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HIGH POWER/LARGE AREA PV SYSTEMS

Joseph Wise (Workshop Cochairman)
AF Wright Aeronautical Laboratories
Wright Patterson AFB, Ohio
and
Cosmo Baraona (Workshop Cochairman)
NASA Lewis Research Center
Cleveland, Ohio

New power requirements in the 50 to 100kW range will be needed prior to the year 2000. The photovoltaic power system option should be developed to meet these needs because of the PV System's proven record for long life, performance, and reliability with no single point of failure in a matrix of series and parallel connected solar cells and modules. In addition, the PV system has high potential for increased efficiency and survivability as well as lower weight and cost.

The workshop generated and ranked the major technology drivers for a wide variety of mission types (see Table 1). Each technology driver was ranked on a scale of high, medium, or low in terms of importance to each particular mission type. The rankings were then compiled to determine the overall importance of each driver over the entire range of space missions. In each case cost was ranked the highest. This led to the general concensus that system cost is the most important driver for high power PV systems.

Each mission also requires different critical capabilities from the solar array. Weight is of paramount importance to high altitude missions while others may be driven by the needs for survivability, radiation resistance, minimum drag, or low cost. For these reasons it is felt that two major photovoltaic solar array developments are required - lightweight planar solar arrays for minimum weight and area for low cost high orbit insertion and concentrator array technology for improved survivability and radiation resistance as enabling technology for survivable mid-altitude orbit missions as well as lower cost technology in the application of very high efficiency solar cells. These developments must be accompanied by improvements in electrical energy storage and power processing to minimize the weight of the entire power system. There are several solar cell concepts currently under consideration in research and development. Because of the long process needed to gain acceptance for a new or modified solar cell type, we must choose carefully which one or two have sufficient promise and improved performance to merit the large resources needed to reach technology readiness and producibility.

The developments needed to exploit the lightweight planar solar array potential are shown in Figure 1. This starts with the development of thin high efficiency cells and definition of solar array concepts and designs which can support these cells for high power missions. As power levels increase the need for modularity and on-orbit assembly becomes greater because the complete satellite may not be put into orbit in a single launch vehicle and on-orbit assembly is required. Also, because high power missions represent a large investment, provisions for maintenance and servicing will need to be incorporated in new system designs. As power levels increase, the voltage at which power is generated, transmitted, and utilized must also be increased. This increases the probability of interaction with the space environment such as leakage to the plasma, arcing due to charge buildup, and contamination of array surfaces. Also, new cell types such as GaAs and InP have demonstrated the ability to recover performance degraded by particulate radiation through relatively low temperature annealing. This capability should be further investigated and exploited in solar array design for operation in high radiation orbits.

Development of concentrator photovoltaic arrays requires more design and testing since it is a new development without prior flight experience, and the performance required from them is greater. The developments and tests needed are shown in Figure 2. The pointing requirements are in the neighborhood of ± 1 degree which is certainly within the state of the art of pointing and tracking systems. Difficulty may arise, however, in keeping a very large area array (5-10 sq. meter/kW) oriented to this accuracy when warping or thermal effects cause bending or distortion of the panels. Also, the concentrators are expected to provide shielding to increase survivability from natural and threat irradiation exposure. These effects need to be modeled and tested. The resultant hardware designs need extensive ground testing such as thermal cycling. They also need space flight testing to determine interactions with the orbital environment, especially plasma and contamination from debris associated with large space vehicles - dust, effluents from altitude control and propulsion thrusters. One of the techniques needed for survivability is autonomy - independence from ground station control. This is a new technology that is just now being investigated. It is more likely to be incorporated into second generation concentrator array technology. One of the more important attributes of concentrator arrays is their potential for high efficiency at low cost because the cell area is only about 1% of the collector area of the array. Thus the cell costs associated with the greater number of processing steps needed for high efficiency multibandgap solar cells are minimized. Each of these new cell types may require customized interconnect, mounting and cooling assemblies to operate for extended periods in space. This also may be second generation technology.

It is apparent that all of the effort outlined in the previous two figures cannot be accomplished instantly and not necessarily in single programs. They are, therefore, divided into three major thrusts as shown in Figure 3. The design concept development is the R&D needed to implement a high power array for a specific vehicle configuration and should be undertaken when the orbit, mission, and potential vehicle characteristics can be specified.

The operational issues cited are for the development and testing needed to intelligently design a high voltage, high power solar array. Defining them involves close work with environmental specialists in modeling of environmental interactions with various hardware configurations and flight testing to both measure the environmental species present and their interaction with the experimental array hardware.

The cell module design and development is that work needed to demonstrate that a particular cell type can be applied to a solar array concept, planar or concentrator. This includes determining the radiation resistance, thermal characteristics, and performance parameters of the cells and fabrication and testing of modules utilizing these cells. Under this thrust we need to choose which concepts should be developed for thin large area, high efficiency cells for planar applications and which are suitable for concentrator applications. These module developments need to be compatible with the large array design concepts but are not necessarily a part of the large concept developments.

TABLE 1

Importance of Technology for High Power Missions

Mission Type

Technology Driver	Electric Propulsion	Planetary	GEO	LEO	Surveillance	Total Pts.
Cost	1	1	1	1	1	5
Conversion Efficiency	2	2	1.5	1	1	7.5
Weight	1	1	1	3	2	8
Environmental Interactions	1	2	2	1	2	8
Heat Rejection	2	2	2	2	1	9
Life (reliability 5-10 yr/maintenance in LEO)	2-3	1	1	3	2	9.5
Military Survivability	3	3	2	1	1	10
Array High Voltage	1	2.5	1	3	2-3	10
Robust	2	2	3	1	3	11
Radiation Resistance	1	3	3	3	1.5	11.5

Technology Ready by year 2000

Importance Scale:
1. High
2. Medium
3. Low

Ranking:
1. Cost
2. Efficiency
3. Weight & Environmental Interactions

DEVELOPMENT NEEDED FOR LIGHTWEIGHT PLANAR ARRAYS

- 0 THIN HIGH EFFICIENCY CELLS
- 0 DEPLOYMENT, STOWAGE CONFIGURATION (DESIGN CONCEPTS)
- 0 ASSEMBLY APPROACHES
- 0 MODULARITY
- 0 300 W/KG
- 0 LOW COST CELL TECHNOLOGY
- 0 $300/WATT ARRAY LEVEL
- 0 ON ORBIT MAINTENANCE ROBOTICS
- 0 200 W/M^2
- 0 ENVIRONMENT CONTROL EFFECTS
- 0 HIGH VOLTAGE
- 0 THIN CELL COVERS
- 0 ANNEALING GaAs, InP

FIGURE 1

DEVELOPMENTS NEEDED FOR CONCENTRATOR ARRAYS

- 0 SURFACE POINTING
- 0 ENVIRONMENTAL SURVIVAL TEST PROGRAM
- 0 UNDERSTAND ENVIRONMENTAL EFFECTS
- 0 STOWAGE, DEPLOYMENT 5-50 KW
- 0 DESIGN FOR ORBIT/FLIGHT PATH
- 0 HIGH EFFICIENCY CELLS, OPTICS
- 0 THERMAL ENVIRONMENT
- 0 EXPERIMENTAL FLIGHT
- 0 DESIGN FOR HIGH VOLTAGE
- 0 ELECTROSTATIC EFFECTS
- 0 THREAT ENVIRONMENTS
- 0 MINIMUM WT. & END OF LIFE
- 0 POWER SYSTEM INTERFACE
- 0 AUTONOMOUS CONTROL
- 0 ELECTRIC ENGINE STORAGE

FIGURE 2

TECHNOLOGY THRUSTS - THREE MAIN THRUSTS

0 DESIGN CONCEPT DEVELOPMENT
- LAUNCH SCENARIO
- STOWAGE, ASSEMBLY, DEPLOYMENT, ORIENTATION, POWER THRUST, AUTONOMOUS CONTROL, VEHICLE INTERACTIONS, STRUCTURE, MATERIALS, TECHNOLOGY

0 OPERATIONAL/ISSUES
- LIFE, RADIATION, ENVIRONMENTAL DEBRIS, O_2, CONTAMINATION, THERMAL CYCLING, MISSION CONSTRAINTS

0 CELL MODULE DESIGN AND DEVELOPMENT
- EFFICIENT EOL WEIGHT, RADIATION RESISTANCE
- COST, THERMAL EFFECTS
- GROUND/FLIGHT TESTS
- LARGER CELL/MODULE SIZE
- NEW APPROACHES OF DESIGNS
- THIN SYSTEMS, THIN MBG A-SI, GAAS ON GE, CLEFT

FIGURE 3