Load Management (Load Shedding)

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1. Introduction

Shipboard power systems are designed such that under normal conditions, sufficient power is generated to serve all online loads. Usually due to equipment failure or through the actions of circuit protection, the power system may occasionally be in a condition where there is insufficient generation to serve the online loads. This insufficiency of generation may be at the total ship level, or may be localized to a zone or some other partition of the power distribution system.

The insufficiency of generation should be corrected quickly. If the insufficiency is not great, generator sets can typically withstand an overload for seconds to minutes. If the insufficiency is too great, the prime mover will slow down, causing the frequency to decrease as well. If the overload lasts too long, on the order of seconds, generator sets will trip off line due to the low frequency and the ship will go dark. The situation with power electronic converters is no better. When overloaded, power electronic converters will enter a current limit mode where the voltage will decrease until the current limit is reached. If the overload persists for more than a few seconds, power electronic converters typically shutdown.

To avoid a dark ship where all generator sets are offline, load management in the form of load shedding is employed to reduce the power demanded by loads by turning off power to a sufficient number of loads such that the online power generation and energy storage have sufficient power capacity to serve the remaining loads.

Historically, load shedding has been implemented in one or more stages based on the priority of the load in meeting the ship's missions. During this mission priority load shedding, upon the detection of the insufficiency of generation, the first stage of load shedding is implemented while the standby generator is started and brought online. If the first stage of load shedding is insufficient, additional stages of load shedding are implemented. Once sufficient generation capacity is brought online, power is restored to the shed loads.

Modern controls enable more sophisticated load shedding algorithms. One approach is to initially employ quality of service (QOS) based load shedding, and resorting to mission priority load shedding if it is not possible to quickly bring sufficient generation capacity online (due to situations such as equipment damage or equipment under maintenance).

Under QOS, a power interruption is only a service interruption if it lasts longer than what a load can tolerate. Many systems can tolerate having equipment offline for several minutes. HVAC systems for space air conditioning and heating, refrigerators, freezers, hot water heaters, and nonemergency lighting are examples of loads that can safely be shed for the several minutes needed to start and bring online the standby generator; a multi-minute long power interruption would not be considered a service interruption for these long term interrupt loads.

This document is largely derived from IEEE Std 45.3. See Doerry and Amy (2011) for additional thoughts.

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2. Quality of service load shedding

Under QOS load shedding, sufficient long term interrupt loads are shed until the remaining power generation and energy storage system capacity is sufficient to serve the remaining loads. If all the long term interrupt loads have been shed and there still isn't sufficient capacity to serve the loads, then the remaining online loads are shed in order of mission priority until enough have been shed. These additional shed loads will likely experience a service interruption because the power interruption will likely be longer than these loads can tolerate.

The design of the power system should ensure that under all operational conditions, with the loss of an online generator set, there is sufficient online capacity and energy storage to serve all of the uninterruptible and short term interrupt loads.

Sufficient generation should be brought online in time to preclude any load suffering a service interruption. If the power interruption lasts as long as the generator start time (t2), the load shed strategy should switch to a mission priority based load shed strategy. Some of the more important long term interrupt loads (such as the refrigerators and freezers) would have their power restored while other short term interrupt loads and possibly uninterruptible loads with a lower mission priority would be shed.

An integrated power system (IPS) ship operating in the open ocean and not in a restricted maneuverability condition, may designate the power allocated to propulsion above that needed for steerageway as a long term interrupt load. No harm is done if propulsion power is lost for several minutes; the ship's speed will coast down, but may not even slow down enough to reach the speed for steerageway during the several minutes needed to restore power generation capability. In many cases of a generator set tripping off line, shedding the propulsion power alone would be sufficient to preclude having to shed any other loads.

Figure 1 depicts a scenario where two generator sets are normally operating with a third in standby; energy storage is not available. Initially, under normal operation, all loads are supplied. When generator set B trips offline, sufficient long-term interrupt loads are shed so as to not overload the remaining generator set A. When the standby generator set, generator set C comes online, power to all loads is restored. Assuming power is restored within time t2, no loads experience a service interruption.

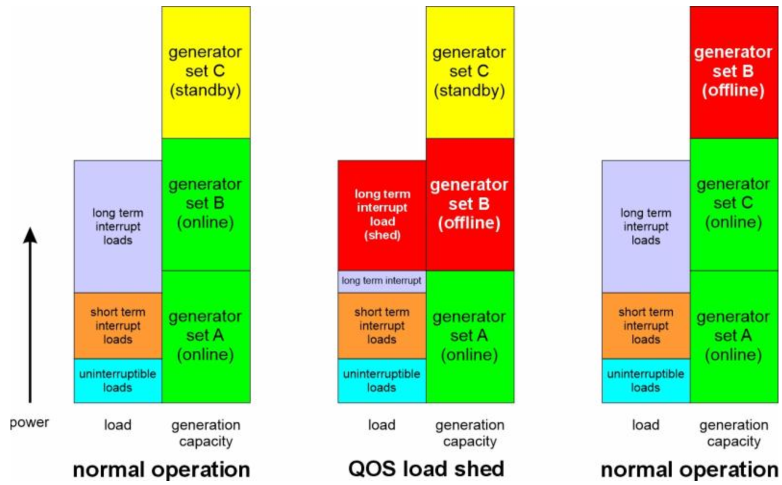

Figure 1: QOS load shedding – no energy storage

Figure 2 depicts a similar system that differs from Figure 1 in that the sum of the uninterruptible loads and short term interrupt loads is greater than the power capacity of a single generator set; and an energy storage system has been added. Under normal operation, the two online generator sets power all of the loads. When generator set B trips offline, the energy storage immediately comes online. The combination of generator set A and the energy storage is sufficient to power all the uninterruptible and short term interrupt loads as well as some of the long term interrupt loads; the remaining long term interrupt loads are shed. When the standby generator set C comes on line, power is restored to all loads and the energy storage reverts back to standby. Any excess generation capacity is used to recharge the energy storage. Assuming power is restored within time t2, no loads experience a service interruption.

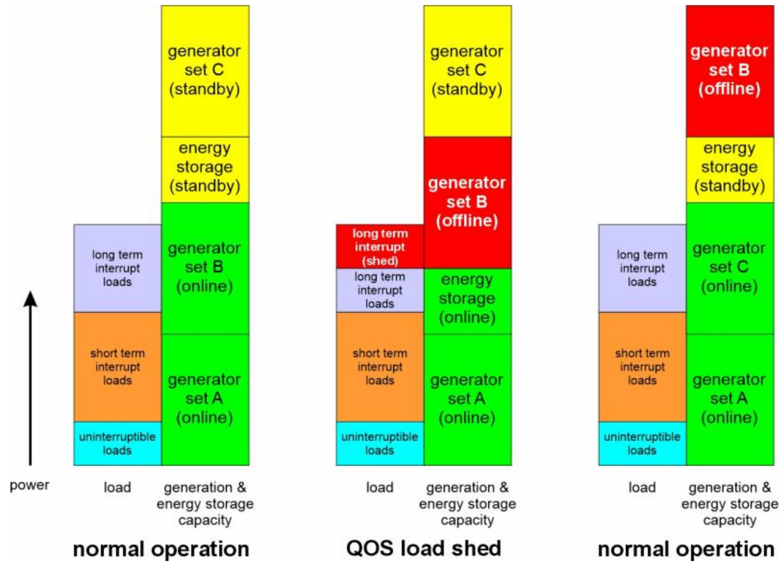

Figure 2: QOS load shedding – with energy storage

Figure 3 depicts a system where one generator set can supply the entire load. The system also has sufficient energy storage to power the uninterruptible and short term interrupt loads. Upon loss of the online generator set, energy storage immediately powers the uninterruptible, short-term interrupt, and some of the long term interrupt loads. When the standby generator set comes online, power is restored to all the loads and the energy storage returns to standby. Any excess generation capacity is used to recharge the energy storage. Assuming power is restored within time t2, no loads experience a service interruption.

Figure 4 depicts a system with two generators sets online, one with a larger rating than the other. The system also has sufficient energy storage such that with the smaller generator set online, there is sufficient capacity to power the uninterruptible and short term interrupt loads. Upon loss of the larger generator set, the energy storage along with the remaining smaller generator power all of the uninterruptible loads , all of the short-term interrupt loads, and some of the long term interrupt loads. When the standby generator set comes online, power is restored to all the loads and the energy storage returns to standby. Any excess generation capacity is used to recharge the energy storage. Assuming power is restored within time t2, no loads experience a service interruption.

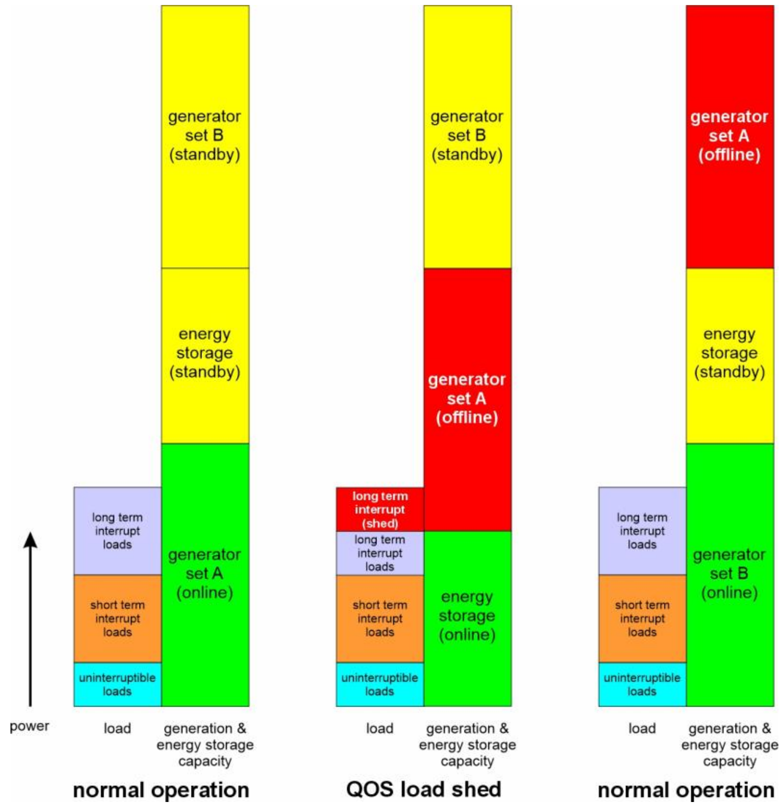

Figure 3: QOS load shedding – one generator set online with energy storage

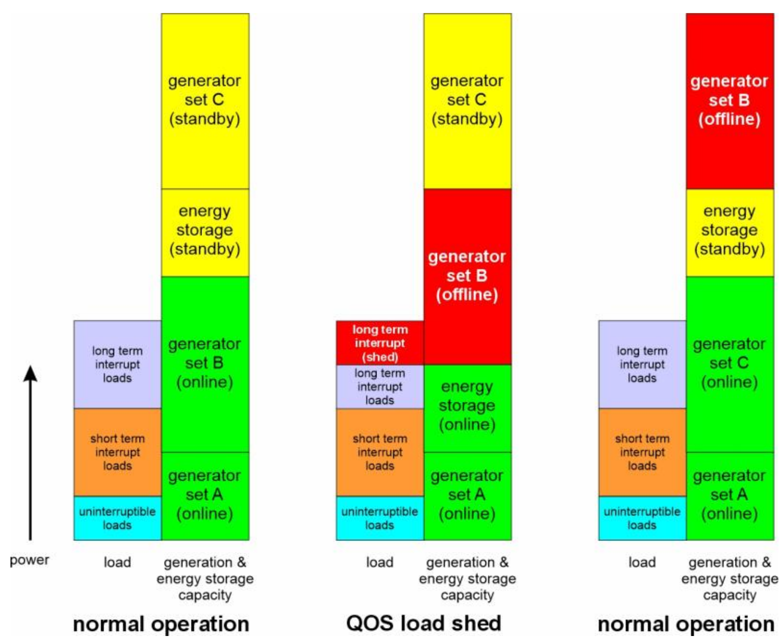

Figure 4: QOS load shedding – large and small generator set with energy storage

3. Mission Priority Load Shedding

3.1. Introduction

Ships have historically implemented mission priority load shedding, primarily because the degree of control of individual loads had been limited. Most ships implemented only one or two levels of load shedding; if shedding these two levels was not adequate, the ship would likely experience a dark ship followed by the emergency generator starting and powering only the emergency loads.

A number of different terms have been used to category the priority of loads. In some cases, the categories overlap each other.

The three levels of mission priority employed on some naval ships are vital, semi-vital, and non-vital. Other ships may employ only two levels: vital and non-vital.

With modern electric plant controls, and the greater ability to control individual loads, more sophisticated load shed strategies are possible. The priority of a given load may vary over time as the missions that the ship is carrying out change. For example, when a destroyer is conducting anti-submarine operations, then the sonar, and anti-submarine warfare (ASW) weapons may have a much higher mission priority than when the destroyer is conducting air defense missions. With advanced controls, it is also straightforward to initially implement QOS load shedding; only when sufficient generation capacity cannot be brought online in time for the power interruption to be limited to t2 would mission priority load shedding be implemented.

3.2. Mission priority categories

3.2.1. Mission Critical Equipment

Mission critical equipment (MCE) is defined in MIL-STD-1399-300-1 as equipment designated to remain operational during emergency conditions. MCE are required to operate through power interruptions of duration t1 (QOS reconfiguration time). MCE are therefore required to be short term interrupt or long term interrupt loads.

3.2.2. Emergency loads

Emergency loads are those powered under the emergency condition. For commercial ships, the emergency loads are defined in 46 CFR Chapter I subchapter J part 112, subpart 112.15 – Emergency Loads.

For naval ships, emergency loads are those powered during the emergency condition. DPC 310-1 defines the emergency condition to be:

“An emergency condition is a ship operating condition in which the ship is on emergency generator with ship service generators down. The emergency generators, as a minimum, supply loads associated with the following:

- Surface combatant . Emergency ship control and selected self defense weapons.

- Aircraft carrier . Emergency ship control and the larger electrical load associate with selected weapons or limited air operations (recovery and strike down of aircraft).

- Amphibious . Emergency ship control and limited unloading operations.

- Auxiliary . As listed in the Code of Federal Regulations, Title 46, Part 112.

- Mine warfare and patrol craft . Emergency ship control”

Emergency ship control is defined as

“ … Generally, emergency ship control includes, as a minimum, the following electrical loads:

a. Steering gear and associated auxiliaries.

b. Vital propulsion and propulsion auxiliaries. Vital propulsion and propulsion auxiliaries are: (1) Required for cold starting the ship’s propulsion plant. (2) Necessary for propulsion machinery protection. (3) Needed to achieve a minimum emergency propulsion capability (typically 7 knots) if propulsion cannot be otherwise restored in less than 2 minutes.

c. Machinery space class W and circle W ventilation.

d. Emergency lighting.

e. Emergency communications and radio communication systems.

f. Navigation Systems and Navigation Lights.

g. Fire pumps, fire containment equipment, magazine sprinkling, dewatering pumps, and associated damage control equipment.

h. Control systems, critical sensors, networks, and interior communications supporting emergency systems.

i. Auxiliaries to support the emergency generator and all equipment necessary to generate and distribute power to the other emergency loads, Auxiliaries required to directly support other emergency loads.

j. Personnel locator.

k. Flammable fluid isolation valves.

l. Exhaust ventilation for desmoking and damage control ventilation."

3.2.3. Vital loads

Vital loads are part of vital systems; vital systems are defined by the Code of Federal Regulations (46 CFR chapter I subchapter F part 62):

> "*Vital system or equipment* is essential to the safety of the vessel, its passengers and crew. This typically includes, but is not limited to, the following:
>
> (1) Fire detection, alarm, and extinguishing systems.
>
> (2) Flooding safety systems.
>
> (3) Ship service and emergency electrical generators, switchgear, and motor control circuits serving vital electrical loads.
>
> (4) The emergency equipment and systems listed in § 112.15 of this chapter.
>
> (5) Propulsion systems, including those provided to meet § 58.01-35 of this subchapter.
>
> (6) Steering systems."

For naval ships, additional mission systems and supporting auxiliary systems may also be designated as vital.

3.2.4. Semi-vital loads

For naval ships, portions of mission systems and supporting auxiliary systems may be designated as semi-vital instead of vital or non-vital. Semi-vital loads may provide redundancy, so the immediate impact of shedding these loads may not be severe.

3.2.5. Non-vital loads

Loads that are neither vital nor semi-vital are non-vital.

3.2.6. Adaptable mission priority

An adaptable mission priority enables the operator to change the relative priority of loads based on the current operational condition. Generally emergency loads should always be the highest priority. The next priority should be loads and systems supporting the current operations of the ship followed by crew support loads. The lowest priority should go to loads that only support missions that are not being conducted, or loads that are optional.

When mission priority load shedding is performed, the loads are shed in order of priority from the lowest priority. Enough loads are shed to enable the online generator sets and energy storage to serve the remaining loads. Once sufficient generation capacity is online, all shed loads are restored.

3.3. Examples

Figure 5 depicts a traditional two stage mission priority load shedding scheme without QOS load shedding. In this case, shedding only the non-vital loads is sufficient to not overload generator set A; once generator set C is online, power is restored to all loads.

Figure 6 depicts a traditional two stage mission priority load shedding scheme with energy storage and QOS load shedding. Initially, QOS load shedding is performed. In this case, time t2 elapses and generator set C is not yet online (perhaps a failed start or two). At t2, the load shedding strategy switches to mission priority; non-vital loads are shed, and any semi-vital or vital loads previously shed are now restored. Because generator set A has sufficient capacity to serve the vital and semi-vital loads, energy storage transitions to the standby state; excess power generator capacity is used to recharge it. When generator set C is online, power is restored to all loads.

Figure 7 depicts a mission priority load shedding scheme employing energy storage. Upon failure of the online generator set, energy storage provides power. Initially, QOS load shedding is performed. After t2 time has passed and generator set B has not come on line, the load shed strategy shifts to mission priority. All non-vital loads are shed to maximize the amount of time that the energy storage powers the vital and semi-vital loads. If the state of charge of the energy storage drops below a threshold value, the semi-vital loads would be shed as well. In this case generator set B comes online prior to shedding the semi-vital loads. Power is restored to all loads and the energy storage recharges.

Figure 8 depicts an adaptable mission priority load shedding scheme. Initially QOS load shedding is performed. Since generator set C is not online after time t2, the load shed strategy switches to the adaptable mission priority load shedding scheme. With the ability to shed individual loads, or small groups of loads, the lowest priority loads for the current operational condition are shed until the remaining load can be powered by the online generator sets and energy storage. Should the energy storage become depleted and go offline, additional lower priority loads would be shed. When generator set C finally comes online, power to all loads is restored and energy storage is in standby and recharging.

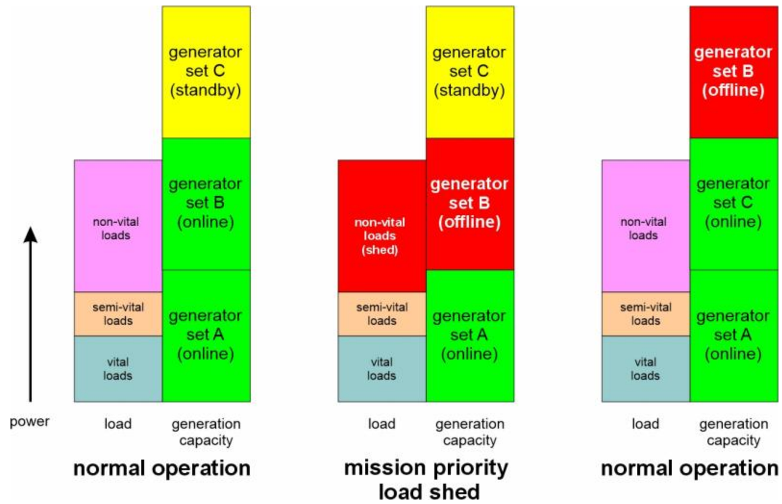

Figure 5: Traditional mission priority load shedding only

Figure 6: QOS and mission priority load shedding

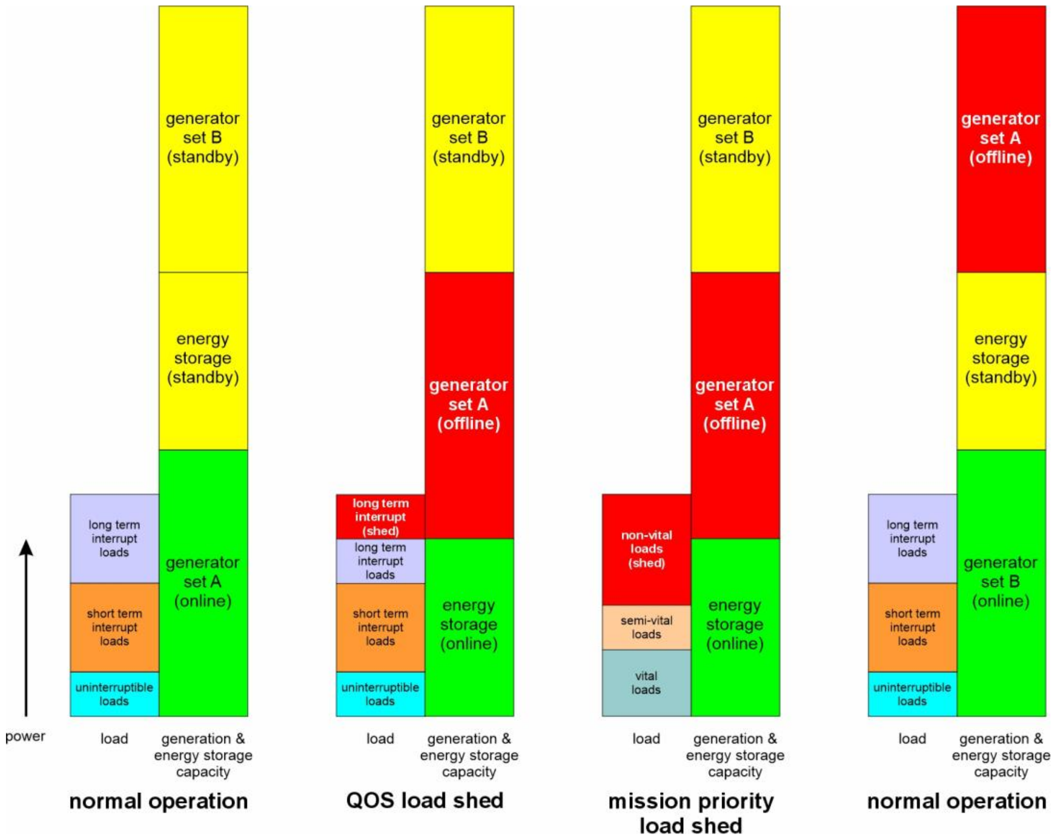

Figure 7: QOS and mission priority load shedding – one generator set online with energy storage

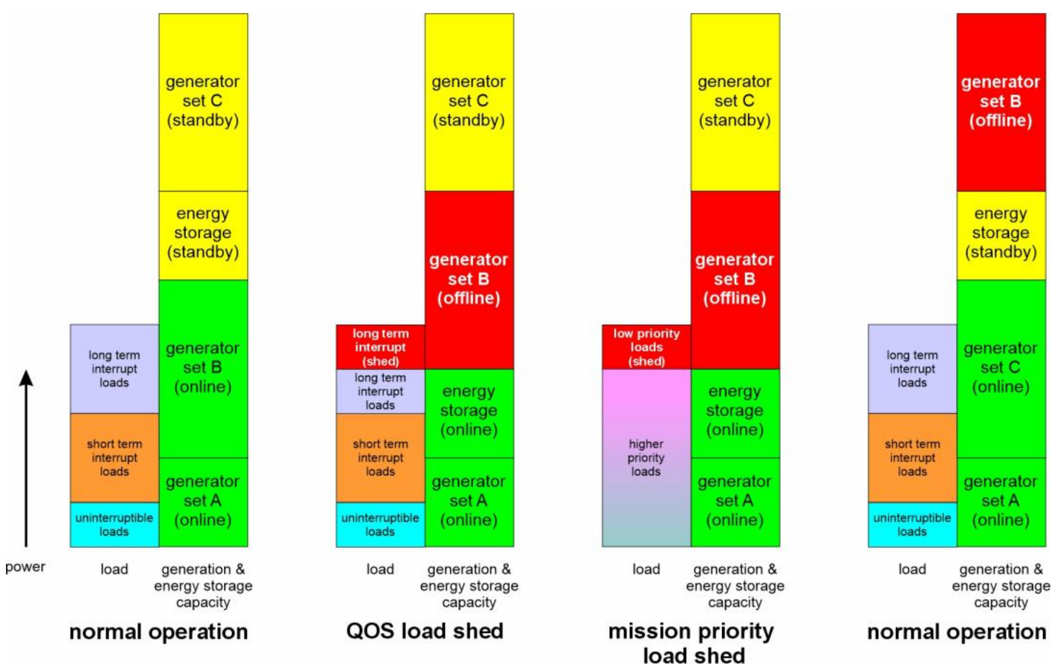

Figure 8: QOS and mission priority load shedding – adaptable mission priority

4. Load shedding implementation

4.1. Traditional mission priority load shedding

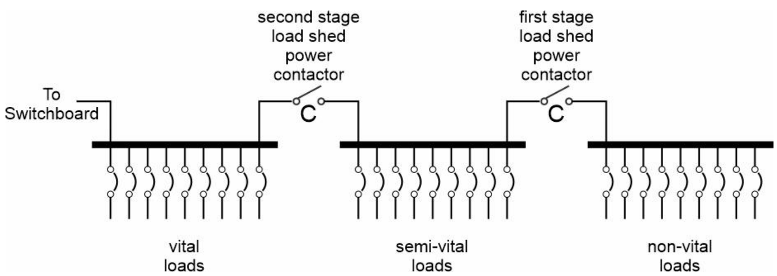

Figure 9: Traditional mission priority load shedding

Load shedding is typically implemented in load centers. Figure 9 depicts a traditional approach to two stage load shedding without QOS load shedding. The loads are connected to vital load, semi-vital load and non-vital load buses within the load center. Power contactors receive command from the control system to open and thereby shed the appropriate loads.

4.2. Traditional load shedding with QOS load shedding

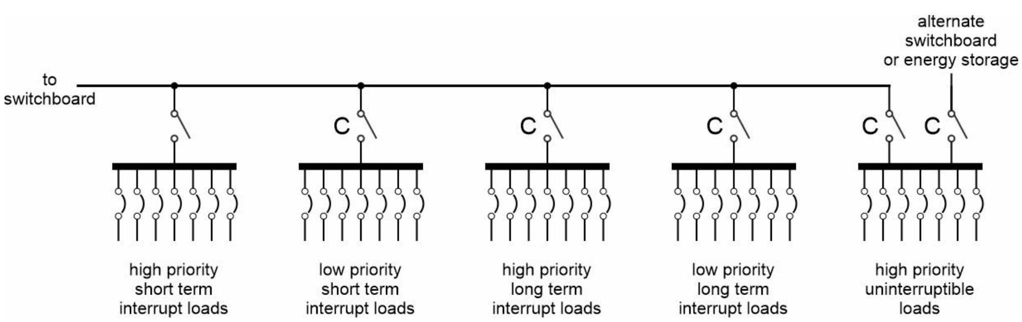

Figure 10: Traditional load shedding with QOS load shedding

Figure 10 depicts an implementation of QOS load shedding with a single stage mission priority load shedding. The control system determines which of the power contactors are open or closed. The circuit assumes all uninterruptible loads are high priority; an additional bus would be needed if low priority uninterruptible loads existed. The power contactors to the high priority uninterruptible bus should be capable of switching sources within time t1 to ensure the uninterruptible loads do not experience a service interruption.

4.3. Controlled breaker load shedding implementation

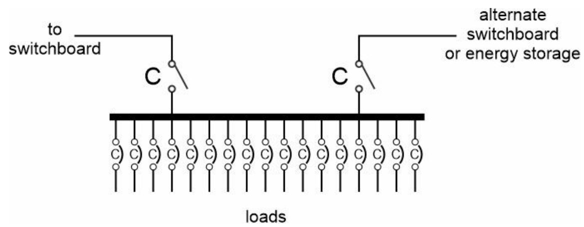

Figure 11: Controlled breaker load shedding implementation

Figure 11depicts the use of controlled circuit breakers to each load; this configuration provides the most flexibility to implementing load shedding, including adaptable mission priority load shedding. Where possible, direct communication with loads should be employed to command loads to perform an orderly shutdown, or enter a reduced power state; the controlled breaker can serve as a backup in case the load does not respond quickly enough. Since each load is individually controlled, the control system can perform both QOS load shedding and adaptable mission priority load shedding. The power contactors to the switchboard and alternate switchboard / energy storage should be capable of switching sources within time t1 to ensure the uninterruptible loads do not experience a service interruption.

5. References

IEEE Std 45.3, IEEE Recommended Practice for Electrical Installations on Shipboard— Systems Engineering

Doerry, Dr. Norbert H. and Dr. John V. Amy Jr., "Implementing Quality of Service in Shipboard Power System Design," Presented at IEEE ESTS 2011, April 11-13, 2011, Alexandria, VA

Code of Federal Regulations - 46 CFR Chapter I

MIL-STD-1399 section 300 part 1, Low Voltage Electric Power, Alternating Current, 25 September 2018.

NAVSEA DPC 310-1 Rev 1 (T9070-A3-DPC-010/310-1), "Design Data Sheet: Electric Power Load Analysis (EPLA) for Surface Ships," 17 September 2012.