Electric Loads

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1. Introduction

Electric loads are the users of electrical power provided by the electrical distribution system; without electric loads, there would not be a need for an electrical power system onboard ship. Indeed, the primary objectives of power system design is a survivable power system that provides continuity of electrical service of the requisite power quality to loads. These objectives are addressed by the following aspects of power system design: Power quality, continuity of service, and survivability.

2. Power Quality

In most power systems, sources of power such as generator sets, power converters, and energy storage control the properties of the voltage waveform. Loads control the properties of the current waveform. Interface standards specify limits on the properties of the load currents assuming that the sources and distribution system abide by specified limits on the properties of the voltage. For loads, the limits cover topics such as harmonic content of the load current and inrush current. Power quality interface standards are defined by IEEE Std. 45.1, MIL-STD-1399-300.1 and MIL-STD-1399-300.2.

3. Continuity of Service

3.1. Power and Energy Capacity

One of the key aspects of providing continuity of service is having sufficient power and energy capacity installed on the ship. The required capacity is determined from an electric power load analysis and the required level of redundancy. Typically, a ship is required to power ship service loads and sufficient propulsion power to achieve a specified speed when the largest generator set is not functional.

3.2. Electric Power Load Analysis

An electric power load analysis (EPLA) tracks all the electrical loads onboard the ship in an electric load list and may use one of several methods to model these loads to determine the required power and energy capacity of the power system. The electric load list may include thousands of individual loads. Early in the design process, many of the loads will not have been determined; there existence is modeled as proxy loads. A proxy load can represent in a single entity a multitude of small loads (such as all the light fixtures in a compartment). A proxy load can also represent equipment that is known will be onboard the ship, but the exact make and model of the equipment is not known. As the design develops, the proxy loads are replaced with characteristics of the actual loads that are installed on the ship. Details on conducting an EPLA are in IEEE Std. 45.1 and DPC 310-1.

3.3. Quality of Service

Quality of service is a measure of continuity of service from the perspective of the load. A failure of continuity of service is a service interruption and a service interruption is defined in terms of what a load can tolerate. Service interruptions are categorized with respect to two properties of the power system; reconfiguration time (t1), and generator start time (t2).

3.3.1. Reconfiguration time (t1)

As defined in IEEE Std 45.1, reconfiguration time (t1) is the maximum time to reconfigure the electrical distribution system or to clear faults without bringing on additional generation capacity. Reconfiguration time is thus the maximum length of time that a load could experience power quality outside of steady-state interface requirements due to circuit breakers clearing faults, or transients from circuit breakers changing the configuration of the electrical distribution system. Reconfiguration time is usually less than 2 seconds and depends on the technology employed for circuit breakers and other circuit protection components.

3.3.2. Generator start time (t2)

As defined in IEEE Std 45.1, generator start time (t2) is the maximum time to bring the slowest standby generator set online. Generator start time is usually between 10 seconds and 5 minutes depending on the technology used for the generator sets.

3.3.3. Service interruption

A service interruption occurs when the length of time that power quality is outside of prescribed standards (or power is lost altogether) is greater than the amount of time a load can tolerate the power quality being outside of prescribed standards.

3.3.4. Mean time between service interruption (MTBSI)

The average amount of time between service interruptions that a load experiences.

3.3.5. Uninterruptible load

If a load would experience a service interruption with power outside of power quality requirements of duration t1, it is classified as an uninterruptible load. Upon loss of the primary source of power to an uninterruptible load, the power system should seamlessly switch the load to an alternate source. The alternate source could be an independent generator set or energy storage.

3.3.6. Short-term interrupt load

If a load would not experience a service interruption with power outside of power quality requirements of duration t1, but would with duration t2, it is classified as a short-term interrupt load. The power system should be designed to have sufficient rolling reserve (power capacity from generator sets and energy storage that is online but not used) such that the loss of a single generator set will result in sufficient remaining power capacity for short-term interrupt and uninterruptible loads.

3.3.7. Long-term interrupt load

If a load would not experience a service interruption with power outside of power quality requirements of duration t2, it is classified as a long-term interrupt load. If needed, these loads can safely remain unpowered while a standby generator is brought online.

3.4. System Stability and Constant Power Loads

In modern power systems, many loads incorporate highly efficient power electronic converters at their interface to the power system. These power electronic converters create an internal fixed voltage that is not highly impacted to changes in the voltage at the power system interface. If the loads draw a relatively constant current from the internal fixed voltage, these loads appear to the power system to be constant power loads. With a constant power load, as the voltage decreases, the current increases. This is an indicator of a negative incremental resistance. This negative incremental resistance can interact with the controls of power system components, filters, and parasitic capacitances and inductances in an unstable manner. If constant power loads are present in the power system, the system designer should conduct a stability analysis to ensure the overall system does not suffer from an instability.

3.5. Electrical Power System control interface

While it would be desirable for the power system to directly communicate with loads to implement load shedding and to optimize the operation of the electric plant, most loads do not interact directly with the power system control system; IEEE Std 45.1 labels these loads as “uncontrolled loads”. With respect to any given load, the only mechanism that the electrical power system control system may have is to turn power off to the load. An uncontrolled load may be augmented with a power system interface device (PSID) to provide control system connectivity between the load and the power system. “Controlled loads” have a control interface to the power system control system; these loads may be commanded to enter a low power state, or if a large load, may request permission from the power system control system to enter a high power state.

3.6. Large loads

A large load is defined as any load requiring more than 20% of the online power capacity supplying that load. A propulsion motor is typically a large load. Power systems with large loads should be analyzed for stability and adherence to transient power quality requirements.

4. Survivability

4.1. Zonal design, zonal survivability and compartment survivability

Zonal survivability addresses the vulnerability of the power distribution system to damage caused by fire, collision, flooding, or weapons. The ship is subdivided into multiple zones; zonal survivability is achieved if any one or two adjacent zones are damaged, loads in the remaining zones do not experience a service interruption.

Zonal design takes advantage of zonal survivability by locating redundant mission critical equipment in separate zones separated by another zone. This ensures continuity of power to one of the two redundant mission critical loads should two adjacent zones be damaged. For a given mission, the mission critical equipment that are not redundant should be located in the same zone to maximize the probability of survivability.

Compartment survivability enables restoration of power to undamaged mission critical equipment within a damaged zone. This may be implemented with normal and alternate power feeds as well as the possible inclusion of casualty power.

4.2. Emergency Loads and Mission Critical Equipment

Emergency loads for commercial ships are defined in IEEE Std 45.1 and in regulations; these loads should be supplied power from an emergency power distribution system that includes an emergency generator and a tie to the normal power distribution system. Under normal conditions, these loads are powered by the normal power distribution system. The emergency generators automatically start and come online upon loss of power to the emergency distribution system.

Naval ships often employ dual-use generators and do not have a separate emergency power distribution system. Instead, load shedding is employed to ensure the emergency loads are powered. The definition of emergency loads for naval ships is similar to commercial ships, but with additional loads.

Naval systems also categorize loads as being mission critical equipment (MCE) or not. Emergency loads are a subset of MCE; as defined in MIL-STD-1399-300.1. MCE are designated to remain operational during emergency conditions. MCE are generally provided with normal and alternate sources of power; the source of power is determined by a bus transfer switch.

4.3. Mission Priority load shedding vs Quality of Service load shedding

Quality of service categorizes loads by the duration of a power outage that does not lead to a service disruption. Mission priority categorizes loads by their contribution to the ability of the ship to fulfill its mission. Traditionally, if a ship experiences a condition where there is insufficient generation online for the total amount of load power, sufficient loads are shed to bring the total amount of load power below the capacity of online generation. A typical mission priority load shedding scheme would categorize the loads into vital, semi-vital, and non-vital categories. The non-vital loads would be shed first; if this was insufficient, then the semi-vitals would also be shed.

Quality of service provides an alternate approach to load shedding for power interruptions of duration less than t2 that minimizes service interruptions. In quality of service load shedding, upon a power interruption of duration greater than t1, long-term interrupt loads are shed. If this is not sufficient, then non-vital (semi-vital) short-term interrupt loads are also shed. Some of the long-term interrupt loads could be vital or semi-vital; as long as power is restored in less than t2, they will not experience a service interruption. Since the standby generators should be online within time t2, only the short-term interrupt loads that were shed could experience a service interruption. If the power system is designed with sufficient reserve capacity including energy storage, then the need to shed short-term interrupt loads can be eliminated.

If at time t2 there is still insufficient power generation capacity, then mission priority load shedding should be employed. Non-vital loads of any quality of service category should be shed to enable restoring semi-vital and vital loads that had been shed under quality of service load shedding. See IEEE Std 45.3 for addition details.

It is also possible for mission priority load shedding to have more levels than vital, semi-vital and non-vital; more levels allows for finer control of the load shedding process.

5. References

IEEE Std 45.1, IEEE Recommended Practice for Electrical Installations on Shipboard – Design.

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

MIL-STD-1399-300-1 Low Voltage Electric Power, Alternating Current

MIL-STD-1399-300-2 Medium Voltage Electric Power, Alternating Current

DPC 310-1 Electric Power Load Analysis (EPLA) for Surface Ships