naasa

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1. Solar Irradiance in Space The solar constant (average solar flux at 1 AU) is:

$$S = 1361\ W/m^2$$

At 500 km altitude, the satellite distance from Earth's center is:

$$r = R_E + h = 6371 + 500 = 6871\ km$$

Neglecting small variation in distance, we take S as constant.

2. Incident Solar and Albedo Power The direct solar power absorbed by a surface of area A and absorptivity α is:

$$P_{direct} = S\, A\, \alpha\, \cos\theta$$

where θ is the angle between the Sun vector and the surface normal. Albedo (reflected sunlight from Earth) is approximated as:

$$P_{albedo} = S\, a\, \frac{R_E^2}{r^2}\, \frac{A\, \alpha}{4}\, V(\varphi)$$

where a is Earth's albedo (0.20) and $V(\varphi) = \frac{1+\cos\varphi}{2}$ models the visible illuminated Earth fraction. Total absorbed power:

$$P_{abs}(\varphi) = P_{direct}(\varphi) + P_{albedo}(\varphi)$$

3. Eclipse Condition When the satellite passes behind Earth (in Earth's shadow), the Sun is blocked. The eclipse fraction $f_{eclipse}$ for circular orbit is found geometrically as:

$$f_{eclipse} = \frac{1}{\pi} \arccos\left(\frac{R_E}{r}\right) \approx 0.3778$$

so the sunlit fraction $f_{sunlit} = 1 - f_{eclipse} \approx 0.6222$.

4. Instantaneous Absorbed Power (Sun-pointed Face) At full sunlight:

$$P_{direct,max} = S\, A\, \alpha = 1361 \times 1 \times 0.7 = 952.7\ W$$

Albedo contribution constant:

$$C_{alb} = Sa\frac{R_E^2}{r^2}\frac{A\alpha}{4} \approx 41.0\ W$$

Total instantaneous absorbed power (max):

$$P_{abs,max} = 952.7 + 41.0 = 993.7\ W$$

5. Orbit-Average Incident Power Orbit-average direct (sun-pointing) power:

$$\overline{P}_{direct} = 952.7 \times f_{sunlit} = 952.7 \times 0.6222 = 592.77\ W$$

Average albedo power:

$$\overline{P}_{albedo} = 41.0 \times 0.5 = 20.5\ W$$

Total orbit-average absorbed power:

$$\overline{P}_{abs} = 592.77 + 20.5 = 613.27\ W$$

6. Electrical Power Generation Photovoltaic (PV) conversion efficiency $\eta = 0.30$. Electrical power is:

$$P_{elec}(\varphi) = \eta\left(P_{direct} + P_{albedo}\right)$$

Orbit-average electrical power:

$$\overline{P}_{elec} = 0.30 \times 613.27 = 184.0\ W/m^2$$

7. Orbital Energy Balance Orbital period (for circular orbit):

$$T = 2\pi\sqrt{\frac{r^3}{\mu}} \approx 5670\ s\ (94.5\ min)$$

Total energy generated per orbit:

$$E_{orbit} = \overline{P}_{elec} \times T = 184.0 \times 5670 = 1.04 \times 10^6\ J = 290\ Wh$$

Eclipse duration:

$$t_{eclipse} = f_{eclipse} \times T = 0.3778 \times 5670 = 2142\ s$$

Energy required from batteries during eclipse:

$$E_{eclipse} = \overline{P}_{elec} \times t_{eclipse} = 184.0 \times 2142 = 3.94 \times 10^5\ J = 109.5\ Wh$$

8. Summary

- Instantaneous peak electrical (sunlit): $\approx 298\ W/m^2$

- Orbit-average electrical: $\approx 184\ W/m^2$
- Energy per orbit: $\approx 290\ Wh/m^2$
- Energy storage required for eclipse: $\approx 110\ Wh/m^2$

Scaling:

- Scale by area (A): multiply by A
- Scale by efficiency (η): multiply by $\eta/0.30$