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Electrical Power System Considerations for Modular, Flexible, and Adaptable Ships

ABSTRACT

Eight technologies for implementing a modular, flexible, and adaptable ship: Modular Hulls, Mission Bays, Container Stacks, Off-Board Vehicles, Weapons Modules, Aperture Stations, Electronic Modular Enclosures, and Flexible Infrastructure are examined to determine their impact on design decisions for the electrical power system. Recommendations are provided for future work to prepare power system designers for future modular, flexible, and adaptable ship designs.

INTRODUCTION

During the summer of 2012, the Chief of Naval Operations wrote in a Naval Institute Proceedings article (Greenert 2012) that “We need to move from ‘luxury-car’ platforms – with their built-in capabilities – toward dependable ‘trucks’ that can handle a changing payload selection.” The modular, flexible, and adaptable ships promoted by the CNO require a new design approach to be successful. In a previous paper (Doerry 2012), the author highlighted eight technologies for implementing a modular, flexible, and adaptable ship: Modular Hulls, Mission Bays, Container Stacks, Off-Board Vehicles, Weapons Modules, Aperture Stations, Electronic Modular Enclosures, and Flexible Infrastructure. This paper examines the impact of these technologies on the design decisions for the electrical power system.

This paper assumes zonal electrical power systems (either as part of an Integrated Power System or stand-alone) are employed as described in (Doerry and Fireman 2006) (Doerry 2007) and (Doerry 2009)

MODULAR HULLS

A modular hull ship design provides options for inserting different parallel midbodies (PMBs). A parallel midbody can be of variable length without impacting the fairing of the bow section and the stern section. In some designs, the option to insert a particular PMB must be exercised only in new construction, while in other designs the insertion or replacement of a modular PMB may additionally be exercised during a major modernization.

The ship design must clearly identify where the parallel midbody can be inserted into the design. To eliminate shaft lines from crossing this boundary, consideration should be given to locating all main propulsion equipment aft of the PMB. This can be accomplished, for example, with electric drive. Mobility survivability can be enhanced by locating a forward, retractable propulsor in the bow section. Requirements documentation must be written to allow this type of arrangement.

To reduce integration costs, as few distributed systems should cross the PMB boundaries as possible. The PMB boundaries should align with an electrical zone boundary. The PMB would therefore consist of one or more complete electrical zones. For the electrical power system, only the longitudinal busses should cross the PMB boundaries.

The design of the longitudinal busses must account for the potential electrical load, energy storage, and electrical power generation associated with the PMB alternatives. The current rating of the longitudinal bus must consider load flow for different PMB options. If the PMB is anticipated to contain additional power generation, the short-circuit analysis must include this potential source of short-circuit current to ensure the proper interrupt rating of circuit breakers. Since the cost of the longitudinal busses is dominated by installation labor which is only moderately influenced by ampacity, consideration should be given to specifying that longitudinal busses be the highest ampacity cable/duct practical at the time of construction.

The anticipated electric load for the different PMB options should be estimated as described in DDS 310-1 Rev 1. In particular, electric load data for PMB options should be captured to enable estimating 24 hour average ship service loads, operating loads, zonal operating loads, and operating loads in each Quality of Service category.

The 24 hour average ship service loads are used to estimate the impact of different PMB options on the ship's endurance (DDS 200-1 Rev 1) and annual fuel usage (DDS 200-2). Operating loads for each of the Quality of Service categories are used to influence the selection of generator sets and energy storage modules as described by Doerry (2007).

MISSION BAYS , CONTAINER STACKS AND ELECTRONIC MODULAR ENCLOSURES

The Littoral Combat Ship (LCS) includes a mission bay to house elements of mission packages. LCS mission packages consist of mission modules, aircraft, and crew detachments. Mission modules are composed of mission systems and support equipment. The mission systems include weapons, sensors, and vehicles. Support equipment consists of support containers, communications systems, and a computing environment. The support containers house much of the mission module equipment and are based on standard ISO containers. These ISO containers are secured to the deck of the mission bay and are not intended to be used operationally in a container stack. (Figure 1) Interface standards have been developed to provide distributed system support to these containers. (PMS 501 2010)

Figure 1 Mission Bay on FSF-1 Sea Fighter

As an alternative to the Mission Bay concept, mission module equipment could be housed in containers that are part of a container stack. These container stacks could be part of a commercial ship converted to military use, or could be incorporated into the design of a combatant. In either case, provisions must be made for personnel access and distributed system routing to each of the containers. Of particular concern is avoiding interference from container lashing systems.

From a power system perspective, the electrical interface to the containers must be defined in an Interface Control Document (ICD). For the LCS, four different types of electrical power that can be provided to a container are defined:

440 VAC 60Hz 3 Phase up to 30 kW

115 VAC 60Hz 1 Phase up to 3 kW

115 VAC 400 Hz 3 Phase up to 15 kW

28 V DC, up to 0.84 kW continuous

Missing from the LCS ICD is an allocation of these requirements to the quality of service categories: Uninterruptible, short-term interruptible, and long-term interruptible. See DDS 310-1 Rev 1 for more information on the quality of service categories.

Consideration should be given to providing some or all the power to a container from an Integrated Power Node Center (IPNC) as defined in MIL-PRF-32272. The IPNC converts 440VAC 3 phase power to the type required by end users. It also provides isolation of the loads from the overall power system. Changes to the power interface for the container can generally be accommodated by switching out output Multi-Function Programmable Modules (MFPMs) in the IPNC; the impact of the change is limited in scope.

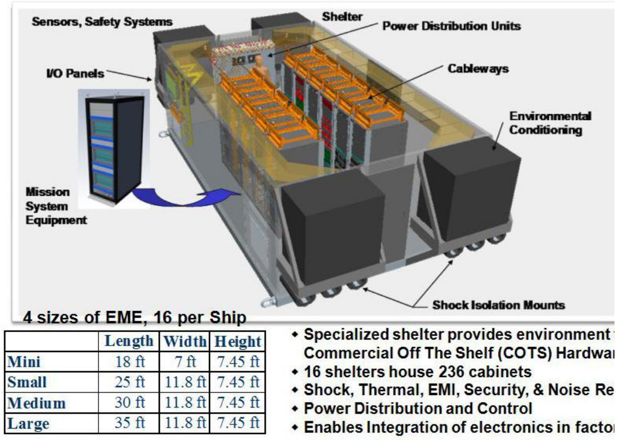
The IPNC can be outfitted with two input MFPMs to provide a seamless transfer between main and alternate sources and thereby provide uninteruptible power to its loads. The IPNC can also be programmed to implement a load shed strategy. In summary the IPNC isolates changes to the power system and power system control for new and different containers.

In addition to the maximum power rating for each power interface, the interface control document should specify sufficient information to enable estimating for the various envisioned containers, the anticipated range for the 24 hour average ship service loads, operating loads, zonal operating loads, and operating loads in each Quality of Service category.

Electronic Modular Enclosures (EMEs) were developed by the DDG 1000 program to isolate Commercial Off The Shelf (COTS) electronics from the extremes of a naval environment: shock, vibration, electromagnetic interference (EMI) and electromagnetic pulse (EMP). Additionally, EMEs provide physical security, noise isolation, cooling, and electrical power of the type and quality needed by the COTS equipment. As described by McWhite, Brennan and Fontes, (2010) and depicted in Figure 2, EMEs have been defined in four sizes: Mini, Small, Medium and Large. Onboard DDG 1000, the EMEs house the Mission System Equipment (MSE) equipment.

EMEs include both Power Distribution Units (PDUs) and a Power Conditioning Unit (PCU). The PCU, external to the EME, converts ship service power to the type of power needed by the COTS equipment. The PCU is backed up by an Uninterruptible Power Supply (UPS). The PDU, physically attached to the EME, distributes the power from the PCU to the COTS equipment within the EME.

From a power system perspective, EMEs can be treated much like containers. Consideration should be given to employing an IPNC to serve as the PCU.



	Length	Width	Height
Mini	18 ft	7 ft	7.45 ft
Small	25 ft	11.8 ft	7.45 ft
Medium	30 ft	11.8 ft	7.45 ft
Large	35 ft	11.8 ft	7.45 ft

- Specialized shelter provides environment Commercial Off The Shelf (COTS) Hardwa
- 16 shelters house 236 cabinets
- Shock, Thermal, EMI, Security, & Noise Re
- Power Distribution and Control
- Enables Integration of electronics in facto

Figure 2: DDG 1000 Electronic Modular Enclosures

OFF-BOARD VEHICLES

The LCS ICD defines power system interfaces for embarked boats (Figure 3) and aircraft, whether manned or unmanned. The types of power provided are the same as for the containers, but the amount of power that must be provided differs. In defining the interface, an important requirement is whether the shipboard power system is expected to start engines or not; starting an engine typically requires a short duration large peak load.

Figure 3: Ship's boat onboard USS Freedom (LCS 1)

The types of boats and aircraft a ship is expected to embark will likely experience significant change over its service life. Consideration should be given to supply some, if not all of the power for embarked vehicles from an IPNC. As with containers, many changes in interface requirements can be accommodated with changing out MFPMs in the IPNC, changing cabling, and changing connectors. Changes to the power system above the IPNC can be avoided unless the total power growth is significant. Consideration should be given to sizing the feeder cable to the IPNC for the largest input MFPM possible, even if a smaller input MFPM is initially used. Growth in load can be accommodated by changes at or below the IPNC level in the power system architecture.

Understanding the power needs under different operational conditions is important for developing estimates for electric power load analysis. Anticipated growth in loads for embarked vehicles should be captured in the ICD for the vehicle module station.

WEAPONS MODULES AND APERTURE STATIONS

The electrical interfaces for weapons modules and aperture stations are conceptually the same as for containers. LCS for example, has defined the types of power and the associated maximum power for its Weapon Mission Module Station (Figure 4). However, the LCS interface is predicated on existing weapons and does not anticipate future directed energy and electromagnetic weapons. Hence the challenge for weapons modules is defining affordable power interfaces that accommodate both existing propellant based weapons and future weapons that require an order of magnitude or more increase in electrical power.

Ideally, several different power system interfaces should be developed for different classes of electric weapons. These interfaces will define the required power type, amount of power required, ramp rates, power quality, and quality of service requirements. Any required monitoring and control signals required for power management should also be defined. These interfaces do not currently exist.

With the above defined interfaces and an understanding of the operating conditions under which the weapons will be employed, the demands on the power system can be determined. Sufficient power generation must be present, either from generator sets or energy storage to fire the weapons when needed. Likewise, the power distribution system must be sized to handle the power flow to the weapons systems.

Figure 4: Littoral Combat Ship (LCS) Weapon Station Module

Since electric weapons typically require pulses of power, one or more levels of energy storage are needed to generate the pulse. Typically, a capacitor bank or flywheel is used to form the pulse directly used by the weapon system and is usually considered part of the weapon system. An intermediate storage system, typically employing batteries, is used to decouple the weapon system dynamics from the power system. Whether this intermediate storage system is part of the power system or part of the weapon system has not yet been settled. If part of the power system, then it could be employed for other power system management functions such as ensuring quality of service, enabling single engine cruise operation, and starting a generator set in a dark ship condition. On the other hand, the power interface to the weapon system becomes much more complex.

The addition of ballistic missile defense (BMD) to the missions of a surface combatant is also driving significant increases in the power requirements for radars. Many of the same issues associated with defining the interface with weapons systems also apply to the interfaces with the radar apertures. Defining these interfaces intelligently in an ICD in terms of power type, power capacity, power quality, quality of service, and control interfaces are key to ensuring the shipboard power system will be able to support upgraded radars and sensor systems over the ship's service life.

FLEXIBLE INFRASTRUCTURE

As shown in Figure 5, Flexible Infrastructure (FI) enables spaces within a ship to be reconfigured rapidly, inexpensively, and without welding. Elements of FI are on existing ships and are being considered by several ship acquisition programs. FI technology consists of (DeVries et al 2010):

- Open structure
- Open power
- Open HVAC
- Open data cabling
- Open lighting
- Open outfitting.

The FI Open power is based on a legacy connectorized power panel or an IPNC depending on the type of power and the quality of service required by the anticipated electrical loads within the space.

Open power and open lighting also enable the reconfiguration of power receptacles, lights, and light switches without the need for welding.

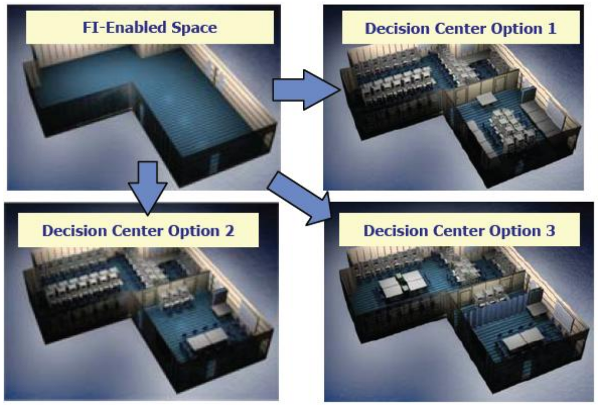


Figure 5: Space Reconfiguration using Flexible Infrastructure

As with the other modular, adaptable technologies, one of the key challenges for the power system is establishing the required power ratings of feeder cables as well as the anticipated operating loads for different operating conditions over the ship's service life. This information should be captured in an ICD. Without a good understanding of the potential growth in electrical load over the ship's service life, significant risk exists that the ship's power generation capacity will not be properly sized.

OTHER POWER SYSTEM CONSIDERATIONS

Traditionally, provisions for growth in loads after ship delivery and during the ship's service life is accounted for in Service Life Allowances (SLA). SLAs are applied to all distributed systems to help ensure sufficient capacity exists over the ship's service life. The SLA values are typically based on experience; they likely are not directly applicable to modular, flexible and adaptable ships.

If the majority of change is expected in those areas addressed with modular, flexible, and adaptable technologies, then the intent of the SLA should be captured in the ICDs for the modular, flexible, and adaptable technologies. The ICD becomes a constraint for future growth, but also has an upfront cost. Achieving the right balance is key to an affordable ship throughout the ship's service life.

Likewise, the requirements for future growth such as spare breakers should be defined in the ICD and minimized elsewhere in the ship's design.

For proper power system design, it is very important that the ICDs go beyond defining a nominal voltage type and current/power rating. Power Quality, Quality of Service, and Load Shedding information must also be included.

FUTURE WORK

In addition to the work identified by Doerry (2012) enabling work for implementing power systems to support modular, flexible, and adaptable ships include:

- Modify MIL-PRF-32272 to include 28 Volt output MFPMs in the INPC. Also modify to include 115 VAC 400 Hz 3 Phase output MFPMs of higher power ratings.

- Revise MIL-STD-1399 sections 300 and 680 to add a power management / power control interface that addresses real-time allowable power levels and ramp rates.

- Create a Design Data Sheet, Design Criteria and Practices Manual or other document detailing the electrical (and other) parameters that must be defined for a modular interface.

- Create standards and specifications for the implementation of Open Power and Open Lighting for FI spaces.

- Create a document describing required survivability features to enable short shaft lines that do not penetrate the parallel mid-body.

- Create an ICD for Weapons Modules and Aperture Stations that anticipate electric weapons and high power sensors.

- Create a specification for a forward, retractable propulsor.

CONCLUSION

Future modular, flexible, adaptable ships require new approaches to defining power system requirements. This paper has described the impact of eight modular, flexible, adaptable ship technologies on shipboard power system design and has identified future work to facilitate integration of these technologies onboard ship.

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