

Document for Electric Power Management

FOREWORD

1. This recommended practices document responds to a need in the aerospace industry for application information, design guidelines and test requirements for managing electric power in twenty-first century aerospace vehicle systems. Emphasis will be on providing criteria for selecting power management architectures and components consistent with vehicle requirements such as safety, survivability, maintainability, reliability, and serviceability.
2. Availability of smart power controllers, both solid state and hybrid, and integration of software/firmware into the control and monitoring of electric power generation, conversion and distribution, provides a multitude of options to the designer to employ in his/her system. Criteria must be established to determine which options are needed and to what extent they should be incorporated into the system.

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1. SCOPE:

This SAE Aerospace Recommended Practices (ARP) covers the definitions, functions and broad application guidelines of modern aerospace vehicle electric power management systems. As aerospace control systems have become more sophisticated and autonomous, the electric power subsystem no longer is just a generation and distribution bus control system. New electric power systems include integration of individual load logic control, protection, generation, distribution, and load management. This system can report to a higher level control system, typically a vehicle management system, or can be an autonomous system within itself reporting and responding to operator commands.

2. REFERENCES:

The following documents are either referenced in this ARP or provide additional information to the reader in understanding and utilizing this ARP.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP1199	Selection, Application, and Inspection of Electric Overcurrent Protective Devices
AS1212	Electric Power, Aircraft, Characteristics and Utilization of
AS1831	Electrical Power, High Voltage Direct Current, Aircraft, Characteristics and Utilization of
AS15531	Standard Digital Time Division Command/Response Multiplex Data Bus

2.2 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-1553	Digital Time Division Command/Response Multiplex Data Bus
MIL-STD-1773	Fiber Optics Mechanization of an Aircraft Internal Time Division Command/Response Multiplex Data Bus
MIL-HDBK-217	Reliability Prediction for Electronic Equipment

2.3 Other Publications:

RTCA DO-160D	Environmental Conditions and Test Procedures for Airborne Equipment
ISO 1540	Characteristics of Aircraft Electrical Systems
ARINC 429	Mark 33 Digital Information Transfer System (DITS)
ARINC 629	Multi-Transmitter Data Bus

3. SYSTEM ARCHITECTURE CONSIDERATIONS:

3.1 Types of Power:

Types of power can be divided into AC and DC power. AC systems can be divided into fixed frequency and variable frequency power. The conventional AC system is 115/200 volts, 400 Hz fixed frequency. Variable frequencies range from 360 Hz to 800 Hz. Higher frequencies (4,000 through 20,000 Hz) may be used in future systems. DC systems can be divided into low and high voltage. The conventional low voltage DC system is 28 volts. The conventional high voltage DC system is 270 volts, but other voltage systems from 120 volts and higher are used and have been proposed. Specifications covering power characteristics, quality and utilization include ISO 1540, DO-160, MIL-STD-704, AS1212 and AS1831.

- 3.1.1 AC Considerations: In some three-phase AC applications, the load is not connected to neutral (three wire "Y"). This poses some problems, especially for solid state switching devices employing sequential zero voltage turn on. The solid state switch used for this application should be capable of withstanding the line-to-line voltage. Since the neutral point of the load is not grounded it will float with the resultant of the three phase vectors. When the first phase is turned on, the potential of the neutral point is identical to the voltage of the first phase. During this period and prior to application of power from the other two phases, the switch(es) that are off are placed between two phases and must withstand the required phase-to-phase voltage.

Another consideration is EMI filtering. Noise filtering on AC power lines is not very easy. The leakage current and the resultant power dissipation normally impose a limit on the size of the capacitor that can be used. Use of inductors or ferrite beads are also impractical due to the sizable current involved (saturation). With the above considerations, the noise should be partially suppressed at the assembly level. Further noise immunity should be designed into the solid state switching devices. Proper isolation between the power section of the switch and the control section should provide adequate immunity to the residual noise (conducted and radiated).

- 3.1.2 Low and High Voltage DC Considerations: With high voltage DC special attention should be given to fault propagation. Arc and corona suppression is of concern with higher voltage DC, especially at altitudes above 20,000 feet. Another consideration is the magnitude of the fault current with high voltage DC. Physical separation of high voltage and controls must be maintained. An advantage of DC systems is that simple make-before-break power transfers can be implemented to provide interrupt-free power transfers.
- 3.1.3 Capacity Requirements: With the ever-increasing demand for electrical power, the generation system capacity and future growth should be carefully evaluated. Proper management of the demand can be facilitated by the use of power management systems. Selective individual load shedding (in lieu of bus shedding) can be used to reduce the peak demands (peak shaving) and use the power where it is needed most. With the help of a modular (distributed) design, the addition of new loads is simplified. To avoid rewiring of the system, spare channels should be considered in the system design of the power distribution modules for future growth.

3.1.4 Types of Loads: There are two basic types of loads, passive and active.

3.1.4.1 Passive Loads: The basic types of passive loads are resistive, capacitive, and inductive. Each of these types of loads has its own unique set of requirements that need to be considered for proper power management.

3.1.4.1.1 Resistive Load: Loads with impedance which is purely resistive, and/or the reactive component of the impedance is negligible with respect to the resistive component, are called "Resistive" loads. In general, these type of loads do not need any special precautions for load management. A special case of resistive load is a lamp load. In its cold state, the lamp filament has a very low resistance that could result in an inrush current of up to 12 times hot filament current. Even though the duration of this current spike is rather short, its magnitude can trigger the protection circuit internal to solid state switching devices.

3.1.4.1.2 Capacitive Load: Capacitive loads are loads that the reactive component of their impedance is capacitive. Similar to the lamp load, the inrush current of the capacitive load should be considered when solid state switching devices are employed. Particularly in DC systems, the capacitive energy storage of the load may be quite large compared to its steady state power requirement. Current limiting could be considered for this type of load.

3.1.4.1.3 Inductive Load: Inductive loads are loads that the reactive component of their impedance is inductive. Fast switching of the solid state switching devices will generate a sizable voltage spike in this type of load. This is detrimental to solid state switches and precautionary protective measures are required to prevent damage to the switch. For large loads, even a small inductance in the system can be damaging. It is highly recommended that the inductance be specified for switching devices with high amperage ratings.

3.1.4.2 Active Loads: Most active loads are constant power loads. Constant power loads are loads that exhibit a negative input impedance characteristic. With a constant power load current increases as the voltage decreases. This type of load may cause problems in power systems, especially DC systems. The increasing input current with decreasing input voltage can make fault coordination and protection difficult to analyze. One approach to be considered is grouping constant power loads by their input filter characteristics. The lowest operational voltage should be considered in the design. Most power supplies for modern electronics fit into the active load category.

When constant power loads form a substantial fraction of the bus loading, it may lead to adverse power stability effects such as poor transient damping, ringing, and nuisance tripping of generators. The adverse effects occur when the negative impedance loads add up to be comparable to the positive source impedance of the power source, leaving a system with large reactive energy transfers and small resistive losses.

3.1.5 Load Shedding: Load shedding is a scheme to remove (turn off) non-essential loads to conserve energy. In conventional designs, the loads are categorized by their importance (i.e., non-critical, critical, essential,...) and accordingly, assigned to the designated bus. When sufficient power is not available, the selected bus is removed (shed) and all the loads connected to this bus are removed from the system. This scheme removes a group of loads regardless of the available power. With a power management system, the available power can be evaluated, either automatically or by the flight crew, and sufficient loads can be turned off in ascending priority to remain within the generation system capacity. The latter scheme provides more freedom for categorizing the loads based on the mission profile and available resources.

3.1.5.1 Load Restoration: The converse of load shedding is also true. As the power availability is increased due to either mission profile changes or reapplication of previously unavailable power sources, a power management system can evaluate the available power and reapply power to previously unpowered loads. This reapplication of power should be accomplished in ascending order of priority to remain within the generation system capacity.

3.1.6 Distribution Architecture: The traditional architecture of vehicle power distribution systems was hierarchical with a primary distribution system feeding a number of AC and/or DC bus bars, each of which had an integrity level or rank dependent upon the loads supported, e.g. primary bus bar, essential bus bar, emergency bus bar, etc. These distribution buses were normally installed in a central location.

With the advent of more intelligent solid state switching devices, it is possible to adopt a more flexible approach, optimized to reduce feeders and increase integrity and also allow spare capacity for modifications at a later stage. The secondary distribution may be carried out in line replaceable assemblies at strategic positions around the vehicle. Some secondary load distribution may be carried out from the primary distribution assemblies. In order to minimize distribution wire weight, the distribution centers can be located near the loads.

3.2 Redundancy:

Redundancy should be considered at multiple levels in the power control and distribution system. Critical loads may be themselves duplicated and should be provided power from independent sources through separate distribution channels and hardware. Other essential loads may not be duplicated but may be provided power, possibly from the same or separate sources, through parallel distribution and control paths. Redundancy at the power source distribution level can be provided by bus transfer and bus tie switching capability. Redundancy should be considered at the system level to minimize the weight and fulfill load redundancy requirements.

3.2.1 Survivability: Survivability is the capability to survive ballistic, nuclear, and biological/chemical threats. Survivability encompasses redundancy of the power distribution but also includes factors such as physical separation of distribution and control hardware and wiring runs, minimizing the size of the hardware to reduce its potential of being struck, providing ground fault clearing protection for power feeders, providing multiple feeder lines, minimizing fault propagation, and use of nuclear hardened components.

3.2.2 Reconfiguration: The power management control system may require the ability to reconfigure the distribution and/or control system to meet the needs of the vehicle to perform alternate missions or recover safely from loss of power sources. This feature is a key consideration when the system architecture and functionality is conceptually developed.

3.3 Reliability:

One consideration for providing high reliability to the power distribution system is the use of SSPCs. Reference Mil-HDBK-217.

3.4 Control and Decision Making:

For critical or sensitive loads consideration should be given to monitoring the quality of the power being delivered.

3.4.1 Autonomous Control: A system that is capable of sustaining its own operation, during normal or abnormal conditions without intervention by other systems and/or crew is called an "Autonomous System." This system capability will allow decision making (logic calculations) to be made at each of the distributed load management units. This will allow faster decisions to be made if this is a critical system or load consideration. In this case, communications via the multiplex bus is not necessary to process inputs, calculate the logic, and provide the output solutions. The configuration must be such that all the inputs required to determine the solutions are provided to the individual load management unit. This may require additional complexity in the vehicle wiring interface if the same inputs are required at multiple load management units. Another aspect of autonomous control is default conditions. Local decisions can be made regarding placing an output into its default mode should the communications link (multiplex bus) be broken. Options such as last commanded state, or safe default state, and availability of limited discrete inputs available to the individual load management unit, can all be considered in making a local decision. The individual load management unit internal system architecture must be designed to accommodate this capability.

3.4.2 Central Control: In this scheme the logic calculations and the decisions are made at one point, such as a vehicle management system which knows the aircraft configuration and power availability. All information is collected by the center and acted upon. Redundancy should be considered.

3.4.3 Local (Distributed) Control: In this scheme the system is partitioned into different subsystems. Each subsystem collects the necessary information and reacts to it based on the prescribed algorithm. Similarly, the host system collects the information from the subsystems and prescribes the actions for the subsystems. The complexity of the system normally increases with this option. Functionality and system availability are enhanced and a single or multiple failure will not necessarily disable the entire system.