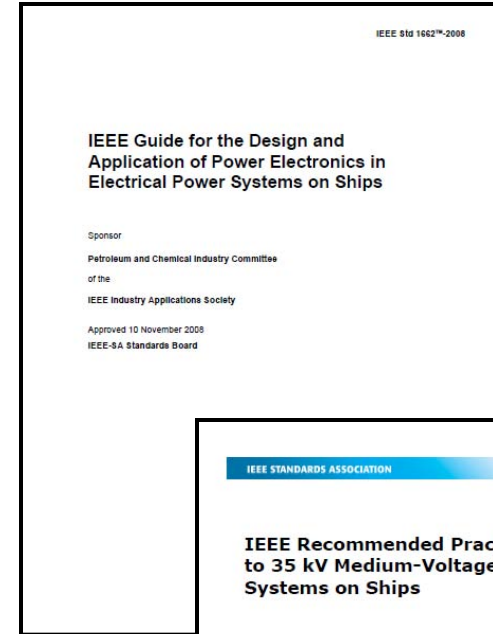
Address dump Build [1057] - Name
FF541E4c fe5105df fe5105df 00000001 ff601128 fe648228 0000021e - NDIS.SYS
ff541e40 fe501368 fe501368 00000246 000910c2 00000000 00000000 - elink.sys
ff541e34 fe481509 fe481509 ff66828c ff668288 00000000 ff668138 - 18042prt.SYS
ff541e30 fe481eab fe481eab fe482078 00000000 ff511094 8013c58a - 18042prt.SYS
ff541e24 fe482078 fe482078 00000000 ff511094 8013c58a ff66828c - 18042prt.SYS
ff541e18 881878a 0118c58a ff66828c ff668288 8018c580 00000031 - mconkrl.exe
ff541e14 88405900 80405900 80000031 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: Writing physical memory to disk: 2000
CRASHDUMP: Physical memory dump complete
    
```



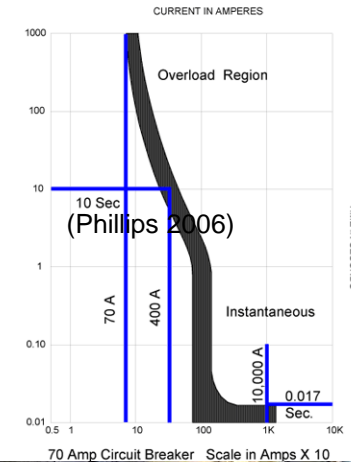
**QUALITY OF SERVICE DEALS WITH ENSURING LOADS RECEIVE A RELIABLE SOURCE OF POWER UNDER NORMAL OPERATING CONDITIONS**

- 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”





- **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.



- “Un-Interruptible” Loads
  - Loads that cannot tolerate power interruptions of duration  $t_1$ .
  - 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  $t_1$ , but cannot tolerate power interruptions of duration  $t_2$ .
  - The power system is designed to provide power with interruptions exceeding time  $t_1$  with the reliability as defined by the customer specified MTBSI.
- “Long Term Interrupt” Loads
  - Loads that can tolerate power interruption greater than  $t_2$  in duration.
  - The power system is designed to provide power with interruptions exceeding time  $t_2$  with the reliability as defined by the customer specified MTBSI.
- “Exempt” Loads
  - Loads that can tolerate power interruption greater than  $t_2$  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*

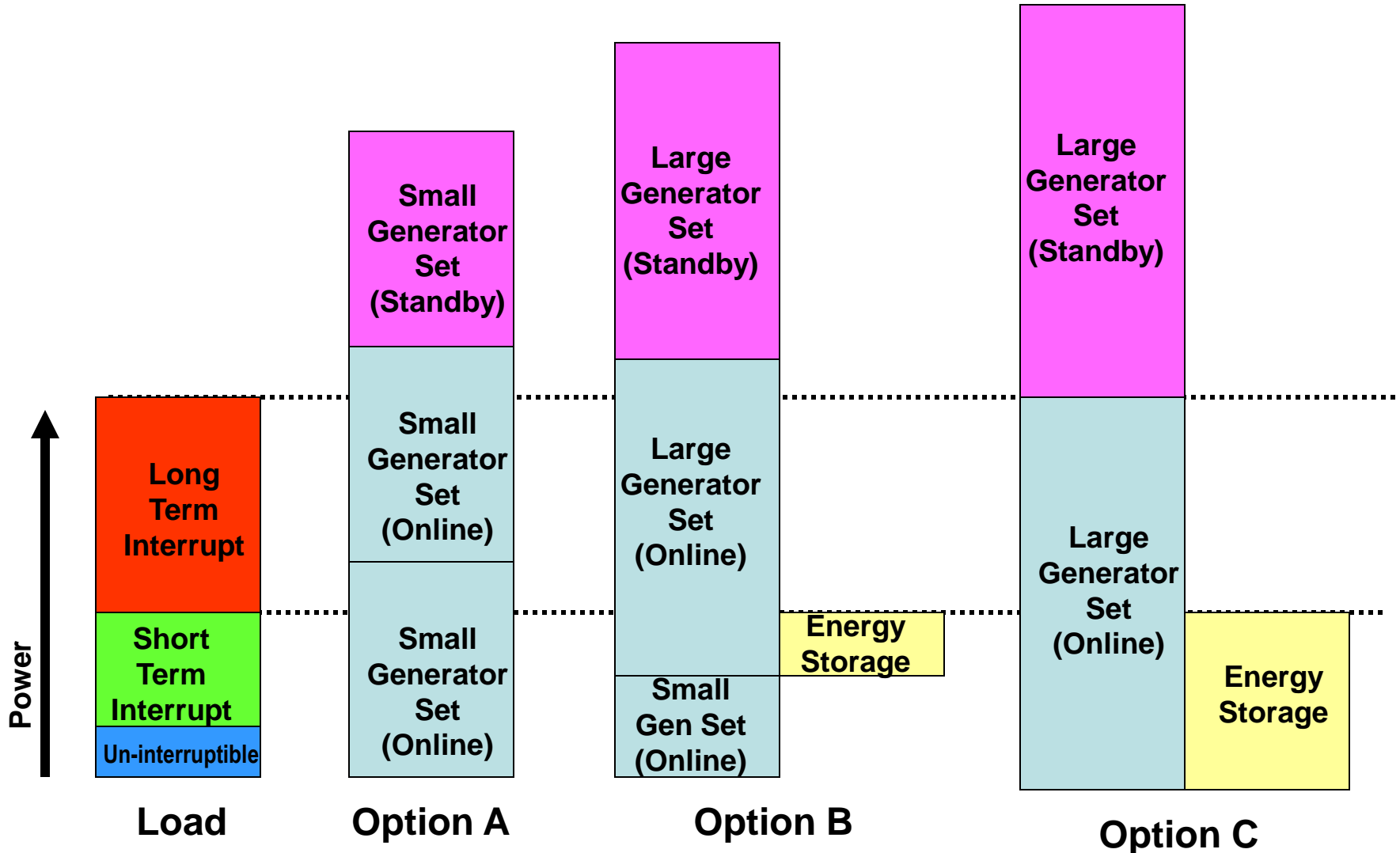


- “Un-Interruptible” Loads
  - Critical Electronic Systems
  - Fast Reaction time Self Defense Weapons Systems
- “Short Term Interrupt” Loads
  - Most Motor Driven equipment (pumps, winches, elevators)
  - AC Plants
  - Lights
- “Long Term Interrupt” Loads
  - Resistive Heaters
  - Heating, Ventilation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

- “Reconfiguration time”  $t_1$ :
  - Making  $t_1$  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”  $t_2$ :
  - Making  $t_2$  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.

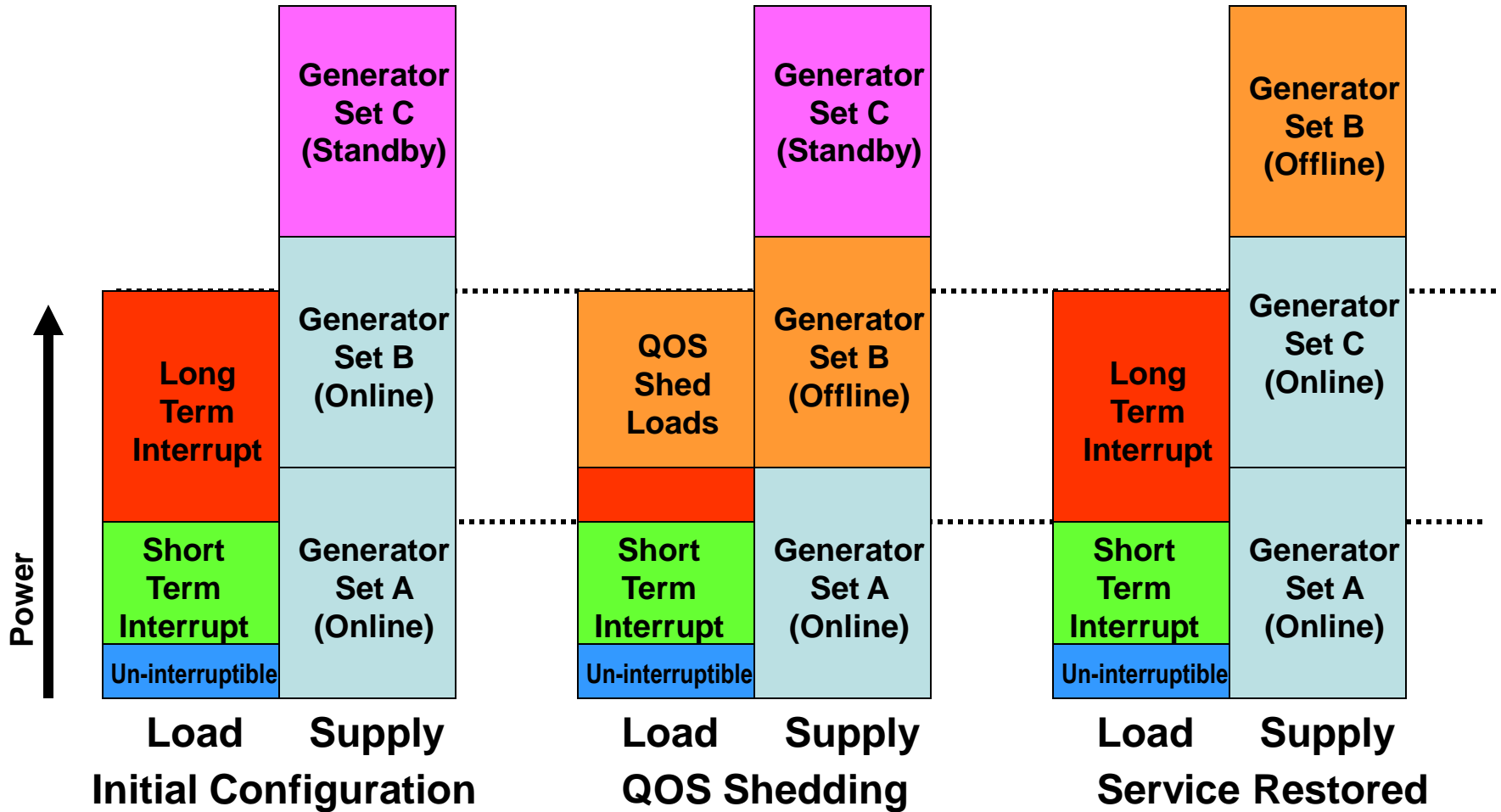
**QOS DESIGN ASSUMES SUFFICIENT GENERATION CAPACITY CAN BE RESTORED WITHIN TIME T2. IF NOT, THEN AT TIME T2 TRANSITION TO SURVIVABILITY BASED LOAD SHEDDING**

# Power Generation Sizing

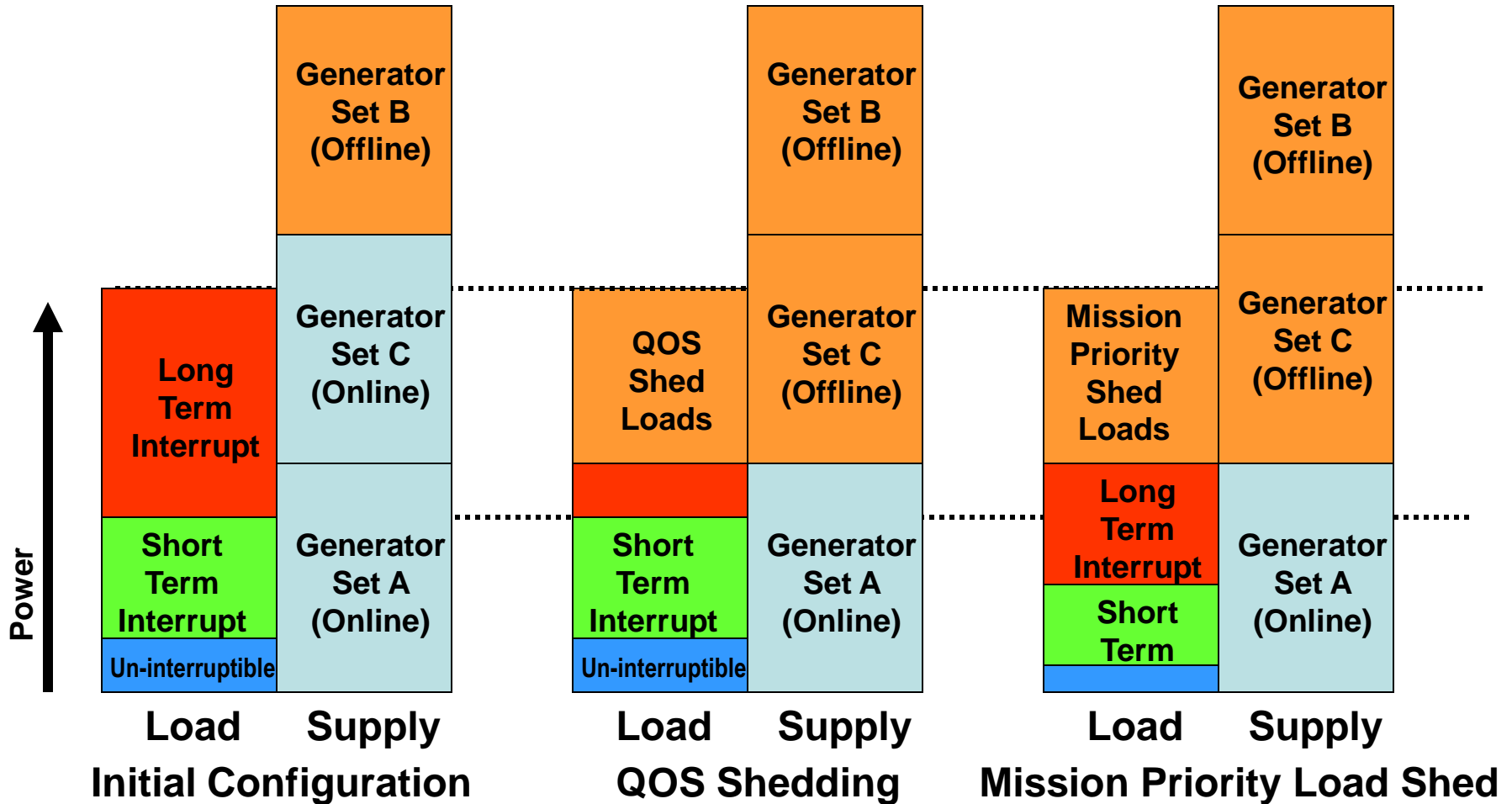


- Un-interruptible Loads
  - Aggregation of Loads enables cheaper and more reliable power conversion, but increases probability that failure of one load will impact QOS to another load.
  - Failure Modes of loads typically not known during early stage design (if at all)
- Short Term Interrupt and Long 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)



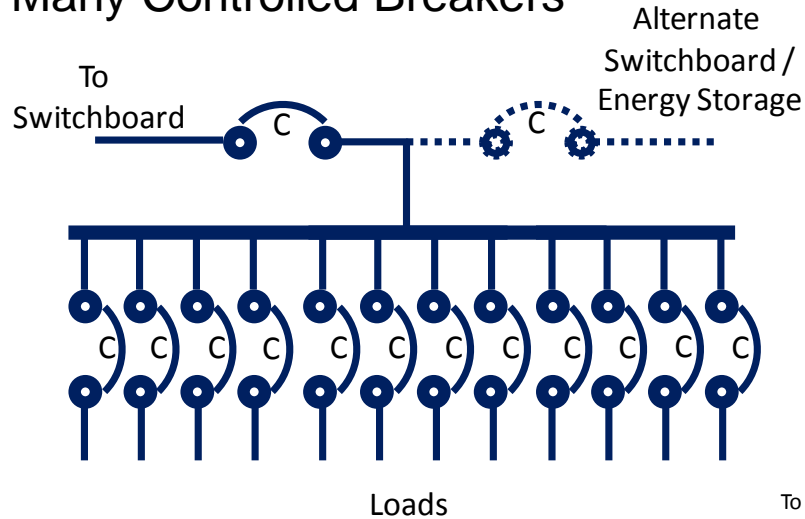
# Example: Machinery Plant Controls (Loss of Second Generator Set)



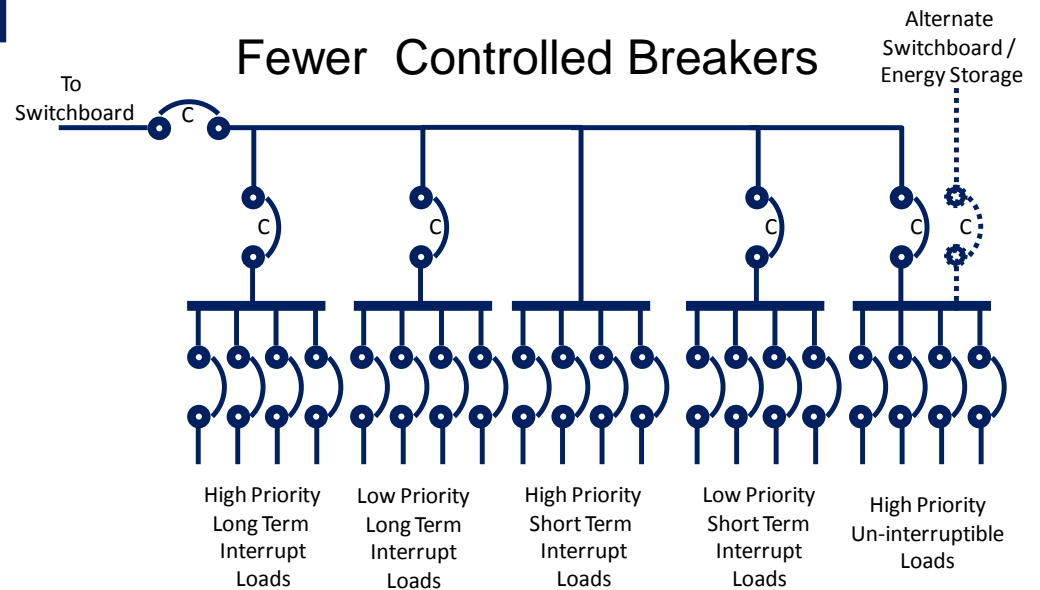
# Quality of Service: Controlling Loads



## 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

- **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  $t_2$ .
  - 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

- 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

