

Power distribution subsystems are required for three elements of the SPS program: (1) orbiting satellite, (2) ground rectenna, and (3) Electric Orbiting Transfer Vehicle (EOTV). Power distribution subsystems receive electrical power from the energy conversion subsystem and provide the power busses, rotary power transfer devices, switchgear, power processing, energy storage, and power management required to deliver regulated power to the load. The grounding, electromagnetic interference control, high voltage plasma interactions, electric thruster interactions, and spacecraft charging of the SPS and the EOTV are also included as part of the power distribution subsystem design.

The satellite power distribution subsystem (PDS) is essential but incurs weight and power loss penalties, representing cost, to the SPS. The design approach must be: (1) to define feasible PDS concepts that can accommodate unprecedented power and voltage levels, (2) to perform system level trade/optimization studies, (3) to select a PDS that minimizes the SPS penalties, and then (4) to develop the high performance components needed to implement the subsystem.

This paper will consider the preliminary SPS concepts developed by Rockwell and Boeing from the standpoints of reducing subsystem requirements and of minimizing SPS penalties. Performance improvements and projections will be addressed and technology developments will be suggested.

The significance of system level studies to the selection of a PDS design can be reviewed with the aid of Figure 1.

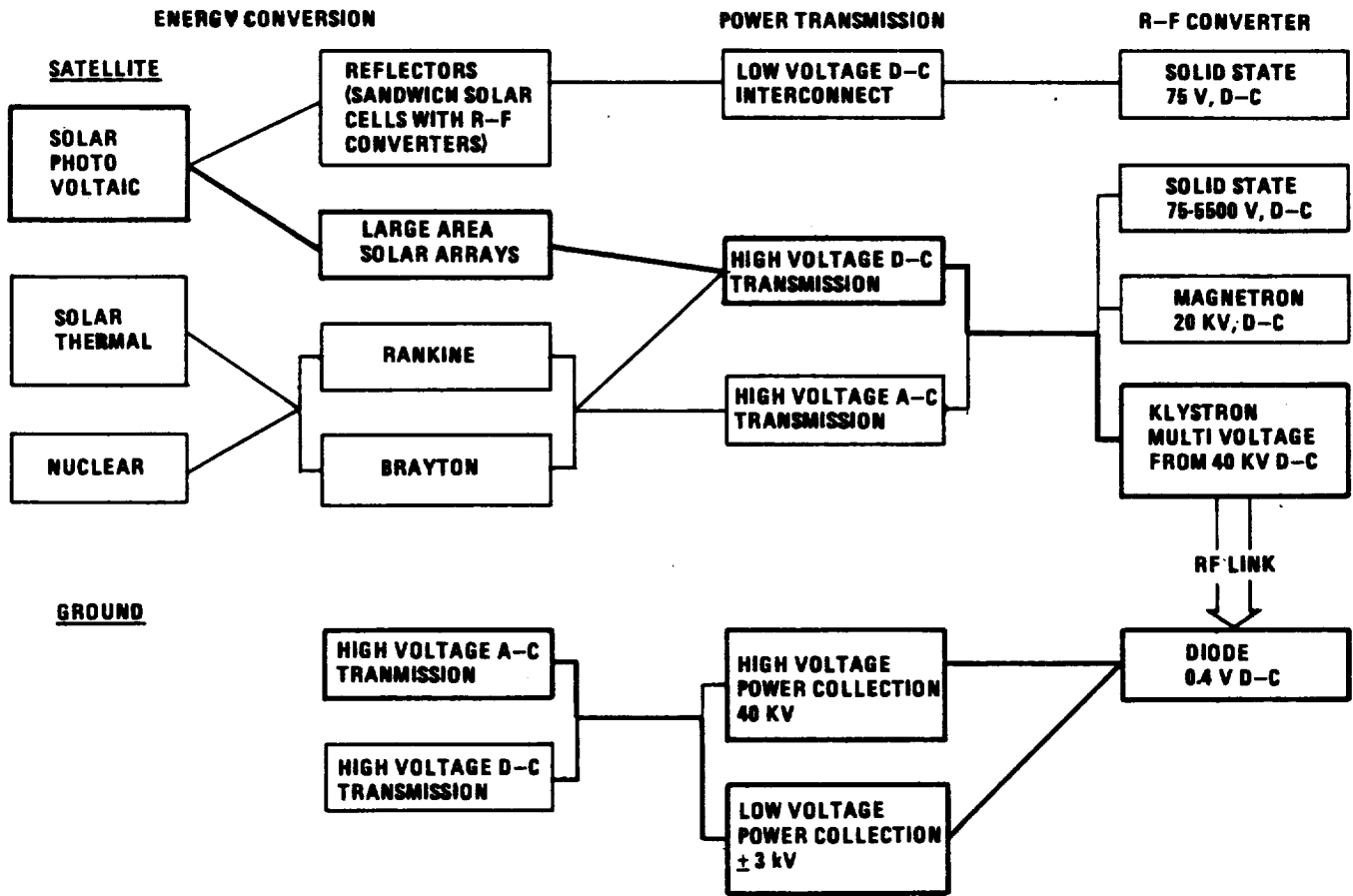
The solar photovoltaic/sandwich concept, wherein solar cells are connected back to back with solid state direct current (d-c) to radio frequency (r-f) converters, requires no switchgear or power processors. The solar cells are merely connected via short interconnect busses to the solid state amplifiers and the result is an ideal negligible PDS.

None of the other system concepts shown in Figure 1 achieve this simplicity because the power source is necessarily located at a distance of several kilometers from the antenna, and for solar concepts, the power source must be pointed at the sun while the antenna maintains earth pointing. Therefore, power must be transferred across a rotary joint and must be transmitted at high voltage to maintain reasonable conductor size and power loss. It also follows that the PDS will require switchgear for the collection and management of power received from multiple sources and for redistribution to individual r-f converters.

The photovoltaic/klystron system design, indicated by heavy lines in Figure 1, is the present reference SPS concept, although it requires a complex PDS. The klystron r-f converter requires bulk power at multiple voltages ranging from 40 kV to 8kV and a small percentage of power at voltages as low as 20 volts. All of the bulk power could be supplied from solar array sections operating at the proper voltage but system studies conducted by Rockwell and Boeing have employed power processors for 20 to 80% of the power due to the heavy conductors required at lower voltages and the added circuit complexity of managing a multi-voltage system.

ELECTRICAL POWER DISTRIBUTION AND MANAGEMENT

FIGURE 1



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A magnetron r-f converter, proposed by Raytheon, has the potential to eliminate power processing requirements. The magnetron can be operated from a single 20 kV buss and has internal voltage tolerance (5 to 10%) which permits direct connection to a 20 kV solar array. The magnetron approach is expected to benefit the reference Boeing design due to their optimistic conductor designs and conservative projections for power processing performance. The opposite could be said for the Rockwell reference design. The magnetron may also favor solar thermal or nuclear concepts because alternating current (a-c) power received from the Brayton or Rankine machines can be easily rectified to 20 kV d-c.

The solid state r-f converter concept, when operated from large area solar arrays or Rankine or Brayton machines, is penalized by low voltage requirements (~200 volts). Power processing, necessary for 100% of the power, incurs a 5×10^6 kg mass and 4% loss penalty.

A similar penalty results from the use of low voltage solar arrays. Low voltage solar arrays (400 volts) have been considered as a contingency pending verification of the feasibility of multi-kV arrays. The power processing penalty would again be 5×10^6 kg mass and 4% loss.

High voltage a-c transmission has been a continuing trade study option and although a-c transmission designs can reduce power conductor and switchgear requirements, they require 100% power processing at the load and have therefore been less attractive than d-c designs.

The remaining element of the PDS, shown in Figure 1, is the ground rectenna system. The ground rectenna receives power from series connected diodes and provides switchgear, and power processors for connection to the utility grid. Equipment requirements have been considered to be relatively in-hand when compared with requirements of the orbiting satellite. The primary concern has been with overall satellite/ground rectenna power management when (1) the SPS is off-line for scheduled maintenance, (2) the SPS or utility grid experience partial failures, (3) peak on slack load is demanded from the utility grid.

The PDS required for the Electric Orbiting Transfer Vehicle (not shown in Figure 1) requires switchgear and power conductors to connect the solar array to the electric thrusters. Power processors may not be necessary, depending on system performance trade studies involving solar cell (Si or GaAs) characteristics as a function of altitude. Energy storage, to operate a minimal number of attitude control thrusters during shadow periods, is dependent on trade studies comparing electric versus chemical thrusters.

The interaction of all satellite subsystems with the space plasma environment or other plasma created by electric thrusters or the outgassing of materials is included in the PDS investigations. This includes technology development to permit solar arrays to be operated in the multi-kV range; selection of insulation material to control spacecraft charging; and trade studies to optimize the location of electric thrusters and to select material with low outgassing characteristics.

Hardware that might be applied to PDS designs exists as high power, high voltage ground utility equipment or as low power, low voltage satellite equipment. The

hardware issues for the SPS designs are: (1) can the necessary large flight worthy equipment be developed to meet the unprecedented electrical requirements? (2) will the equipment meet performance and life goals? These issues require resolution through a Ground Based Exploratory Development (GBED) program.

Important issues that could benefit through exploratory development are tabulated in Table 1. The necessity for detailed investigations can be illustrated by considering power processing, space plasma interactions and energy storage.

TABLE 1. ISSUE TREE

ISSUES	SUB-ISSUES
Power Processing, Distribution, and Management High Voltage/High Performance 0.4 - 1.0 kg/kW 90% Efficiency 30 Year Life	Power Processing Performance and Thermal Control 0.2 to 1.0 kg/kW Switchgear 99.9% Efficiency Rotary Joint 200kA Power Conductors 0.124 w/g Insulators and Stand-Offs Auto Power Management
Space Environmental Interactions 1.0% Loss	S/C Charging @GEO High Voltage/Plasma Breakdown Thruster Interactions Plasma Interactions
Energy Storage Satellite Systems Management during Eclipse	High Performance Secondary Batteries 200 Wh/kg Fuel Cells/Ni H ₂ Batteries/ Superconducting Magnetics 40 Wh/kg Thermal 200 Wh/kg

High performance power processors are required for several system concepts of the SPS. Typical designs require 9×10^6 kW as input power to the satellite r-f converters to deliver 5×10^6 kW to the ground utility grid. Existing satellite power processors, with specific weights of 10 kg/kW, would add a clearly unacceptable 90×10^6 kg to an SPS reference designs having a total weight of 30 to 50×10^6 kg. Conceptual studies performed by Westinghouse and GE have projected that specific weights might be reduced to the range of 1 to .2 kg/kW. Although PDS designs strive to minimize power processing requirements, the effect that this type of uncertainty has on system level studies should be apparent.

The interaction between high voltage solar arrays and the space plasma is complex and made uncertain by the difficulty in obtaining credible test data. It is generally believed that present solar array designs will not operate satisfactorily at voltages above 400V. The major concern at this time is in finding a solution

to the glow discharge on "sparking" observed in vacuum chamber tests at LeRC and at JSC. A second concern is with charge exchange ions from electric thrusters that are attracted to solar cell surfaces and cause a high shunting power loss. The loss may be minimized for the SPS by proper location of the attitude control thrusters but it appears that biased screens will be required for the EOTV to prevent the charge exchange ions from reaching the solar array. Power loss due to the interaction of the solar array with the space plasma at low orbits is an additional major concern for the EOTV.

Energy storage is required by the SPS (1 to 15 mWh) and EOTV (0 to 300 kWh) to maintain attitude control during shadow periods. On-going development of high performance fused salt batteries (200-300 Wh/kg) by the DOE should be supported and alternative energy storage systems should be investigated.