# 4 Power

## 4.1 Power Subsystem of a spacecraft

Consider a satellite in a circular orbit around Earth at an altitude of 700 km with a corresponding period of revolution of 98.7 minutes. The satellite will experience a solar eclipse of 35.4 minutes per revolution due to the shadowing of planet Earth. Assume that the satellite needs 110 W of power throughout the whole lifecycle of 6 years.

Answer the following questions:

1. Calculate the needed area for the solar panel $A_{SP} = 1.2A_{SC}$, where $A_{SC}$ denotes the required area of solar cells, in order to obtain a constant power supply throughout the whole lifecycle?
2. What is the total generated power needed to be collected during the sunlit phase in order to fulfill the requirement of 110W constant power supply?
3. Compute the energy storage and the required mass of the two battery types shown in the graph below.

- Solar Constant at 1 A.U. is $G_S = 1420W/m^2$
- Path efficiency $\eta_{path} = 0.85$
- Storage efficiency $\eta_{storage} = 0.75$
- Solar Cell efficiency $\eta_{solar} = 0.15$
- EOL coefficient of SI-Cells $\sigma_{EOL} = 0.775$
- Energy density for NiCd 25-30 Wh/kg
- Energy density for NiH 25-40 Wh/kg



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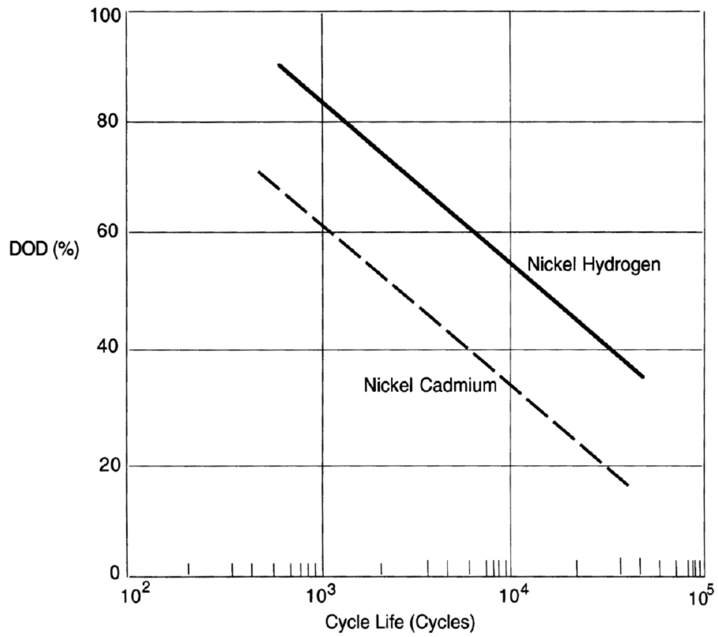


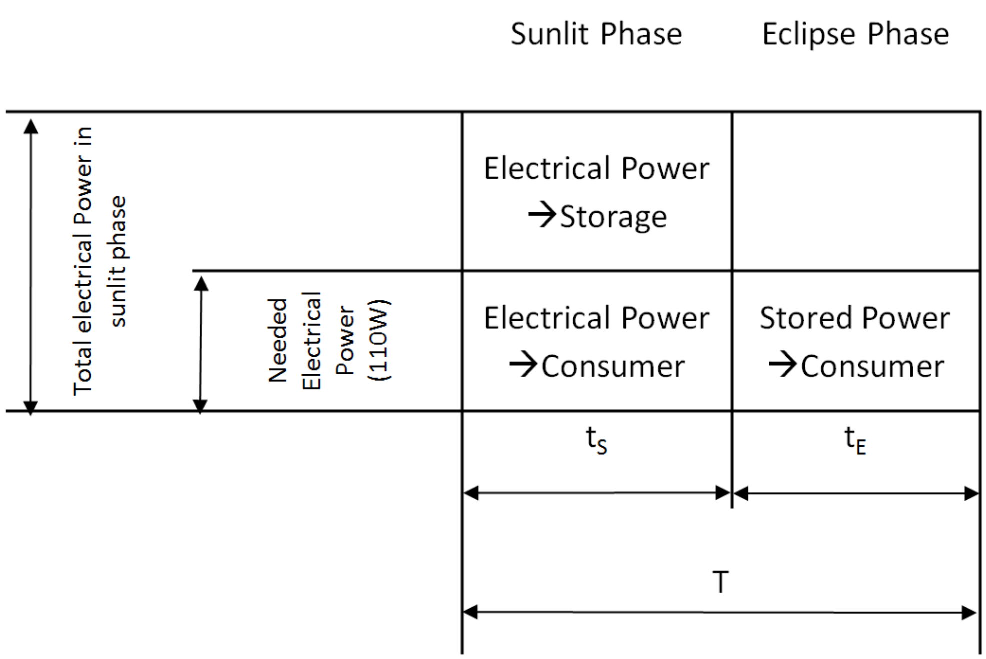




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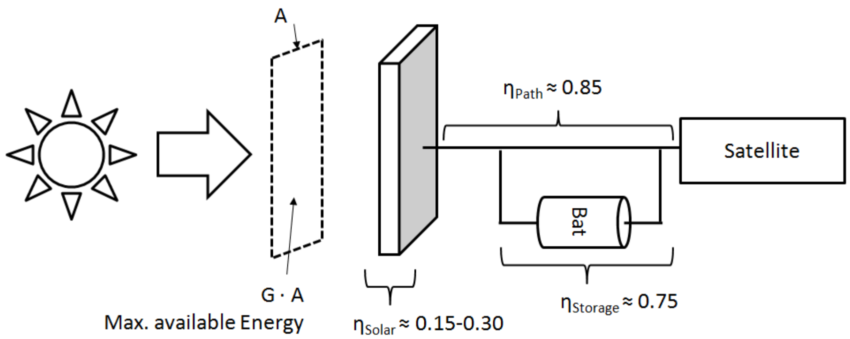


1.
We start with the equations for the electrical energy needed during the two orbit phases (eclipse and sunlit). For the eclipse phase we can use the folloiwing equation:

$$P \cdot t_E = G_S \cdot A_1 \cdot \eta_{solar} \cdot \eta_{path} \cdot \eta_{storage} \cdot (T - t_E)$$

The left part of the equation denotes the energy needed by the spacecraft during the time of the eclipse. The first two parameters on the right hand side are the available energy from the sunlight at the distand of 1 AU. The theoretical available energy is multiplied with the three efficiencies for the solar cells, the path losses and the storage. This is multiplied with the time when this energy can be collected which is the sunlit phase.

For the sunlit phase we use an similiar equation which even can be simplified:

$$P \cdot (T - t_E) = G_S \cdot A_2 \cdot \eta_{solar} \cdot \eta_{path} \cdot (T - t_E)$$

Hete the time can be canceled out:

$$P = G_S \cdot A_2 \cdot \eta_{solar} \cdot \eta_{path}$$

Now the two areas $A_1$ and $A_2$ have to bee added up to obtain the total area needed for supplying the satellite:

$$A_{SC} = A_1 + A_2$$

This leads to

$$A_{SC} = \frac{P}{G_S \cdot \eta_{solar} \cdot \eta path} \cdot \left(1 + \frac{t_E}{\eta storage \cdot (T_{tE})}\right) = 1.06m^2$$

Now we have to take into account that the solar cells degrade during their lifetime and to be sure that they deliver enough power at the end (after 6 years) we have to multiply the calculated value with the $\sigma_{BOL/EOL}$ coefficient. This gives us an area of

$$A_{SC,EOL} = \frac{\sigma_{BOL}}{\sigma_{EOL}} \cdot A_{SC}$$

$$A_{SC,EOL} = \frac{1}{0.775} \cdot 1.06m^2 = 1.37m^2$$



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Note that the value for $\sigma_{BOL}$ is always set to 1!!! The value of $\sigma_{EOL}$ shows how much the decrease of the cells is. The lower the EOL values is the higher is the degradation of the cells (which means that they cells are getting worse at the end of the mission).

Now we are considering the the size of the solar panel is larger than the size of the solar cells as we need a base amterial to fix the cells to and also some space is needed for pathways and fixture points. We are using the rule of thumb given in the problem statement:

$$A_{SP} = 1.2A_{SC} = 1.64m^2$$

This value can be used for a first rough estimate of the panel size. In real life you would also have to consider effects like a temperature dependant $\eta_{solar}$ or pointing errors of the panels which lead to slightly lower energy that can be used for the satellite.

2.

No we want to calculate the power that is generated during the sunlit phase. Therfore we use the following equation:

$$P_{tot} \cdot \left(T - t_E\right) = \frac{P_E \cdot t_E}{\eta_{path} \cdot \eta storage} + \frac{P_S \cdot (T - t_E)}{\eta_{path}}$$

This leads to:

$$P_{tot} = 225W$$

This is the output power of the solar generator. Thie generator has to generate enough power during the sunlit phase to keep the system alive during the eclipse where no external power is available. It also has to generate enough power to compensate the losses (path and storage) in the satellite.

3.

First we have to calculate how much energy has to be stored in the batteries which can be calculated with the following equation:

$$W_{el,ideal} = \frac{P_e \cdot t_e}{\eta_{storage} \cdot \eta_{path}} = 101.8Wh$$

To calculate the needed batteries we then evaluate how many charge cycles the batteries will endure during the mission. The number of life cycles can be found with the following equation:

$$n = \frac{6y \cdot 365d \cdot 24h \cdot 60min}{98.7min} = 32000cycles$$

This is important as the battery performance decreases as it is charged and discharged during the mission. From the graph in the problem statement we can find the values for the depth of discharge (DOD) that can be used for two different battery types. For NiCd the DOD is approxiate 18 percent for NiH it is 38 percent. This leads to a total energy capacity of:

$$W_{el,NiCd} = \frac{W_{el,ideal}}{DOD_{NiCd}} = 566Wh$$

$$W_{el,NiH} = \frac{W_{el,ideal}}{DOD_{NiH}} = 268Wh$$

With the given energy densities this leads to a battery weight of:

NiCd: 18.9-22.6 kg
NiH: 6.7-10.7 kg



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