THAPAR UNIVERSITY STUDENT SATELLITE

General Analysis Report Of Power System

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1. INTRODUCTION

Electrical power system is basically concerned with collecting power from the sun and distributing this power to various subsystems on the satellite.
Typically, one-third of the total weight of the satellite is taken by the power subsystem, with batteries weighing one-third of the power system.

1.1 Objectives of Power system

- **Power generation**

  There are 3 main sources of power:

  1.Solar Power from direct sunlight.
  2.Power from Earth's Albedo.
  3.Power from thermal radiations emitted from the earth.

- **Power storage**

  Power storage is necessary in a satellite and serves as a backup power source that supplies power during the eclipse period.

- **Power conditioning**

  Voltage regulator and converters are used as power conditioning module that convert the raw battery or solar panel voltage into a regulated voltage for the loads.

- **Power distribution**

  The primary aim of the power system is to provide power to other subsystems of satellite as per their power requirements.

- **Power protection**

  The power supply circuit and its components have to be protected against various faults and malfunctions.

2. POWER GENERATION

2.1 Incident solar radiation

The main source of power on the satellite are the solar radiations. They are converted into electrical energy through solar cells. Several cells together form a solar panel.

2.1.1 Solar constant

The solar constant is the amount of incoming solar electromagnetic radiation per unit area incident on a plane perpendicular to the rays. When solar irradiance is measured on the outer surface of Earth's atmosphere, the measurements can be adjusted using the inverse square law.

Since altitude of the TUSSAT is not yet finalized we shall take solar constant as 1353W/m2 (calculated at 670km from the earth surface) for all our calculations.

2.1.2 Solar power calculation

Two methods are considered:

- Using vector analysis.
- Using numerical method algorithm based on simple formulas and probability.
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We will use the vector form method since it is more accurate.

Approach Used-

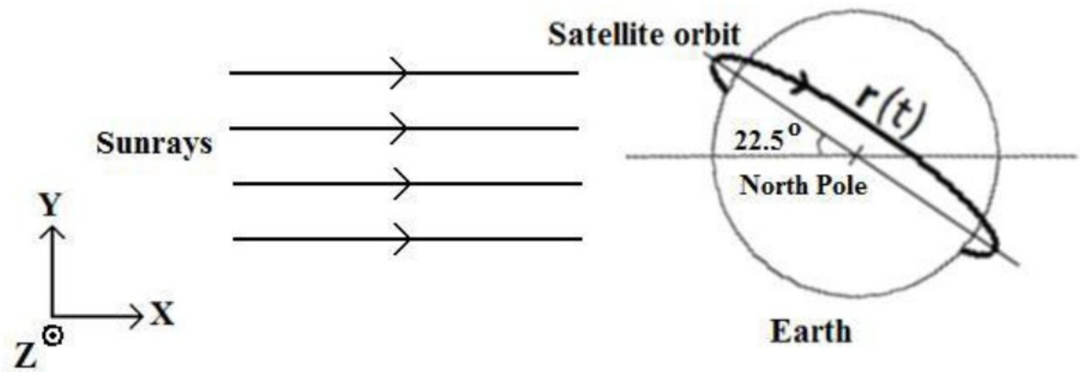
1) Find Solar Constant at the respective altitude
2) Find the average solar energy incident on each face of the TUSSAT.
3) To include the effect of eclipse in the calculations.
4) To simulate to find the average energy on each face.
5) Solar cell selection.
6) Configuration of solar panels on each face.
7) Calculation of useful power generated by the solar cells.
8) The Power Budget & Calculation of losses

The average intensity on each face for a set of different altitudes and inclination has been calculated through a simple program made in C since simulation could not be done at present. The error found in the calculation was quite tolerable. The results of C program have been attached for reference.

Explanation of the method used for solar power calculation (reference IITB satellite):

The following assumptions were made since final TUSSAT parameters are not yet finalized

- 10.30 am sun-synchronous orbit
- Thus time period of orbit=5916sec
- And angular speed=0.00106rad/sec
- The satellite will start its orbit from the point just above the North Pole.
-



In the above diagram, Earth is taken as the origin for the coordinate system. The position of the satellite as a function of time, starting with the point just above the North Pole is

$$\therefore \vec{r}(t) = R\begin{bmatrix} \cos\lambda & \sin\lambda & 0 \\ -\sin\lambda & \cos\lambda & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} \sin(\omega t) \\ \cos(\omega t)\sin 8° \\ \cos(\omega t)\cos 8° \end{bmatrix} = R\begin{bmatrix} \cos\lambda\sin(\omega t) + \sin\lambda\cos(\omega t)\sin 8° \\ -\sin\lambda\sin(\omega t) + \cos\lambda\cos(\omega t)\sin 8° \\ \cos(\omega t)\cos 8° \end{bmatrix}$$

Hence, the velocity of the satellite is

$$\therefore \vec{v}(t) = R\omega\begin{bmatrix} \cos\lambda\cos(\omega t) - \sin\lambda\sin(\omega t)\sin 8° \\ -\sin\lambda\cos(\omega t) - \cos\lambda\sin(\omega t)\sin 8° \\ -\sin(\omega t)\cos 8° \end{bmatrix}$$

Thus, the normals to the three faces A, B and C are found to be

$$\hat{n}_1(t) = \begin{bmatrix} \cos\lambda \sin(\omega t) + \sin\lambda \cos(\omega t) \sin 8° \\ -\sin\lambda \sin(\omega t) + \cos\lambda \cos(\omega t) \sin 8° \\ \cos(\omega t) \cos 8° \end{bmatrix}$$

$$\hat{n}_2(t) = \begin{bmatrix} \cos\lambda \cos(\omega t) - \sin\lambda \sin(\omega t) \sin 8° \\ -\sin\lambda \cos(\omega t) - \cos\lambda \sin(\omega t) \sin 8° \\ -\sin(\omega t) \cos 8° \end{bmatrix}$$

$$\hat{n}_3(t) = \hat{n}_1(t) \times \hat{n}_2(t)$$

From this, the angle of incidence of sunlight on the faces A, B and C are found. If the angles are denoted as α, β and γ respectively, then

$$\cos\alpha = -\hat{i} \cdot \hat{n}_1(t) = -\cos\lambda \sin(\omega t) - \sin\lambda \cos(\omega t) \sin 8°$$
$$\cos\beta = -\hat{i} \cdot \hat{n}_2(t) = -\cos\lambda \cos(\omega t) + \sin\lambda \sin(\omega t) \sin 8°$$
$$\cos\gamma = -\hat{i} \cdot \hat{n}_3(t) = -\sin\lambda \cos 8°$$

The intensity of light incident on face A is

$$I_A = S\cos\alpha \text{ when } \cos\alpha > 0 \text{ and } 0 \text{ otherwise}$$

Similarly, for the other faces,

$$I_{A'} = S\cos\alpha \text{ when } \cos\alpha < 0 \text{ and } 0 \text{ otherwise}$$

$$I_B = S\cos\beta \text{ when } \cos\beta > 0 \text{ and } 0 \text{ otherwise}$$
$$I_{B'} = S\cos\beta \text{ when } \cos\beta < 0 \text{ and } 0 \text{ otherwise}$$

$$I_C = S\cos\gamma \text{ when } \cos\gamma > 0 \text{ and } 0 \text{ otherwise}$$

$$I_{C'} = S\cos\gamma \text{ when } \cos\gamma < 0 \text{ and } 0 \text{ otherwise}$$

The averages of I_A, $I_{A'}$, I_B, $I_{B'}$, I_C and $I_{C'}$ over one orbit have to be calculated taking the eclipse region into account.

2.2 Earth's Albedo

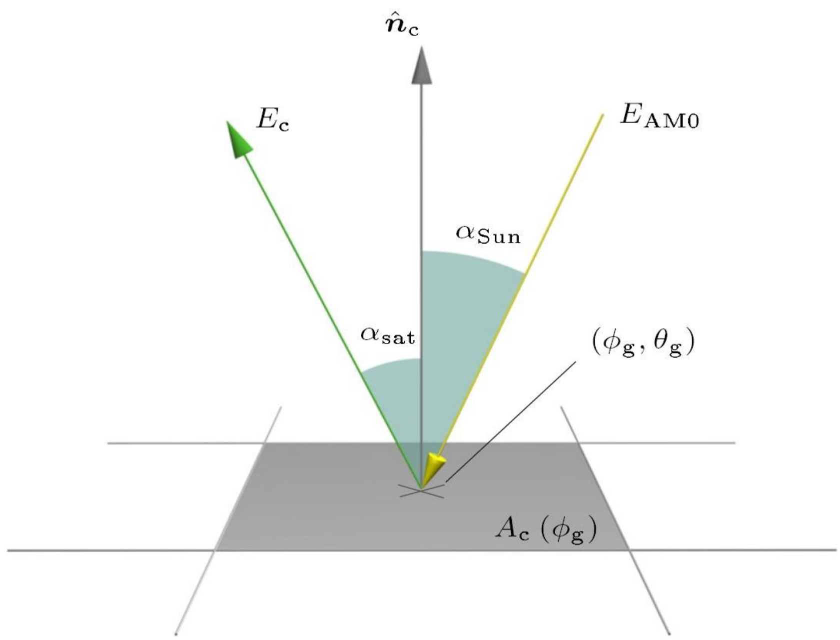
Earth albedo is the sunlight reflected off the Earth's surface.It is therefore a more specific form of the term reflectivity. It can be defined as the ratio of diffusely reflected to incident electromagnetic radiation. The Earth albedo induces power in solar cells just like direct sunlight. An extremely reflective surface has an albedo of

1(bright) while the surface that reflects none of the light that hits it has an albedo of 0(dark).

Earth's overall average albedo is about 0.31. It includes the albedo due to earth surface and albedo due to clouds. Without clouds our planet's albedo would be around 0.15, so clouds roughly double the Earth's albedo. Albedo is typically treated as noise to the attitude determination system (ADS) which can be filtered out statistically in kalman algorithms but to power system it is a source of power.

Earth albedo model

The model is used to calculate the amount of earth albedo arriving at an object in space. In this model the earth is partitioned into a number of cells and the earth albedo contribution from each cell is calculated. Three input parameters in the ECEF frame is required : sun position vector, satellite position vector and and earth surface reflectivity. The reflectivity data is obtained from the TOMS (total ozone mass spectrometer) project . The resolution of the TOMS data is 180 x 288 data points. That is 51,840 cells of 1 deg latitude and 1.25 deg longitude.



Reflection from a single data point.

The incoming irradiance is equal to the solar AM0 irradiance, multiplied by a cosine term dependent on the incident angle Sun, which is the angle between the cell normal ˆ***n***c and the Sun LOS vector ˆ***r***Sun.

The incident radiant flux is given by:

$$\boxed{P_c(\phi_g, \theta_g) = E_{AM0} A_c(\phi_g) \left\{ \hat{\boldsymbol{r}}_{Sun}^{T} \hat{\boldsymbol{n}}_c \right\}}$$

The reflected radiant flux:

$$\boxed{P_{\mathrm{r}}\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)=\rho\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right) P_{\mathrm{c}}\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)}$$

where $\boxed{\rho\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)}$ is the mean reflectivity at grid point $\boxed{\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)}$

The amount of Earth albedo from a single cell, seen from the satellite, depends on the distance to the satellite and the angle between the cell normal and the satellite LOS vector from the grid point, ˆ***r***sat.

The irradiance from the cell is given by:

$$\boxed{E_{\mathrm{r}}\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)=\frac{P_{\mathrm{r}}\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)}{\pi}.}$$

Now from the Inverse Square Law the intensity of the irradiance decreases with the square of the distance from the grid point to the satellite, given by:

Finally the irradiance at the satellite depends on the visible area of the cell surface seen from the satellite.

The visible area is related to $\boxed{\alpha_{\mathrm{sat}}}$ by the cosine function

$$\boxed{E_{\mathrm{c}}\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)=\frac{P_{\mathrm{r}}\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)\left\{\hat{\boldsymbol{r}}_{\mathrm{sat}}^{\mathrm{T}} \hat{\boldsymbol{n}}_{\mathrm{c}}\right\}}{\pi\left|\left|\hat{\boldsymbol{r}}_{\mathrm{sat}}\right|\right|^{2}}}$$

The full Earth albedo model is expressed as:

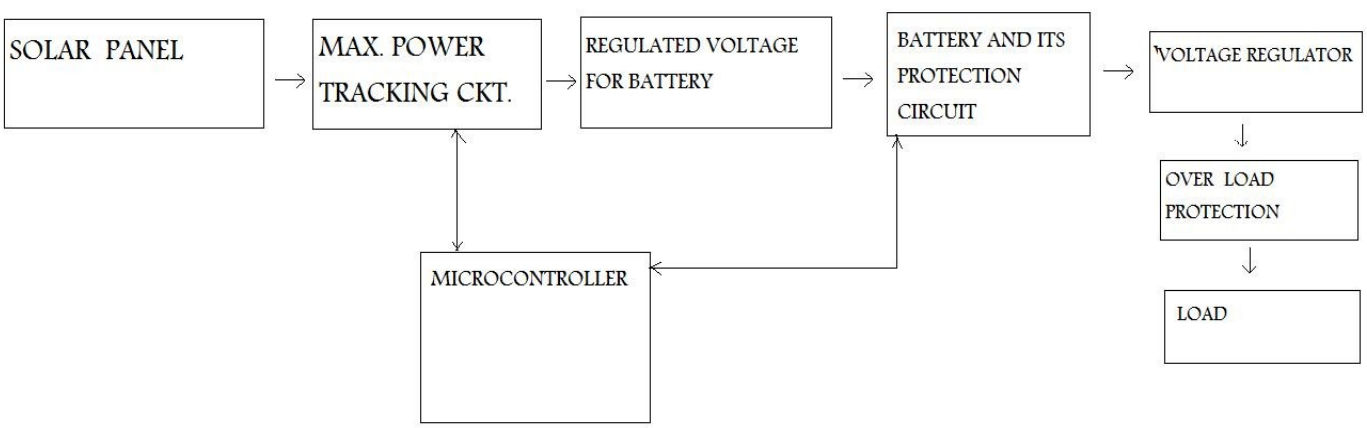
$$\boxed{E_{\mathrm{c}}\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)=\begin{cases}\frac{\rho\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right) E_{\mathrm{AM0}} A_{\mathrm{c}}\left(\phi_{\mathrm{g}}\right) \hat{\boldsymbol{r}}_{\mathrm{Sun}}^{\mathrm{T}} \hat{\boldsymbol{n}}_{\mathrm{c}} \hat{\boldsymbol{r}}_{\mathrm{sat}}^{\mathrm{T}} \hat{\boldsymbol{n}}_{\mathrm{c}}}{\pi\left|\left|\hat{\boldsymbol{r}}_{\mathrm{sat}}\right|\right|^{2}} & \text{if } \left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right) \in \boldsymbol{V}_{\mathrm{Sun}} \cap \boldsymbol{V}_{\mathrm{sat}} \\ 0 & \text{else}\end{cases}}$$

The sets ***V*** Sun ***D*** and ***V*** sat ***D*** are the grid points visible from the Sun and satellite, respectively, i.e. ***V*** Sun ***V*** sat is the set of sunlit grid points visible from the satellite, which are necessary conditions for a cell to reflect solar irradiance to the satellite.
The irradiance on the solar panel decreases when the angle between the solar panel normal and the incident irradiance vector increases.

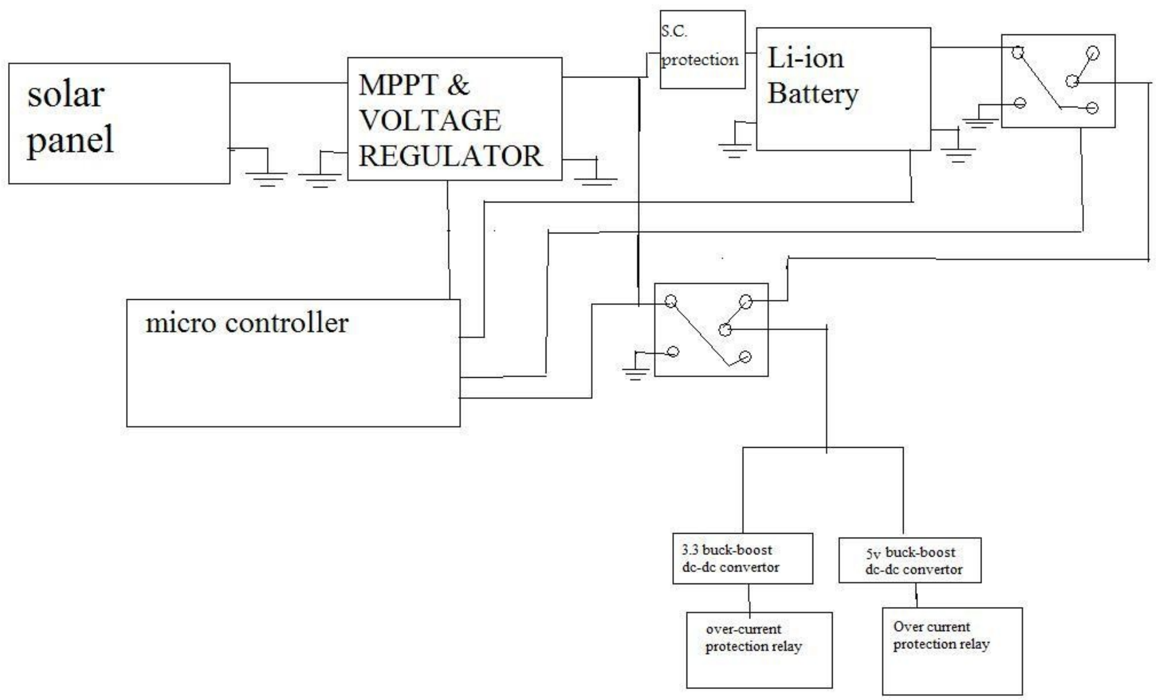
The total albedo irradiance *E*a at the satellite position may be calculated as the sum of irradiances from all cells:

$$\boxed{E_{\mathrm{a}} = \sum_{\boldsymbol{V}_{\mathrm{Sun}} \cap \boldsymbol{V}_{\mathrm{sat}}} E_{\mathrm{c}}\left(\phi_{\mathrm{g}}, \theta_{\mathrm{g}}\right)}$$

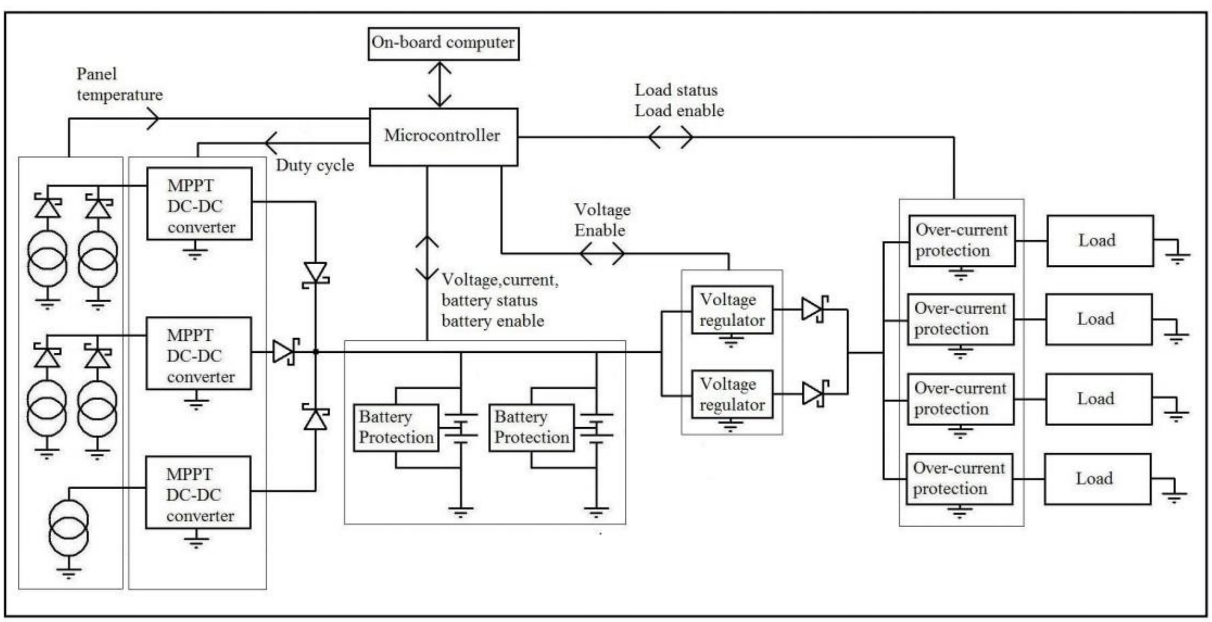
1. BASIC LAYOUT OF POWER SYSTEM



3.1 Our first proposed circuit: This was the first basic circuit developed by us. Later on the relays were replaced by protection IC's.

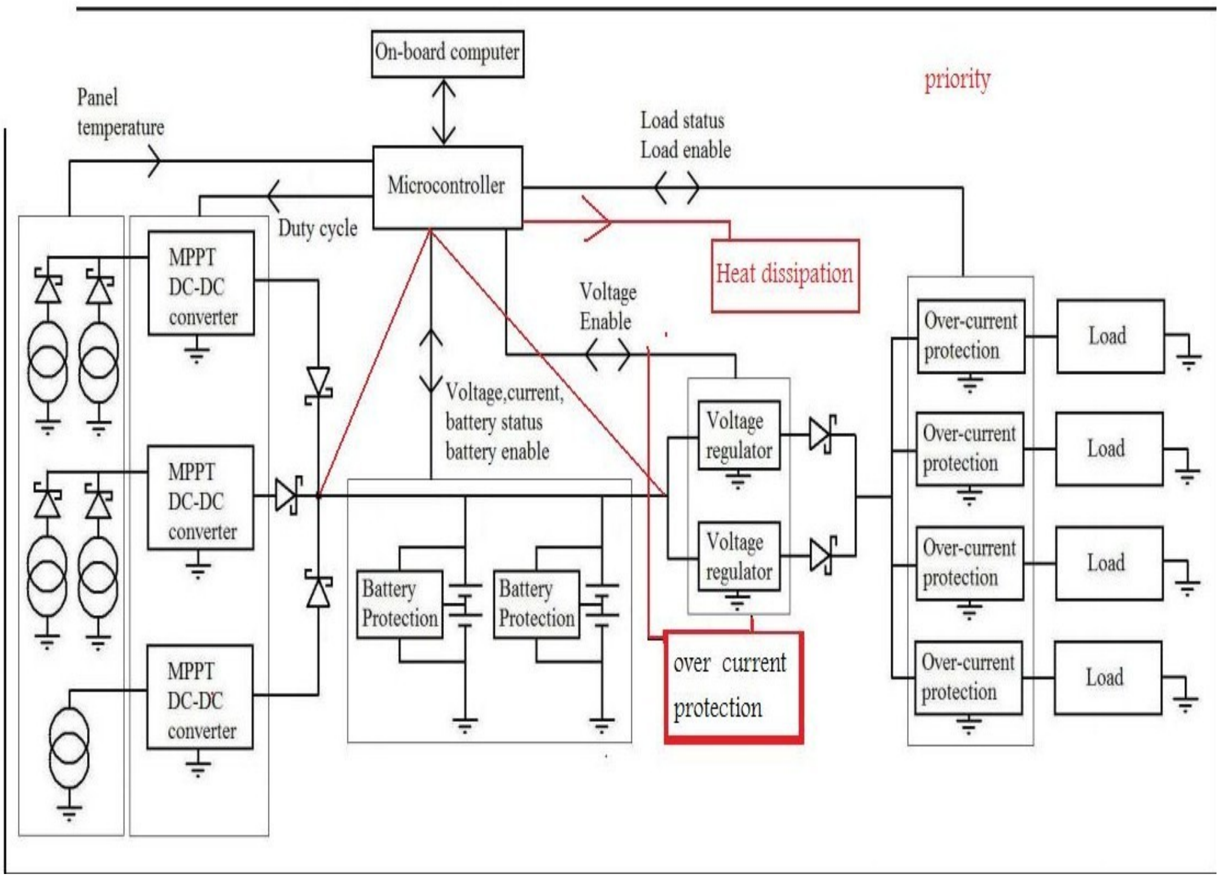


3.2 IIT Mumbai satellite's power circuit (taken as reference)



IIT MUMBAI POWER CIRCUIT

3.3 Our final proposed circuit



The following modifications were made in the IIT Mumbai power circuit

- Heat dissipation system to dissipate the energy generated by solar cells if the battery is completely charged.
- Over current protection for voltage regulators.
- Switching to solar light in case direct power is available.

4. COMPONENTS

4.1 Solar Cells

Solar cells are the semiconductor photovoltaic cells that convert the elctromagnetic energy from solar radiations to electrical energy.
Advanced AM0 tripple junction Gallium Arsenide cells (rectangular)
have been
chosen for TUSSAT power system.

4.2 Batteries

Rechargeable batteries are used in power system that are charged during the period when solar radiation is falling on the satellite and then supply power to the satellite during the period of eclipse.

Eclipse period is the period when satellites orbiting the Earth pass through a shadow region on the opposite side of Earth from the Sun. Depending on the type of orbit, this can happen just a few times a year or every few hours. During these so-called ‘eclipses’, the solar panels cannot produce electrical energy and hence batteries are used.

Selection of batteries will be done on the basis of:

- Weight
- Efficiency
- Life-time
- Ratings

Three types of batteries are considered:

- Ni-Cd (nickel-cadmium)
- Ni-Hydride (nickel-hydride)
- Li-ion (lithium ion)

Of these Li-ion batteries have been chosen for TUSSAT.

Comparison of the three batteries and their impact on the system is as follows:

	NiCd	NiH2	Li-Ion	System Impact
Energy Density (Wh/kg)	30	60	125	Weight Saving
Energy Efficiency %	72	70	96	Reduction of charge Power : solar panel
Thermal Power (Scale : 1-10)	8	10	3	Reduction of radiator, heat pipes sizes
Self Discharge %/month	10	80	1	No trickkle and simple management at Launch pad
Temperature Range °C	0 to 40	-15 to 20	10 to 35	Management at ambient
Memory Effect	Yes	Yes	No	No reconditionning
Energy Gauge/Monitor	No	Pressure	Voltage	Better observability of State Of Charge
Charge Management	CC	CC	CC CV+ Balancing	Balancing system needed
Modularity	No	No	Yes	One Cell Design, Ability to put cells in parallel

4.3 Diodes

Diodes are used to prevent the flow of current from batteries to solar panels in case of over-charging. Schottkey diodes have been chosen in place of general P-N diodes because of the following:

- Reverse recovery time of p-n diode is of the order of hundreds of nano second while for schottkey diode it is of the order of less than 100 pico second.
- Voltage drop in p-n diode is 0.3/0.7 V while for schottkey diode it is 0.15/0.45 V.

4.4 Current Distribution Switches

The primary aim of power system is to provide power to other subsystems of satellite as per their power requirements.

Hence the power has to be distributed to various loads on the satellite. This can be achieved through various current distribution switches.
MOSFET switches of very low internal resistance will be used for power distribution.

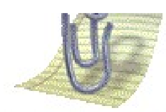
4.5 Battery Protection

Two battery protection IC's have been shortlisted:

1) S-8232 from Seikos Instruments:- It is a lithium ion/ lithium-polymer rechargeable battery protection IC incorporating high accuracy voltage detection circuit and delay circuit.

2) UCC3911-1 FROM Texas Instruments:- It is a two-cell lithium ion battery pack protector device that incorporates an on-chip series FET switch thus reducing manufacturing costs and increasing reliability. The device's primary function is to protect both lithium ion cells in a two cell battery pack from being either overcharged (over voltage) or over-discharged (under voltage).

Features of S 8232 are as follows:



- Internal high-accuracy voltage detection circuit
  Overcharge detection voltage: 3.90V ± 25mV to 4.60V ± 25mV, 5mV-step
  Overcharge release voltage: 3.60V ± 50mV to 4.60V ± 50mV, 5mV-step
  (The Overcharge release voltage can be selected within the range where a difference from Overcharge detection voltage is 0 to 0.3V)
  Overdischarge detection voltage: 1.70V ± 80mV to 2.60V ± 80mV, 50mV-step
  Overdischarge release voltage: 1.70 ± 100mV to 3.80V ± 100mV, 50mV-step
  (The Overdischarge release voltage can be selected within the range where a difference from Overdischarge detection voltage is 0 to 1.2V)
  Overcurrent detection voltage 1: 0.07V ± 20mV to 0.30V ± 20mV, 5mV-step
- High input-voltage device (absolute maximum rating: 18V)
- Wide operating voltage range: 2.0V to 16V
- The delay time for every detection can be set via an external capacitor.
  Each delay time for Overcharge detection, Overdischarge detection, Overcurrent detection are "Proportion of hundred to ten to one".
- Two overcurrent detection levels (protection for short-circuiting)
- Internal auxiliary over voltage detection circuit (Fail safe for over voltage)
- Internal charge circuit for 0V battery (Unavailable is option)
- Low current consumption
  Operation: 7.5 µA typ. 14.2 µA max (-40 to +85°C)
  Power-down mode: 0.2 nA typ. 0.1 µA max (-40 to +85°C)
- Package: 8-pinTSSOP
- Lead-free products

Features of UCC3911-1 are as follows:

- Protects Sensitive Lithium-Ion Cells from Overcharging and Over-Discharging
- Used for Two-Cell Lithium-Ion Battery Packs
- No External FETs Required
- Provides Protection Against Battery Pack Output Short Circuit
- Extremely Low Power Drain on Batteries of About 20µA
- Low Internal FET Switch Voltage Drop
- User Controllable Delay for Tripping Short Circuit Current Protector
- 3A Current Capacity

4.6 Voltage Regulation

2 voltage regulator IC's have been shortlisted but the final selection will be made after the specifications are known-

PTR 08060W FEATURES (VOLTAGE REGULATOR IC)

- Wide Input Voltage Range (4.5 V to 14 V)
- Wide-Output Voltage Adjust (0.6 V to 5.5 V)
- Efficiencies Up To 96%
- ON/OFF Inhibit
- Undervoltage Lockout (UVLO)
- Output Overcurrent Protection (Nonlatching, Auto-Reset)
- Overtemperature Protection
- Ambient Temp. Range: -40°C to 85°C
- Space Saving Vertical SIP Package
- APPLICATIONS
  - Instrumentation
  - Consumer Electronics
  - Servers
  - General-Purpose Circuits

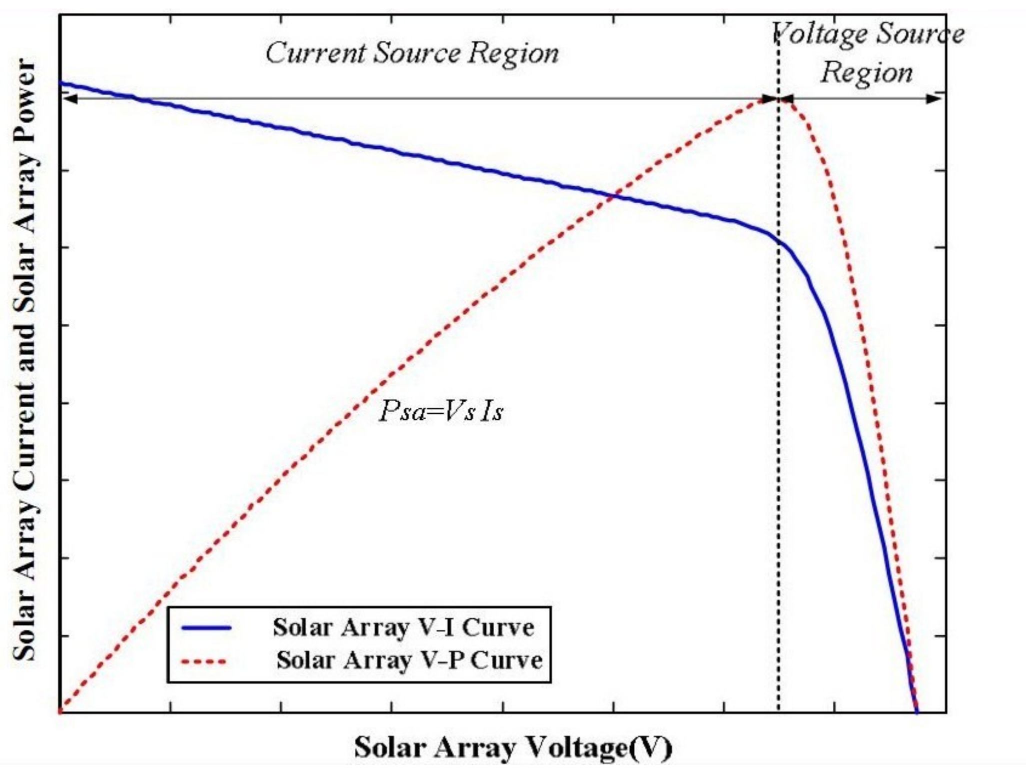
FEATURES OF TPS 77001.

. 50-ma low-dropout regulator.
. Available in 1.2v, 1.5v, 1.8v,2.5v,2.7v,2.8v,3v,3.3v and 5v Fixed output and adjustable version.
. Only 17 micro ampere quiescent current at 50 ma.
. 1 micro ammpere quiscent current at 50 ma.
. Dropout voltage typically 35 mv at 50 ma.
. Over current limitation.

5. Maximum Power Point Tracking (MPPT)

The MPPT is a high efficiency DC to DC converter whose main purpose is to move the array operating voltage close to the MPP under changing atmospheric conditions.
The MPPT system is most useful when the panels are cold or the battery is discharged. In this way the system is capable to track autonomously the solar array maximum power operative condition, adapting to changing illumination and temperature events during the orbital phases.

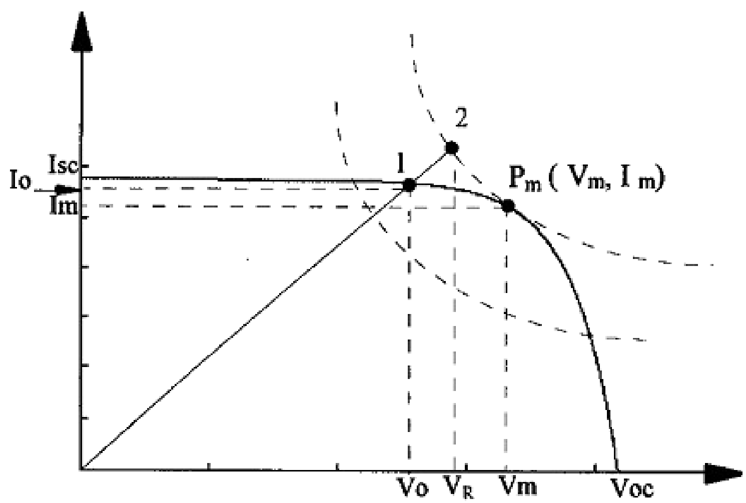
The solar array has an inherent nonlinear characteristic, as shown:



The graph shows the maximum power point (MPP) of the solar array.

Maximum power transfer theorem:

If the solar energy system provides power to a load, the system often operates away from the maximum power point of the solar array. The following figure shows the I-V characteristics of the solar array and the load, together with constant power curves (P = VI = const). It is seen that the delivered output power, which is represented by the operating point 1. is significantly smaller than the maximum output power which is represented by point 2. in order to ensure a maximum power transfer, DC/DC converters are used to adjust the voltage at the load to the value of $V_R = \sqrt{P_m \cdot R}$ where r is the equivalent resistance of the load.



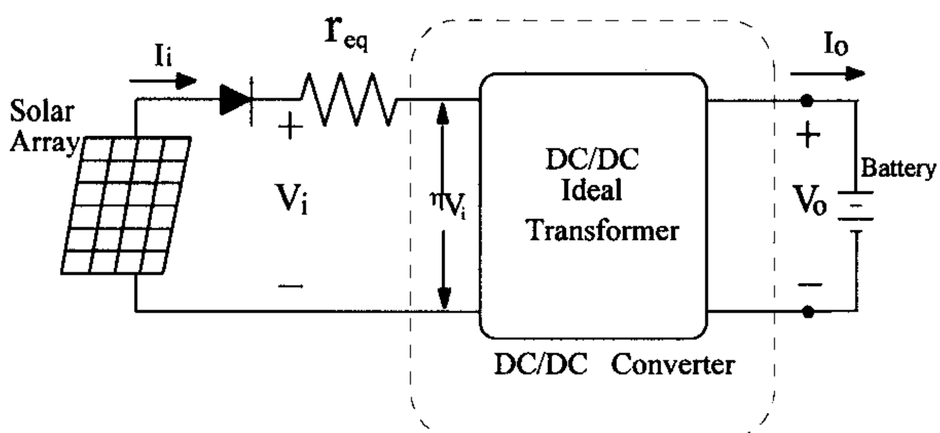


Fig. 6 Equivalent circuit model for dc/dc converter.

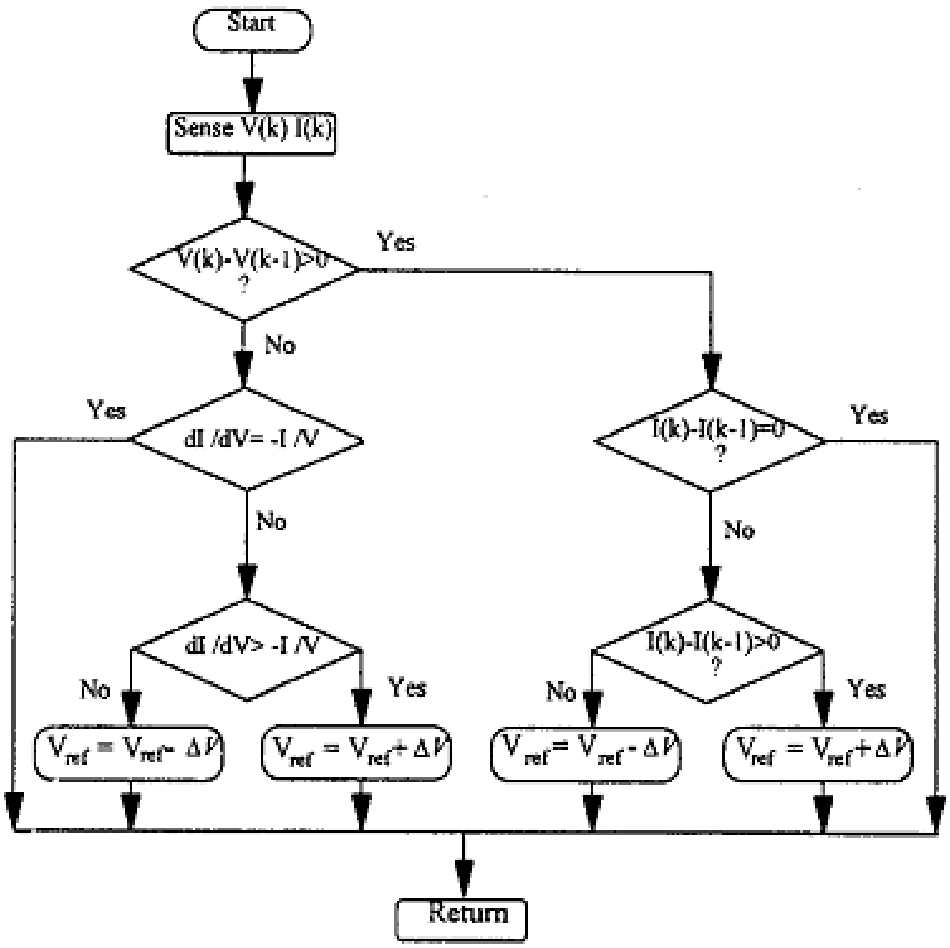
MPPT control algorithm:

Two control algorithms have been studied to achieve MPPT:

1) The incremental conductance method (IncCond).
2) Perturbation and observation method (P&O).

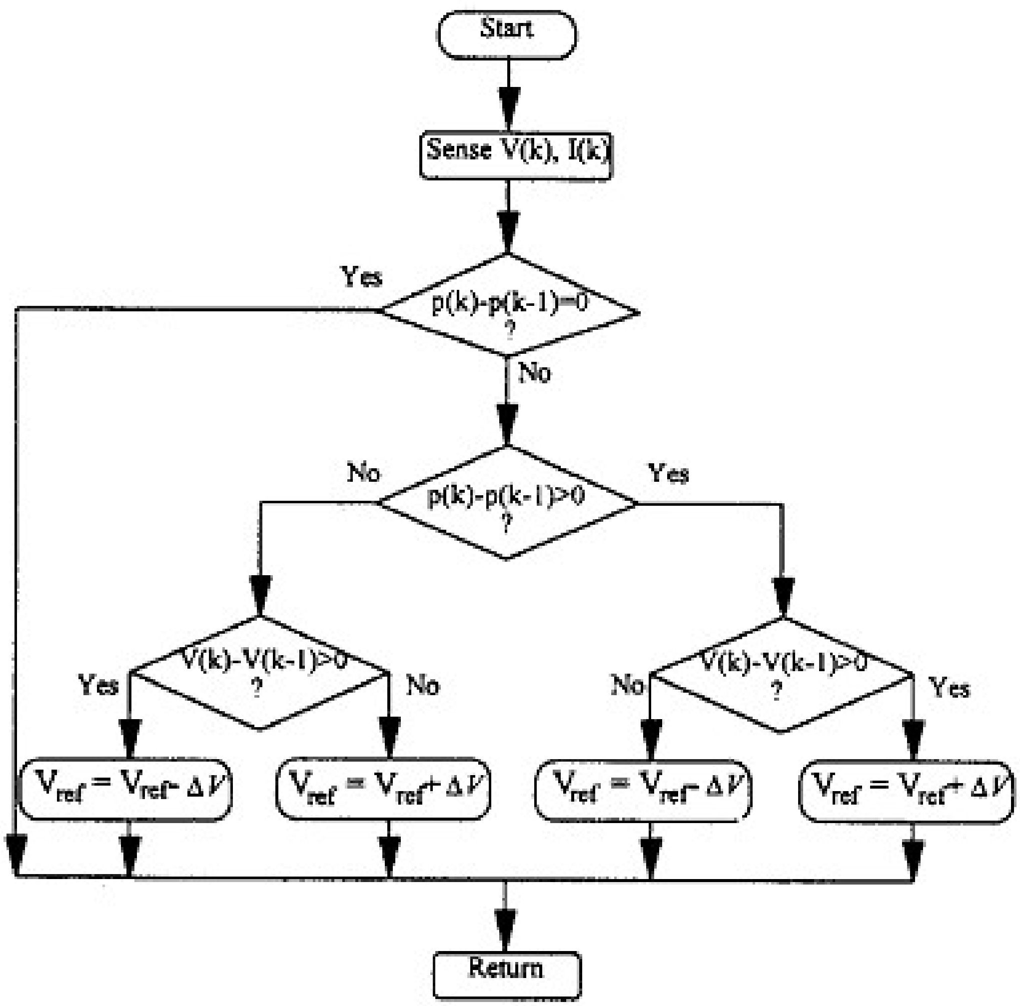
Of these the second method has been chosen for the system.

1) IncCond method:



In this method, the solar array terminal voltage can be adjusted relative to the MPP voltage by measuring the incremental and instantaneous array conductance (dI/dV and I/V, respectively). Although this method offers good performance under rapidly changing atmospheric conditions, four sensors are required to perform the computations. The drawback is that sensor devices require more conversion time thus result in a large amount of power loss.

2) P & O method:



The P & O method has been widely used because of its simple feedback structure and fewer measured parameters. The peak power tracker operates by periodically incrementing or decrementing the solar array voltage. If the given perturbation leads to an increase(decrease) in array power, the subsequent perturbation is made in the same(opposite) direction. In this manner , the peak power tracker continuously hunts or seek the peak power conditions.

SUMMARY-

- Direct solar power on the faces of the satellite have been calculated for various combinations. Exact value will be found out using the same method when the final parameters of the TUSSAT is decided.
- Method to calculate usable solar power generated by the cells has been studied. Exact values will be found when MPPT simulation is done and parameters of the solar cell are given.
- Methodology of albedo calculation has been studied.
- The main circuitry of the TUSSAT Power Supply system has been made.
- The IC needed for battery protection has been shortlisted to 2 products. Final selection can only be made when the power budget is available.
- Following components have been studied but the manufacturers could not be decided since the specification were unavailable on the basis of the power budget.
- 1.Mosfet switches.
- 2.Schottky diode.
- 3.Buck Boost Converter.
- 4.Overload protection IC.
- Both the algorithms for MPPT realization has been studied. P&O(Perturbation and Observation) has been chosen to function in the TUSSAT

FUTURE WORK-

- Power available from Thermal Radiations.
- Simulations required for Space Ionization Dose (Radiation effects on the power system).
- More study and research in Microcontrollers.
- Manufacturers to be finalized for the following components-
- 1.Mosfet switches.
- 2.Schottky diode.
- 3.Buck Boost Converter.
- 4.Overload protection IC.
- **Components to be studied-**
- 1.Power bus.
-
- **M.P.P.T**
- Circuit design to be finalized.
- Sensors to be finalized.
- To co-ordiante the system with MICRO-CONTROLLER

- SIMULATIONS-
- 1.To calculate the incident solar power on the faces of TUSSAT.
- 2.To calculate the usable power available from the solar panel.
- 3.To calculate Albedo.
- 4.To analyse the working of the circuit.
- 5.To calculate the losses in the system.
- 6.To analyse various MPPT circuits.

REQUIREMENTS-

- 1.Shadow Analysis
- 2.Power Budget
- 3.Orbit Calculations

The table for the results of solar power calculation has been attached for reference.