**LIST OF ABBREVIATIONS**

**EPS-** Electrical Power System

**PDU-** Power Distribution Unit

**SoC-** State of Charge

**DoD**- Depth of Discharge

**MPPT-** Maximum Power Point Tracking Controllers

**BMS** – Battery Management Systems

**SSR**- Solid State Relays

**OBC-** On Board Computer

**THE EPS OF A 1U SATELITTE.**

A 1U satellite specifically refers to a single unit of a CubeSat standard. It is basically a cube with dimensions of 10 x 10 x 10 cm (1 unit in size) and normally weighs from around 1- 1.33 kg.

The designing of an EPS requires in depth understanding of the satellite’s power requirements, the environment it shall operate in and the constraints imposed by the limited space and weight.

The main components of the EPS include:

1. Power generation
2. Energy Storage
3. Power distribution and Management
4. Thermal Considerations.
5. Monitoring of the EPS
6. **POWER GENERATION**

this involves making of power sufficient for use by the satellite subsystems. Calculations are often done to understand and quantify the power demand by each of the subsystems. This is done in terms of the average power consumed, the foreseen peak power, power demand during normal operations, power demand during specific tasks and an allowable safety margin for unforeseen events. These parameters guide the designer on the type of generation scheme to employ and how to size it.

The most common and efficient method is the use of solar energy. This can either be **body mounted solar panels** or **deployable solar panels**. The latter is less commonly used due to the limited space in a 1u satellite. It however, provides increased surface area as compared to the body mounted solar panels. Body mounted solar panels are more common and are fixed to the satellite’s exterior surfaces. Due to their limited area, they provide less power output.

Commonly used and recommended solar panel cells are the **Multi-junction (triple junction) Gallium Arsenide (GaAs) solar cells.** This is because:

* They are proven to have be efficient (approximately 26%- 32%) and suitable for compact designs.
* They work well even when exposed to radiation.
* They can handle temperature swings pretty well.
* Are light in nature.

They can however be proven to be more costly than other options. Below is a list of the other options:

1. **Silicon (Si) solar cells**- these have been used before and the technology of their use is well understood. They however have less efficiency and poorer radiation tolerance exposing them to faster degradation.
2. **Copper Indium Gallium Selenide (CIGS) thin film solar cells-** these are lightweight and flexible with moderate efficiency of up to 20%. Their long-term durability is however questionable.
3. **Perovskite Solar Cells -** this is a newer technology that stands unproven. It has a high theoretical efficiency potential but is sensitive to moisture and temperatures and hence degrades faster.
4. **Amorphous Silicon (a-Si)**- this is a low cost option that is radiation tolerant but offers a very low efficiency of about 6-10%.

It is also important to ensure that the solar arrays can maintain optimal orientation towards the sun for maximized energy collection at all times when the sun is available. This can be done by the use of Maximum Power Point Tracking Controllers (MPPT).

1. **ENERGY STORAGE**

This is an essential part of the EPS. It allows the satellite to be fully powered and functional even when not actively generating power. This essential in satellites that use solar power as they will not always be exposed to the sun (during eclipse periods). It also comes in handy in storage of any excess power generated at a given time (when not all power generated in directly consumed) making the systems more efficient and enhancing redundancy.

Excess energy generated can be stored in batteries. Commonly used batteries are the **Lithium-ion (Li-ion)** or the **Lithium-polymer (LiPo)**.

Lithium based batteries are commonly preferred because:

* Lithium offers compact, efficient and reliable energy storage in harsh environments.
* Lithium has a high electrochemical potential. They can therefore store more energy per unit mass and volume therefore boosting its energy density.
* It has a low self-discharge rate
* Offers a long-life cycle.
* Is light; has a low atomic weight.
* Lithium can operate well in a wide range of temperatures which are essential in satellite applications.
* Lithium has the confidence of space heritage.

Lithium ion cells are however preferred over Lithium polymer cells for a number of reasons, the main one being its durability and thermal performance. Below lays a list of the various advantages and disadvantages of using the Lithium ion over the Lithium polymer.

*Advantages*

1. Lithium ion has a higher energy density.
2. Lithium ion has the confidence of proven space heritage.
3. Lithium ion has better thermal stability and hence is less prone to swelling or thermal runaway under vacuum and temperature extremes.
4. Lithium ion has a longer life cycle.

*Disadvantages*

1. Lithium ion is slightly heavier and larger than some configurations of the Lithium polymer.
2. Lithium ion has less form factor, i.e. is less flexible to altercations in its shape. This would have been useful to allow it to fit in small spaces.
3. Lithium ion has a lower discharge rate as compared to Lithium polymer.

Most commonly used cells are 3.7 V Li-ion cells connected in series (to meet power demand and increase capacity) and parallel (to offer redundancy).

Other batteries that have been used before include:

1. **Nickel-Cadmium batteries-** have lower energy density but operate well in low temperatures.
2. **Supercapacitors-** provide high bursts of power during peak demand periods. Can be used in combination with batteries in case of momentary power spikes to avoid drawing lots of energy from the batteries at a given instant.

The life of the chosen battery should be proven to be able to survive the expected mission duration.

An important consideration in the making of the EPS is the battery charging mechanism that optimizes solar panel output and protects against overcharging. These circuits regulate the voltage and current sent to the battery to avoid reduction in battery life.

**BMS** systems are therefore employed to monitor and protect the battery through monitoring of charge and discharge cycles, temperature and SoC. **Current and voltage sensors** are also employed for monitoring purposes and interfacing with the telemetry subsystem.

1. **POWER DISTRIBUTION AND MANAGEMENT**

This is a very crucial part of the EPS that routes power from the solar panels and/ or battery to the various satellite subsystems through the PDU. This design involves understanding the power requirements of each subsystem at a given time instant and balancing them out for optimization of power distribution. Each subsystem's voltage, current, and duty cycle need to be defined in the power budget.

*Functions.*

* **Voltage Regulation -** It should have logic that allows it to manage voltage levels. Given that various components operate at different voltage levels, this subsystem must have DC-DC converters that transform the voltage level to the desired one for the particular application. Buck and Boost converters could be used in this case. Linear converters can be employed where noise and ripple minimization are crucial, though they are less efficient.
* **Power switching -** handle power failures and prioritize power allocation to critical systems. This includes turning off certain non-essential systems during low-power periods.
* **Current monitoring** - To monitor the current consumption of different subsystems and ensure the EPS operates within safe limits.
* **Power conditioning -** to filter out noise and harmonics and provide clean power to sensitive electronics.

**Interface Boards (Power Bus)** and **Power Connectors** provide physical connections between the EPS and subsystems. The boards distribute the required power to the various subsystems while the power connectors ensure efficient transmission of this same power. In designing of the Power Bus, the following considerations should be made:

* **Current Capacity**: The bus should be designed to handle the maximum current draw from all subsystems. Ensure that the traces or wires can handle the required current with adequate safety margins.
* **Voltage Drop**: Minimize voltage drop across the bus, especially for long traces. High current draw can result in significant voltage losses.
* **Routing**: Keep the bus layout simple and as short as possible to reduce losses and interference.
* **Redundancy**: In some designs, redundancy in the power bus ensures that if one path fails (e.g., a short circuit or disconnect), power can still be delivered through a backup path.

**Solid State Relays (SSR)** and **MOSFETs** can be employed as electronic switches to control power flow. This can be made possible by the use of logic signals from the OBC to control the flow of power as required, especially when limited.

1. **THERMAL CONSIDERATIONS**

The solar panels, batteries and even other components inevitably produce heat. Thermal management systems are essential in this case. Due to the limited size of the 1u satellite, passive thermal control systems are necessary to maintain battery and component temperatures within safe operating limits. Such methods include thermal coatings and heat pipes.

It is also important to note that during eclipse periods, as the satellite is not exposed to the sun as much, rapid cooling will be experienced. The cooling mechanisms should therefore be sensitive to such changes to avoid exposing the satellite to extreme temperatures past its range.

1. **MONITORING OF THE EPS**

It is important to constantly monitor the state of the EPS especially in terms of the battery’s charge level, temperature and health. This is to prevent it from over discharging or overheating. This means that sensors have to be integrated to provide real time telemetry data for monitoring.

1. **OTHER CONSIDERATIONS.**

* ***Redundancy***

To minimize the risk of a failure causing the whole system to shut down, there should be redundant sources of power like backup power converters, backup solar arrays and backup batteries as the space allows.

Mechanisms could also be employed to power down non-critical systems during low sunlight or eclipse modes.

* ***Protection***

Systems should be put in place to effectively detect faults in real time and prevent cascading failure in the face of power faults like over voltages, over currents and short circuits.

Such entail inclusion of (resettable) fuses and circuit breakers.

* ***Radiation effects***

Space radiation can degrade the performance of solar panels and batteries, which needs to be accounted for in the EPS design.

1. **IMPORTANT CALCULATIONS.**

* ***Power Generation***
* ***Available /Incident Solar Power***

To estimate the power available from the solar panels, we need to know the solar irradiance at the satellite’s orbit and the efficiency of the solar panels.

Where:

* ***Panel Area Calculation***

To find the required area of solar panels to meet the power requirements:

Where:

* ***Solar Panel Orientation and Exposure Time***

To calculate the average solar power depending on the exposure time to the sun.

Where:

Sunlight fraction depends on the orbit and orientation. It normally ranges from 0.2 to 1 in high exposure orbits.

* ***Energy Storage Calculations. - for battery sizing.***
* ***Required battery capacity***

The battery capacity should be able to supply the satellite during the eclipse periods.

Where:

* ***SoC calculations***

This is essential to ensure the battery forever operates in its safe operating conditions and does not discharge.

Where:

* ***Battery Voltage and Size***

To find the total number of battery cells is a matter of consideration of the capacity of a cell vs the number of cells that can be housed in the structure. This is a matter of optimization.

Where:

* ***Power Consumption Calculations***

This involves calculations of the power consumption of all satellite subsystems. Care should be taken to incorporate all sensors and peripherals power needs to avoid shortage during operations.

Where:

The total power drawn from the battery should also account for the losses due to factors such as converter efficiency and heat loss. This means that the total power drawn from the battery or solar cells should be slightly higher than the one calculated above if all the subsystems should receive adequate power.

* ***Battery Capacity***

Where­­­­­­:

* ***Charging time***

Where­­­­­­:

* ***Discharging time***

Where­­­­­­: