MORE POWER FOR THE DOLLAR

Price vs Value

A Technical Guide

NAVSO P- 3641A
(Replaces NAVMAT P-4855-1A)
October 1999

Office of the Assistant Secretary
of the Navy (RD&A)
Acquisition and Business Management

PREFACE

The focus of the ASN(RD&A) strategic plan is to reduce total ownership costs of our systems, supplies and services. We can achieve this goal by applying modern business practices and relying on commercial vendors to take advantage of new or emerging technologies and advancements to improve system performance while reducing cost. We believe that sharing information with industry and communicating with our stakeholders will enable us to achieve this goal.

This guide represents an initiative to improve power system management within the Department of the Navy. Developed by senior Navy professionals and the power system industry, this guide provides a useful and substantive reference for a hierarchy of information pertaining to all aspects of power supply management—Program Management, Systems Engineering, Low Voltage DC and High Voltage DC Power Supplies, and AC Power Supplies. I encourage everyone to become familiar with this guide and to apply the concepts and techniques presented to meet our power supply objectives.

G. H. Jenkins, Jr.
Rear Admiral, SC US Navy
Deputy for Acquisition &
Business Management

- **Developing Power Systems Utilizing High Density DC/DC Modules -** Reliable power supply designs with high output power density are generally achievable using standard switching power supply components and topologies widely available in industry today. To minimize cost and the time to develop a power system, existing high density DC/DC modules are often incorporated into the design. High density modules are available that provide electromagnetic compatibility, thermal management, prime power rectification, input voltage multiplication, power factor correction and non-isolated and isolated user output voltage conversion.

  The design approach to incorporate these modules, however, is not as simple as may be indicated by many of the manufacturers' literature. The advertised power densities of DC/DC converter modules should not be considered as the total allotted power system packaging volume. It is not uncommon to see advertised power densities in excess of 70 watts/cubic inch. However, a review of the manufacturer's data would reveal that the advertised power density is only accomplished at moderately low temperatures and at a specific input and output voltage. Moreover, these power density figures are often a calculation of only a DC/DC converter module without other components that must be added in order to meet the complete power system specification. These added components may include:

  1. EMI filtering,
  2. input AC/DC rectification with filtering/bulk input hold-up capacitance,
  3. supplemental output filtering,
  4. auxiliary function circuitry (sequencing, synchronization, BIT, on/off control etc.)
  5. cooling, and
  6. physical packaging.

  Selection of DC/DC converter modules should take into consideration the manufacturer's reputation in supplying reliable products for applications consistent with weapon system requirements. Once viable vendors have been identified, a detailed examination should be conducted for each electrical and physical parameter applicable to the power system requirements. A power system consists not only of DC/DC high density converters, but often includes EMC management, thermal management, prime power conditioning/ protection, monitoring and control as well as common mode and differential filtering. When all of the above is taken into consideration, it is not uncommon to achieve an overall power system power density of between 10 and 15 watts per cubic inch, well below the advertised 70 watts/cubic inch. Detail considerations are discussed in Section 3 of this document.

- **Developing Power Systems Utilizing AC Power Supplies (DC-AC Inverters, Frequency Changers, Voltage Conditioners, and AC UPS Systems)**
  The military platform power DC or 400 Hz AC, is often not compatible with COTS equipment. However, regulated AC power supplies can electronically convert the platform DC power bus into a standard AC bus that provides commercial voltages,

enabling greater use of COTS/NDI equipment (computers, monitors, etc.) in the weapon system. The resulting power architecture with its universal power grid allows flexibility in supporting weapon system re-configuration without costly power supply and equipment redesign.

AC power conversion architecture should always be considered in trade studies. With power supplies often constituting less then 10% of the total system cost, it often proves cost effective to convert the platform power to a commercial-standard AC bus. The standard power allows the use of COTS end-user equipment, thus affording the opportunity to utilize standard computers, monitors, printers, and related equipment. As a result, NDI utilization is expanded to the major portion of the system.

The corollary benefit of commercial-standard AC bus utilization is system flexibility. Availability of COTS end-user equipment allows simple system re-configuration or redesign. Unlike customized end-user equipment, change of vendors or sequential system alterations will not require extensive engineering and qualification effort.

Bulk power conversion (not limited to AC only) creates a potential single-point of failure. A failure of the bulk power supply may result in total system shutdown if power is not effectively distributed. When addressing mission-critical applications, provisions for safety bypass or redundancy should also be evaluated.

1.2.3 Modeling and Simulation

System level modeling and simulation supports the allocation of requirements component by component. The performance of each component is simulated to investigate proper operation of the power system, e.g., meeting the requirements, determining compatibility among all components, and determining compatibility between each component and the power system. A thorough consideration of the interface design margins can minimize tolerance problems that may arise later in the power supply design phase or the system test and integration phase. Simulations can provide support for design review and analysis, interface characteristics, systems integration, power supply requirements, and the facilitation of system trade offs.

1.2.4 Design Reviews

An important part of the systems engineering process is the periodic review of power system development. These reviews are necessary to verify power supply compliance with the power system interface requirements (see Appendix B, Design Review Checklist for Power Systems and Power Supplies).

Table 1.5-1. Power Supply TOC Comparisons

Power Supply (PS) Performance & Purchase Data	***PS-1*** ***COTS /NDI***	***PS-2*** ***Modified COTS/NDI***	***PS-3*** ***Custom***
A. Initial Quantity Purchased	50 Units	50 Units	50 Units
B. # of Spare PSs Purchased	50 Units	50 Units	50 Units
C. Total Purchase Quantity (A+B)	100 Units	100 Units	100 Units
D. Power Supply Unit Price	$1,000	$1,500	$2,500
E. Extended Price (@ 100 units) (C*D)	$100,000	$150,000	$250,000
F. Systems Engineering & Qualification (Prime Contractor)	960 Hours	1580 Hours	2080 Hours
G. Engineering Overhead Cost (Prime Contractor)	$150/Hour	$150/Hour	$150/Hour
H. Total Systems Engineering & Qualification (Prime Contractor) (F*G)	$144,000	$237,000	$312,000
I. Other Nonrecurring Engineering Development Cost	$0	$40,000	$75,000
J. Total Acquisition Cost (I+H+E)	$244,000	$427,000	$637,000
K. System Life Expectancy	50,000 Hours	50,000 Hours	50,000 Hours
L. Power Supply MTBF	50,000 Hours	100,000 Hours	300,000 Hours
M. Average Wearout Time	50,000 Hours	70,000 Hours	70,000 Hours
N. # of Failures/System Life Expectancy (K/L)	1 Unit	0.5 Units	0.166 Units
O. Replacement Downtime (due to Wearout Planned Maintenance)	1 Hour	1 Hour	1Hour
P. # of PS Replaced If (N<1, then 0.0, else (N*A))	50 Units	0 Units	0 Units
Q. Downtime to Detect/Fix Failure	10 Hours	10 Hours	10 Hours
R. Total System Downtime Q*(A*N) + (P*O)	550 Hours	250 Hours	83 Hours
S. Cost of System Downtime/Hr.	$1000/Hour	$1000/Hour	$1000/Hour
T. Total Cost of System Downtime (R*S)	$550,000	$250,000	$83,000
U. Total Ownership Cost (T+J)	$794,000	$677,000	$720,000

<u>Low Voltage Power Supplies – Watch Out For…</u>

- Inflated power density claims of greater than 60 watts/cubic inch
- Junction temperatures above 110°C
- New and unverified circuits required to provide power supply functions
- Power supplies with claimed reliability based only on MIL-HDBK- 217 predictions
- Use of unvalidated software analysis programs
- COTS/NDI power supplies lacking qualification data
- Spares and repairs that have not been subjected to the same manufacturing, inspection, and test processes as the original equipment
- Not testing to failure

<u>High Voltage Power Supplies – Watch Out For…</u>

- Vendors who lack experience designing, producing, testing and screening high voltage rectifiers, capacitors and resistors
- Hand-mixing of insulation compounds
- A high voltage power section in close proximity to a low voltage area
- Thermal measurements requiring thermocouples in the high voltage field
- Components with incompatible temperature coefficients
- Validity of corona inception voltage measurement equipment
- <u>An increase in the corona level after temperature cycling</u>

<u>AC Output Power Supplies – Watch Out For…</u>

- Load incompatibility with an AC squarewave source
- High DC content on AC output which may lead to power transformer overload
- Crest Factor capability below 2.5
- Reactive Load capability and Inrush rating if powering motors or filters
- Resonance with external filters
- A UPS holdup time not specified over the full environmental range
- Excessive recharge time requirements
- Transfer time in excess of 10 milliseconds on stand-by UPS

Table 2.2-1 shows some of the common specifications and their typical applications. These are general specifications and the Procuring Agency should tailor these to match unique platform requirements.

Table 2.2-1. Common Military Power Specifications

Power Specification	Power Type	Typical Application
MIL-STD-704	28VDC, 270 VDC 115 VAC 400 Hz, 230 VAC 400Hz	Aircraft, Spacecraft
MIL-STD-1399 Section 300	440, 115 or 115/200Vrms 60 Hz 440 or 115 Vrms 400Hz 440 or 115V or 115/200Vrms 400Hz	Shipboard, Type 1 Shipboard, Type 2 Shipboard limited use-Type 3
MIL-STD-1399 Section 390	155 VDC	Submarine
MIL-STD-1275	28 VDC	Vehicle

2.3 ELECTROMAGNETIC COMPATIBILITY

Electromagnetic compatibility must be accomplished throughout the weapon system by controlling EMI at each power conversion node. EMI requirements and performance are critical to proper system operation, and are specified in MIL-STD-461. A common mistake is to impose full compliance with these requirements at the power supply level, whereas the power supply is only one of the system components contributing to EMI.

Overall weapon system performance may be affected by the introduction of EMI filters external to the individual power supplies. Voltage excursions as seen by the actual power conditioning circuitry can be vastly different with the introduction of filters, particularly under dynamic load conditions. Power system specifications must clearly define the input power characteristics at the power supply such that the interface can be established, including the effect of isolation transformers, additional power supplies or a common EMI filter.

COTS/NDI equipment is often tested for FCC compliance. The user should not assume that the FCC compliance implies MIL-STD-461 compliance. Currently, FCC requirements are not consistent with MIL-STD-461. For instance, in contrast to the MIL-STD-461 CE101 spectrum that starts at 10 kHz, the conducted spectrum in the FCC specification starts at 450 kHz. The switching frequency of most power supplies is below the range controlled by the FCC. Similarly, the FCC radiated limits begin at 30 MHz while the military limits start at 10 kHz.

The complex interactions between EMI filters and power supplies are often discovered during system integration, when the resolution can be difficult to achieve, time consuming and costly. Wherever possible, simulation techniques should be employed to avert this situation. The simulation must include the source, distribution, and power supply load characteristics, as well as elements of resistance and parasitic reactance.