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Space Station Power System Requirements

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SPACE STATION POWER SYSTEM REQUIREMENTS

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ABSTRACT

This paper will present an overview of the requirements upon which the Space Station Electric Power System design is based as well as a summary of the design itself. The current design, which is based on silicon photovoltaic arrays, NiH2 batteries, and 20 kHz distribution technology, meets all of the requirements.

INTRODUCTION

The Space Station Manned Core is a much larger orbiting vehicle than NASA has ever flown before. The current configuration is shown in Fig. 1. Man has long dreamed of building such a facility enabling scientists, astronomers, and other specialists to explore the nature of the universe from space and to exploit the unique features of near-zero gravity and near-perfect vacuum. The Space Station is to be a flexible, long-lived orbiting facility which will enable those capabilities. The Space Station Program has entered Phase C/D and is about to embark on preliminary design. Design criteria different from those of previous programs must be met. These considerations are reflected in the power system design in several ways. This paper will briefly discuss the requirements, the need for high power levels, and the present design. One primary goal of the power system is to develop and implement a utility type system which can be operated in a highly automatic and autonomous fashion for extended periods of time.

Although a polar platform is part of the program, most of the comments in the paper will address the manned core.

The Space Station Electric Power System (EPS) is the responsibility of Work Package-04 (WP-04) of the Space Station program. The NASA Lewis Research Center has contracted with Rocketdyne to develop and build the EPS hardware and software and to integrate the solar power module which houses the generation and storage functions. Rocketdyne will also provide EPS components to the polar platform which is a Goddard Space Flight Center responsibility.

REQUIREMENTS

The prime sizing requirement for the electric power system is the expressed need for 75 kW of electricity available to be consumed on the station. This power must be available continuously during normal operation. In addition, the EPS must be able to deliver up to 100 kW of peak power for a duration of 15 min each orbit. The station must maintain an energy balance for each orbit. The present design will make available 112.5 kWh of energy during each orbit. In addition, the Station should be able to provide power during a contingency such as loss of station orientation. The design solution for a contingency is to take full advantage of the energy stored in the batteries by allowing greater depth of discharge than normal.

Major "Design-To" Considerations

Every piece of the Space Station will be launched into orbit using the STS and after each assembly flight the station will be a functioning spacecraft. This requirement has placed severe limits on the first several assembly flights since every system must be present in at least a minimum configuration and every system requires power in order to function. In the present assembly sequence, one solar power module increment (one pair of arrays and associated equipment) is launched on the first flight. Only 40 percent of the possible battery complement is present on the first flight due to weight limitations. It may be necessary to make changes in the details of the EPS architecture for the first flight in order to permit enough equipment from other distributed systems to be launched to meet the functioning spacecraft requirement.

The station is in a low altitude (200 nmi) and low inclination (28.5°) orbit which means that a significant amount of the energy consumed during each orbit must be generated and stored during the 60 min of sunlight for use during the 30 min of eclipse. There will be more than 5000 eclipse cycles each year. The utility-like concept implies that light/dark power scheduling need not be done. This requirement has been satisfied by providing NiH2 battery storage for the 37.5 kWh of energy required during the eclipse. The batteries will typically operate at 80 percent depth of discharge. A technology development program has increased the cycle life so that the low Earth orbit application is viable.

The power generation subsystem is a significant contributor to the total aerodynamic drag forces on the station. Therefore, the EPS should be as efficient as is economically possible to minimize the area of the generation subsystem while still making 75 kW available to the station. Each subsystem and component of the EPS has been evaluated during trade studies for on station level impacts such as aerodynamic drag and the resultant need for propellant. This led to the early decision for a hybrid PV and Solar Dynamic generation subsystem.

The power generation equipment must be articulated and be sun pointing while the core station is earth oriented. This minimizes the size and cost of the generation and storage subsystems and provides a stable viewing platform for earth and stellar observation. Each array is capable of being oriented toward the sun.

The EPS must meet the redundancy requirements for manned critical systems. The EPS should be tolerant of two failures and still be able to provide power for critical functions associated with crew safety. Due to built-in redundancy, a total electrical failure the alpha joints is not considered credible. Due to the symmetry of the station EPS most power outlets should be able to survive three EPS failures and still be able to provide power. In addition to the redundancy requirements, the EPS should fail to a safe and restorable condition.

The station has a design life of 30 years. Therefore, the EPS must be designed to function for a period of 30 years. This is be accomplished by replacement and/or repair of on-orbit components. Maintenance may be performed either by an astronaut or a robot which has added an additional design complexity in the packaging of components for robotic replacement. The frequency and complexity of repair or replacement operations have become design drivers and significantly influence the cost of the EPS over the life of the station.

The design should minimize initial cost within the constraint of efficient design of long-lived components which will minimize maintenance and logistics costs.

The system should be capable of accommodating growth to 300 kW and should be designed so that new technology can be infused into the system without major disruption of service.

The EPS should operate automatically and autonomously with minimum crew or ground support. However, the crew or the ground should be able to interupt and gain control of the EPS. Additionally, the crew interface is through the same computer screen and keyboard as is used for all other station applications. Dedicated displays have been discouraged. The software which controls the EPS will be written with several levels of autonomy to accommodate processor failures. Hooks and scars will be built into the controls to allow future incorporation of Expert System and Artificial Intellegence technology. The first application will most likely be used for predictive diagnostics to enhance the reliability of the EPS.

The EPS should be adaptable to varying kinds and types of loads as the experiment manifest and the housekeeping technology changes with time. The EPS should accomplish this in a "user friendly" fashion while maintaining a simple consistent power interface. The initial design of the EPS incorporates a common ac, 20 kHz, 208 V interface with the same capacity available at each outlet. Programmable solid state switches can accommodate changing levels of "overload" conditions to protect the EPS, the station, and secondarily the experiment or housekeeping load.

Many of the power distribution components will be installed into elements of the Space Station which are the responsibility of other work packages. This has caused a modification in the "normal" approach to verification and delivery of flight hardware. Components are tested and accepted by WP-04 and then shipped to the other WP's for installation. WP-04 has a responsibility to support the other WP's during their installation and checkout activities. Completed station elements with all the installed distributed systems will be shipped to the launch site for launch.

Because the various systems of the Space Station are being developed by different work packages, the process to insure compatability and mutual functioning is different and has a greater visibility. There is presently under consideration a single facility to allow combined testing of the software from the distributed systems. Each of the distributed systems and elements will use simulators during the development process to assure compatible functioning in the Station level environment.

<u>Housekeeping and User Power Needs</u>

Currently, the allocated split of power between the housekeeping functions and the users of the station is being debated. It is clear that the 75 kW which was initially thought to provide a "power rich" station is now a precious commodity. The program is in the process of implementing changes which should reduce the anticipated need for power to match the current capability. These changes will impact system and component design efficiencies as well as operational strategies. The following operational guidelines (which have generally not been followed) were stated during the Space Station "Skunkworks" in 1984: (1) turn off redundancy; (2) use lighting appropriate to the task; (3) do not use electricity to make heat if an adjacent heat source is available; and (4) do not double convert power.

The power consumption by the housekeeping functions is significant. Current estimates based on the Phase C/D contractor proposals is approximately 55 kW. This is nearly five times the orbit average power available to Skylab and nearly five times the orbit average power available to the Soviet Mir Space Station. Several studies have addressed the magnitude of the power needed by the U.S. Space Station housekeeping functions. In nearly every case a trade had been made between logistics and power. The cost of operating a closed or regenerative system was traded against the cost of providing supplies to an open system. Since the cost of resupply involves launch to orbit, the closed system which consumes more power generally wins the trade. There are two classic examples.

The propulsion system generates its own fuel (hydrogen and oxygen) by electrolyzing water. Water can be obtained from the NSTS as a byproduct from its fuel cells and from the station life support system since the station is a net producer of water. In either case the logistics costs are carried by another function. The cost is only that marginal cost to produce more power to run the electrolyzer. The marginal cost to provide more EPS capacity has always been less than the cost to transport to orbit the required amount of consumable propellant to keep the station on orbit each year. The life cycle cost profile shows a payback of the development costs in about 1 year.

The other example is the life support system. Of the housekeeping systems, it is the single largest consumer of power. However, early trades indicated that there was not enough STS capacity available to support an open life support system such as that on STS or on Skylab. The life support system currently proposed by WP-01 (Marshall Space Flight Center/Boeing) is partially closed. Oxygen is regenerated from exhaled carbon dioxide but water is only partially reclaimed. This chemical process requires more energy than an open system. The life support system also consumes a significant amount of power just to circulate air in the pressurized modules. In this case there seems to be no choice since the capacity of the transportation system would be stretched beyond its capacity if the station were to utilize an open life support system.

The power needs of the users of the Space Station are also significant. Pending the results of several current studies, as much as 45 kW of power may be allocated to experimenters. Several materials processing experiments are proposed which may consume as much as 15 kW each. Trial payload manifests consistently require more power than the available allocation. This should not be interpreted as meaning that experiments will not be performed but that some intellegent operational scheduling must be done after the station is active. This scheduling, which may also involve housekeeping, will require the attention of ground planning, on-orbit management, and the ability of the EPS to react to dynamic changes in the geographic distribution of power consumption.

CURRENT DESIGN

The power system for the Space Station consists of four classic subsystems: generation, storage, distribution, and control. A functional block diagram of the EPS is shown in Fig. 2. Within each of these subsystems several candidate technologies have been considered before selecting the current design. The selection of each technology was heavily influenced by the transportation system available to the station (STS), by the requirements of the users of the station, and the other requirements mentioned above. The comments below will only represent the current design of the EPS.

Generation

The EPS converts sunlight into electricity using transparent back 8 by 8 cm silicon photovoltaic cells. The large area minimizes the number of cells and the number of interconnects which results in a lower cost. The transparent back provides some additional power generation by allowing a lower operating temperature and allowing some back illumination. The cells are mounted on coated Kapton panels which are hinged to adjacent panels to form a blanket which is approximately 15 ft wide and 100 ft long. The coating is to provide protection to the Kapton from degradation by atomic oxygen. Each PV array wing is composed of two blankets. A deployable mast between the blankets is used to extend the array and provide structural support. The array voltage is controlled at aproximately 160 Vdc. A flexible, deployable array design was selected to minimize mass and to allow automated array deployment with little crew involvement. A similar array which used only one blanket was flown and tested on STS 41-D. Figure 3 illustrates an array wing. During launch the arrays are stored in the blanket boxes. After deployment the box becomes part of the structural support with additional stiffening being provided by tension wires.

PV arrays are mounted on rotary jounts to provide seasonal sun-tracking. The entire outboard sections (solar power modules) of the station as shown in Figure 1 are attached to the main body of the station via rotary joints to allow orbital sun-tracking. Both the alpha and beta joints have 360° rotational capabilibity. The solar power module also contains the battery storage subsystem, a thermal control subsystem, sufficient electronics to control the generation and storage subsystems, and structure to support the equipment.

During the summer of 1987, the solar dynamic power generation technology was moved into the second phase of the Space Station program. What remains is to assure growth paths and compatibility with the solar dynamic technology. The proof-of-concept test has been postponed until 1990.

Storage

Nickel-hydrogen batteries have been selected as the energy storage subsystem for the EPS. These batteries were lighter than the other possibilities and have some space flight heritage. The cells could also be common with the polar platform and thus reduce program costs. The Ni-H2 cells have a capacity of about 80 A-hr and are packaged into assemblies which contain a wiring harness, mechanical support, and thermal transport components. Several assemblies are configured into a battery. Five batteries are present in each solar power module. Electronics which control the charge and discharge of each battery are packaged separately. Each assembly is mounted on a cold plate which is cooled by the thermal control subsystem in the solar power module.

Distribution

The most significant distribution decisions are the selection of the distribution frequency and voltage. The PMAD Workshop in 1984 suggested that the interface to users of electrical power be ac and that the distribution voltage be as high as practical. The high voltage minimizes wire weight and distribution losses in electronic switches. The ac interface allows users to change voltage levels easily using only a transformer rather than a complex dc/dc converter. ac distribution also facilitates ground isolation by modules and payloads. The final selection of 20 kHz as the distribution frequency was based on the sensitivity of some experiments to conducted and radiated EMI. The 20 kHz frequency produces less EMI and shielding is more easily accomplished at both the source and experiment. The 20 kHz distribution system is also lighter and less costly than the alternatives.

The baseline architecture of the distribution subsystem is shown in Fig. 4. The 160 Vdc from the arrays and batteries is inverted to 440 Vac, 1 phase, 20 kHz using clocked resonant converters to maintain proper frequency and phase on the main power bus. The power is transmitted across the alpha joint using roll rings which are sized for the growth station. A main bus switching assembly on either side of the alpha joint permits reconfiguration of the source and distribution buses. The EPS uses a ring bus on the truss inside the alpha joint and a second ring bus inside the pressurized modules. Due to potential module depressurization, the distribution voltage inside the modules is reduced to 208 Vdc. Each area outside and each pressurized module are transformer isolated. The interface to the users is always 208 V, 20 kHz. The final switching within the EPS before the user's equipment is aggregated into power distribution control assemblies. One is located in each area on the truss where power is consumed. Each U.S. pressurized module has five. The current internal architecture of a PDCA is shown in Fig. 5. Each PDCA can service 10 load centers with three fault tolerant power, 20 load centers with single fault tolerant power, or a mix.

In order to maintain the high efficiency of the distribution system, users of power have been encouraged to convert the power only once from 20 kHz to their final needs. This is similar to using 60 Hz directly in an instrument in a laboratory on the ground. As a transistion aide, for those users who need assistance adapting to 20 kHz, the Space Station program will provide education and lists of qualified vendors. The Space Station will make available to experimenters two types of bulk converters. These will produce 28 Vdc and 60 Hz. Double conversion of power is inefficient and the losses will be charged to the experimenter.

Control And Management

The control architecture for the EPS uses a hierarchical, distributed computing capability and a dedicated control data bus. Some software at the lower levels in the heirarchy will be burned onto chips to provide startup and recovery capability independent of higher level controllers. The EPS also utilizes a dedicated low power distribution bus to assure that all switches are set in proper positions before applying power to the main distribution buses. A Power Management Controller (PMC) is installed in each of the back nodes. These are the master controllers for the EPS and also provide the interface to the Data Management System which provides communication paths to the other-systems and hosts the Operation Management System (OMS). The OMS provides the day-to-day operational scheduling of the activities onboard the station. It can also respond with a global perspective to an event or a problem on the station.

Just below the PMC in the controller heirarchy are the controllers in each PV module increment and in each PDCA. These respond to the PMC and also have the capability to function autonomously to maintain EPS capability in case of a failure of both PMC's.

CONCLUSIONS

This paper has presented an overview of the requirements upon which the EPS and solar power module designs are based as well as a summary of the design itself. The current design meets all of the requirements including total power level, redundancy, and launchability.

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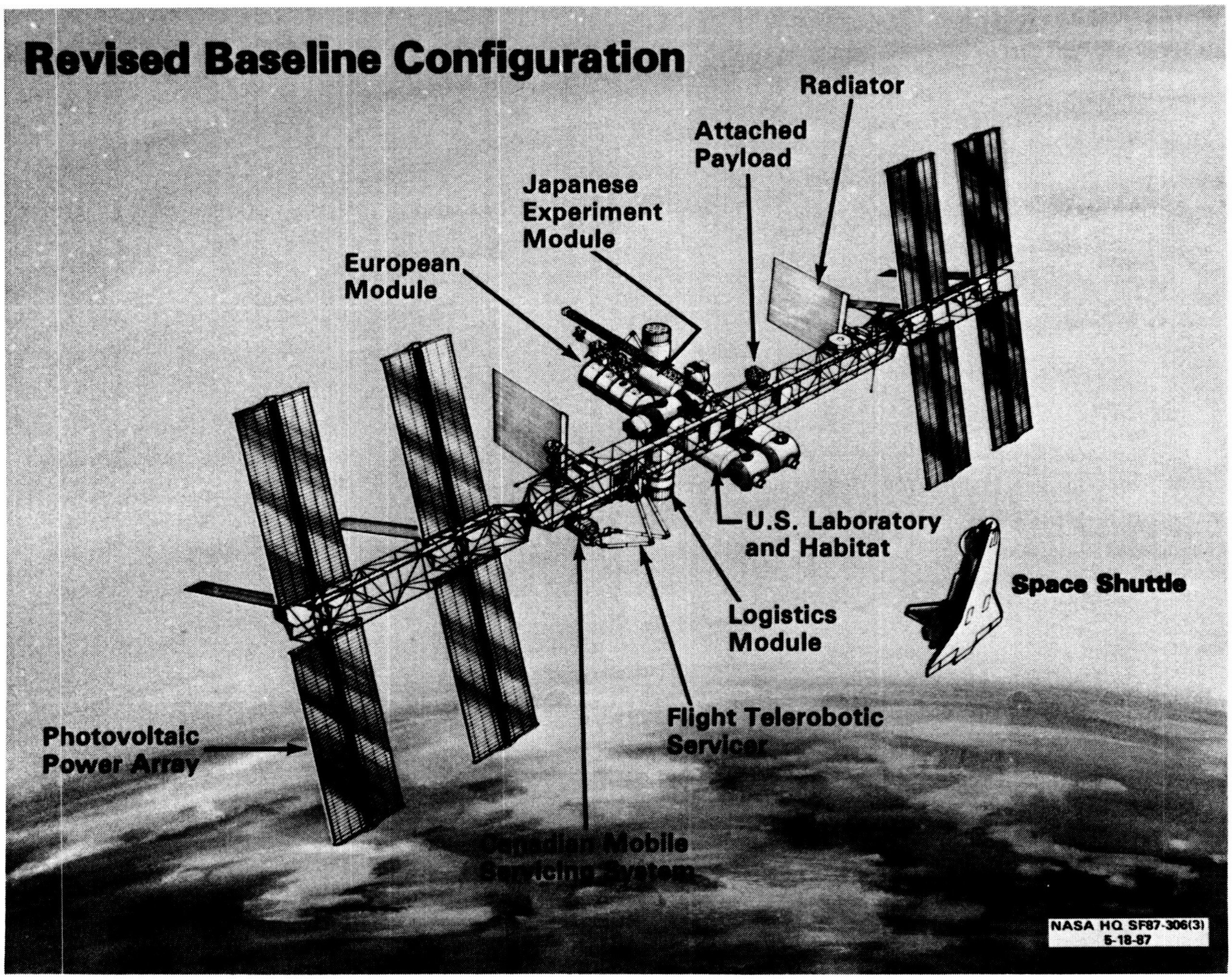


FIGURE 1. - REVISED BASELINE CONFIGURATION (NASA HQ SF87-306 (3) 5-18-87).

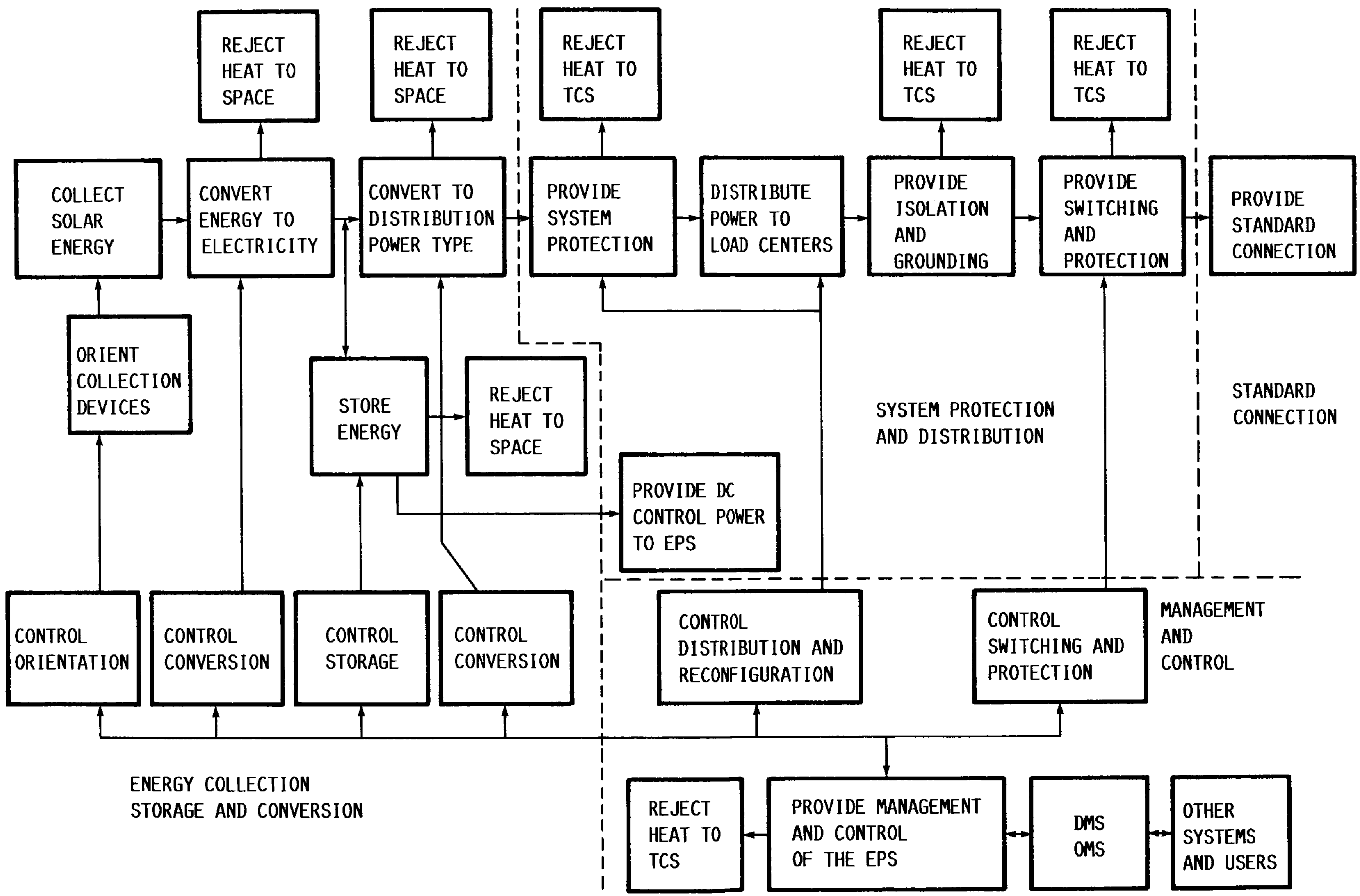


FIGURE 2. - ELECTRICAL POWER SYSTEM (EPS) TOP LEVEL FUNCTIONAL SCHEMATIC.

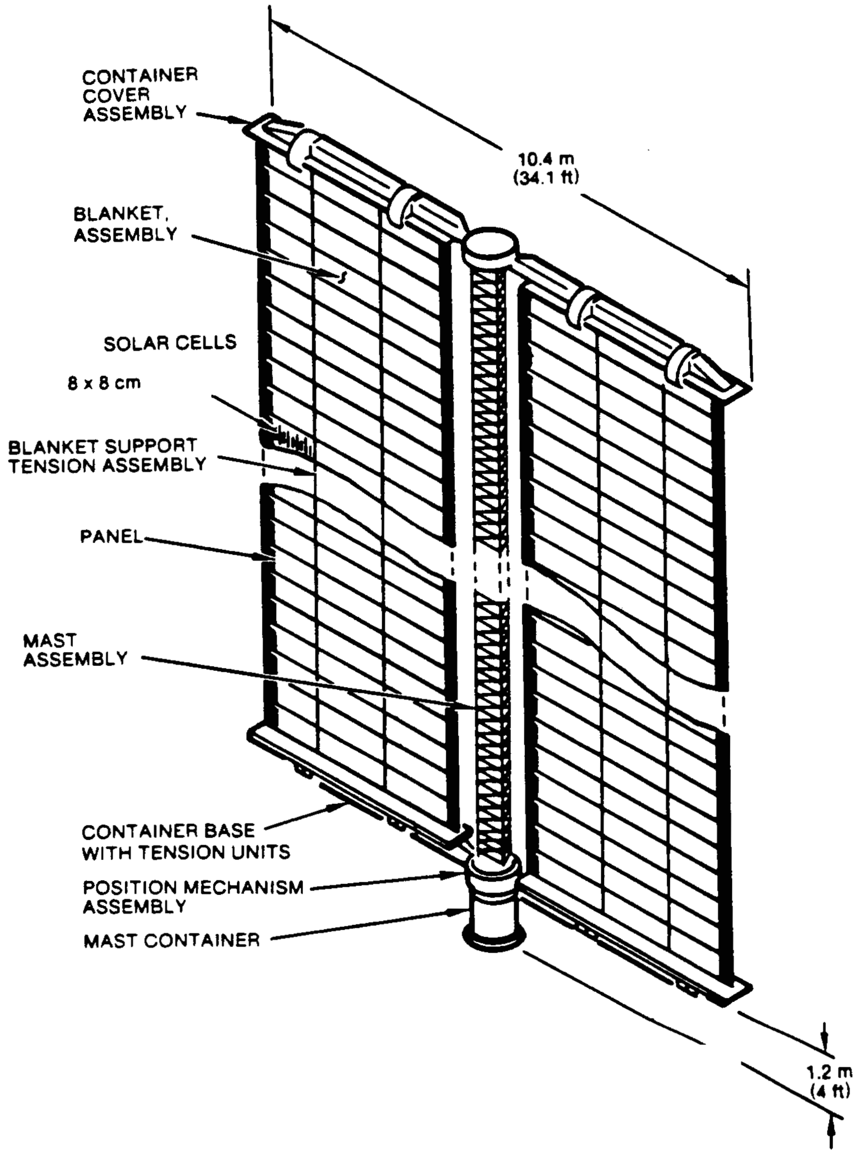


FIGURE 3. - TWO-BLANKET FLEXIBLE SOLAR ARRAY.

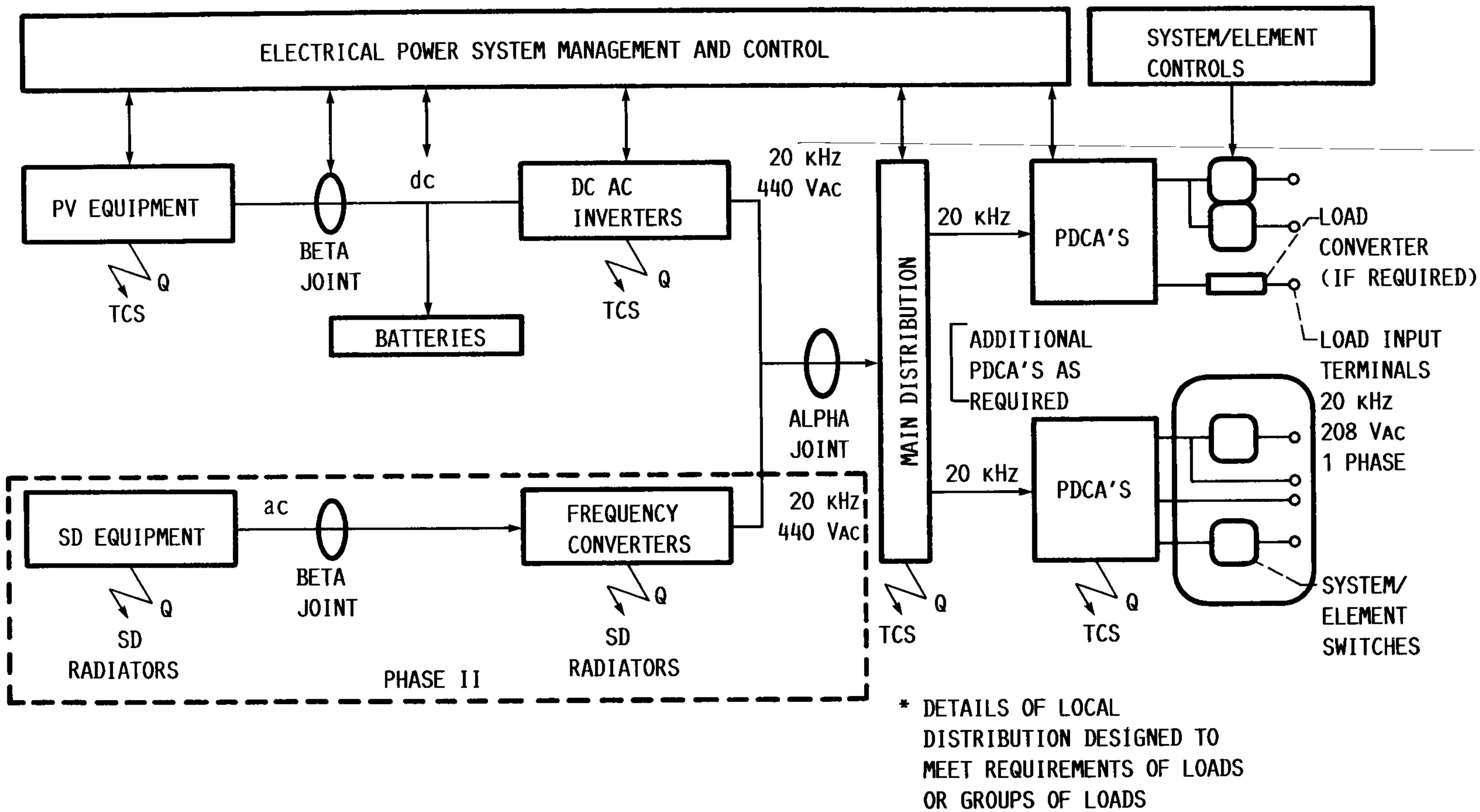
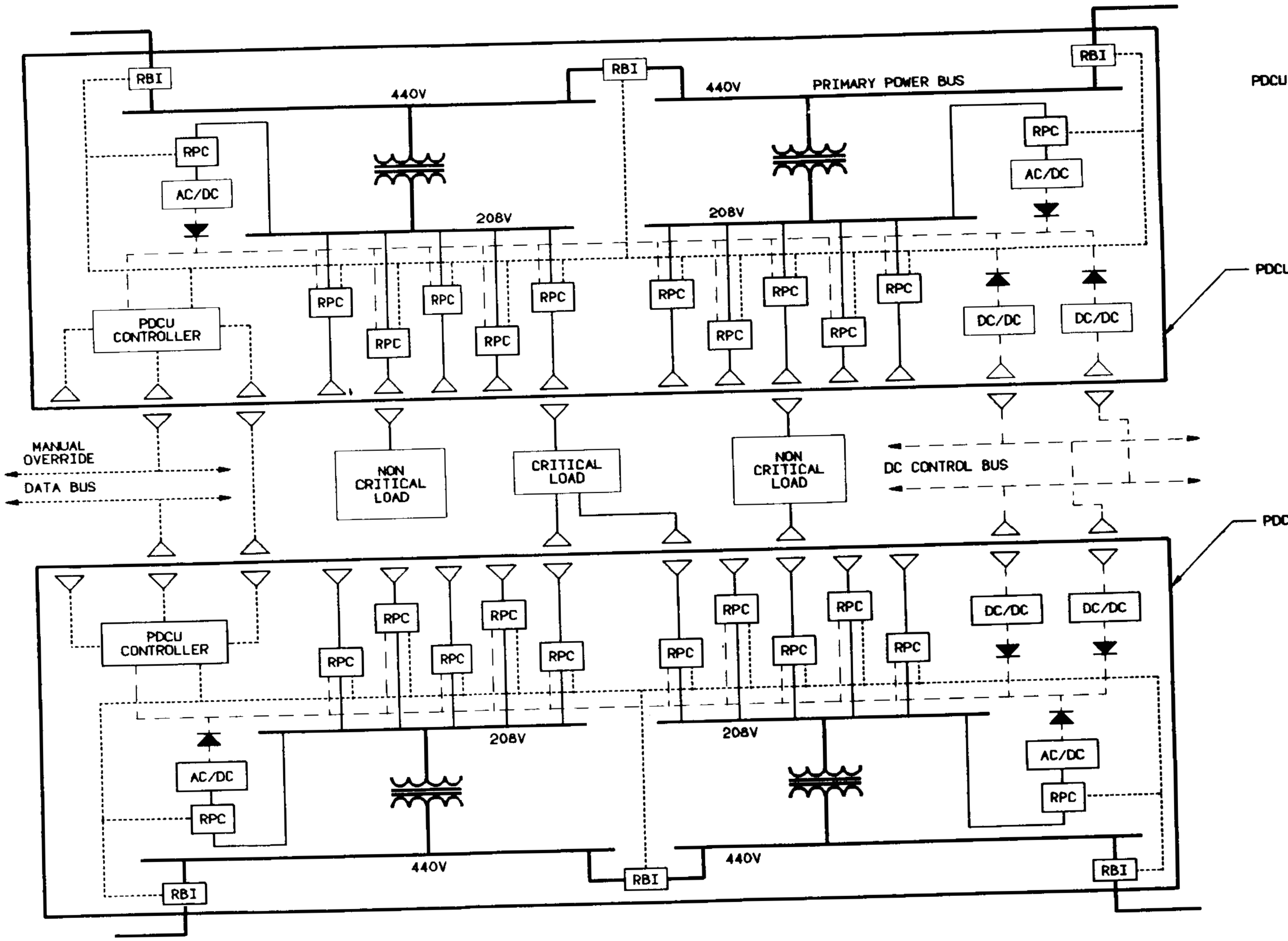


FIGURE 4. - SIMPLIFIED FEATURES OF THE ELECTRICAL POWER SYSTEM (EPS) ARCHITECTURE.



PDCU - POWER DISTRIBUTION AND CONTROL UNIT

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FIGURE 5. - POWER DISTRIBUTION AND CONTROL ASSEMBLY (EXTERNAL).

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16. Abstract

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