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Modeling and Simulation of Solar Power Calculations for GOES-13 & SS-1 Satellite

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***Abstract*—** The proposed work to calculate the orbital velocity, orbital period and efficiency for different power conditions of GOES 13 and SS 1 satellites. The Satellite Power System (SPS) is a possibility for delivering critical amounts of base-load power utilizing sunlight-based vitality as the source such as photovoltaic (PV) cell. In order to ensure that the persistent tasks of the satellite are kept up; it is basic to plan and create its capacity frameworks to meet different prerequisites of the satellites that are available in the earth orbits known as Earth orbit satellites. The satellites, which spin at an elevation over 35,000km, collectively known as Geo-synchronous satellites, which are available in the Geo-synchronous orbits. To control these sort of satellites a special asset of intensity framework is required.

***Keywords*—** Current parameters, PV module, Photovoltaic cell, Power system, Solar efficiency, Time period

I. INTRODUCTION

The geosynchronous orbit resembles the geostationary orbit. LEO: Low Earth Orbit, generally circular at 200 to 2000-km from sea level. HEO: Highly Elliptical Orbit. A GEO satellite heading from west to east at altitude of nearly 35780km with a apparent hover time of 24h and remains unchanged with respect. A satellite comprises of different frameworks intended to meet the strategic necessities [1]. Everything except the easiest satellites require a typical arrangement of frameworks appeared by the strong lines in fig. The frameworks are ordered into two gatherings, the subsystems and the transport. The subsystem comprises of the interchanges gear in business satellites in investigate satellites.

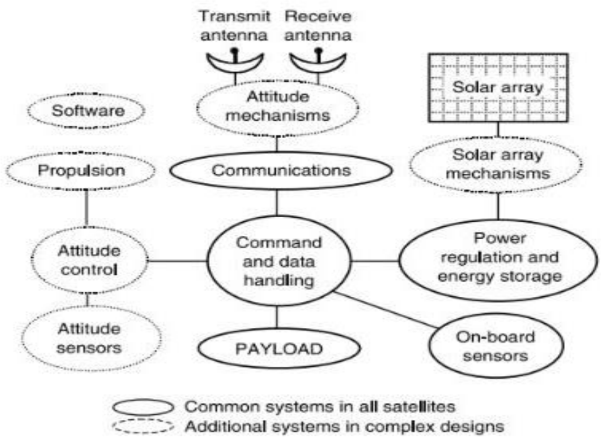

Figure 1. Components of satellite

The transport comprises of all outstanding gear assembled into a few useful frameworks that help the payload [2]. The power framework is one of the transport frameworks that comprise of the sunlight based cluster, battery, control gadgets, conveyance outfit, and controls.

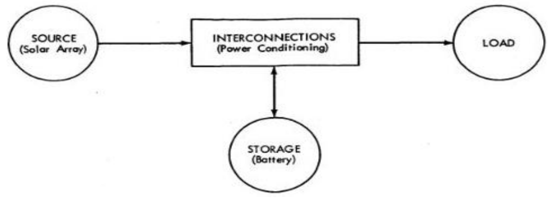

Figure 2. Power system of satellite

The systems must worked as so as to achieve an energy balance and to run the battery for longer duration the energy coming out from the battery [3].

II. RELATED WORK

On many studies on the topic of interest "Designing of the Power system for Earth Orbiting satellite" several parameters are achieved from many sources and research papers. As the power system design for different satellites orbiting in different orbits around the Earth is not same, a lot of research is necessary to obtain the various important parameters on which the power system design depends.

Article [1] titled "Solar Energy". In this article, the energy band diagram for a p-n junction solar cell is illustrated. Band diagram for PV cells are outlined. Plot of efficiency and band gap energy for single junction solar cells are depicted.

Article [2] titled "Solar Energy *Utilization*". In this article, the different classification of the Earth orbits for satellite manoeuvre is explained. The advantages and usages of these individual orbits are explained.

Article [3] titled "Spacecraft Power Systems" published by Mukund R. Patel. In this article, the basic design for the satellite system is defined. The various components associated with the satellite design are illustrated. The values for the solar flux and eccentricity for the calculation of efficiency of the solar arrays is also interpreted in this article.

Article [5] titled "Solar Power Systems for satellites in Near-Earth Orbit" published by C. M. Mackenzie. In this article, basic power system configuration for the Earth orbiting satellite is illustrated. The article also describes the designing parameters for the solar array which consists of some solar panels on which some amount of solar cells are mounted for absorption of solar energy. Power control and distribution is also an important part of the description of this article.

Article [6] titled "Power system challenges for small satellite missions" published by Craig S. Clark, Alejandro Lopez Mazarias. In this article, solar array characteristics are illustrated along with the common power system design approaches.

Article [7] titled "Solar power satellite and microwave transmission from space to Earth for generating Electrical power" published by Professor V Parameswaram, Mateen Khan M Pathan. In this article the transmission of the microwave with the help of rectenna and then further conversion to electrical power are described.

III. METHODOLOGY

Geostationary Operational Environmental Satellite (GOES)-13 and Surya Satellite(SS-1) in which GOES-13 is launched at geostationary orbit at an altitude of 35786km, radius of orbit is 42164.14km (r_e+h) and mass is 1670kg, Power=2300watts and SS-1 is expected to orbit at low earth (LEO) with the altitude 400km and inclination at 51.6º respectively. In this environment the orbit duration is around 90 minutes with the 1/3 is in eclipse and 2/3 of it is in daylight [4].

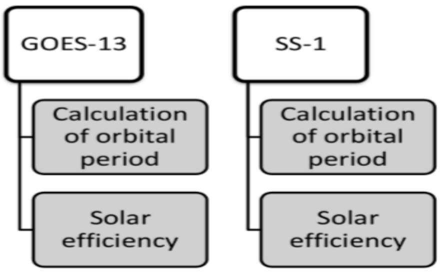

Figure 3. Design methodology

Mission goals of GOES-13 satellite are:

- To increase the life time of the satellite and reliable operation
- Continuously track the surface of the earth in terrain awareness system
- Ocean data observation to monitor the wave & tide dynamics

IV. MODELING AND SIMULATION CALCULATIONS

We have taken Geostationary Operational Environment-al. Satellite (GOES)-13 and Surya Satellite(SS-1) in which GOES-13 is launched at geostationary orbit at an altitude of 35786km, radius of orbit is 42164.14km (r_e+h) and mass is 1670kg, Power = 2300watts and SS-1 is expected to orbit at low earth (LEO) with the altitude 400km and inclination at 51.6º respectively. In this environment the orbit duration is around 90 minutes with the 1/3 is in eclipse and 2/3 of it is in daylight [8].

Now we determine the orbital velocity and time period of the satellites:

Orbital Velocity-

$$V = \sqrt{\frac{GMe}{r}} \quad (1)$$

where M_e is the mass of earth and G is gravitational constant = $6.67 \times 10^{-11} m^3/kg/s^{-2}$

Orbital Period-

$$T = 2\pi\sqrt{\frac{r3}{GMe}} \quad (2)$$

where r is the radius of geostationary orbit. By using the above equations we can calculate the orbital time period of the satellite through which we can obtain the time period for radiation stage and eclipse stage. The period's ratio during which the satellite is under the sun is shown as:

$$\frac{tsunlight}{T} = \frac{\left[\pi + 2\arccos\left(\frac{Re}{r}\right)\right]}{2\pi} \quad (3)$$

The time period for eclipse stage can be calculated by: T-$t_{sunlight}$ = $t_{eclipse}$

Radiation Stage –

The maximum power radiated comes from photovoltaic cell (solar cells).

Solar efficiency –

$$\eta = \frac{P}{E*A} \quad (4)$$

where P = maximum power radiated (in watts) E = solar flux(in watt/m^2), A= capture area

FOE GEO – Mass of earth=5.972×1024kg, Radius of earth= 6378.14km, Radius of orbit= 42164.14km, altitude of satellite= 35786km from eqn (1)

Orbital velocity $V = \sqrt{\frac{GMe}{r}}$ = 3072.34m/s

Orbital period $T = 2\pi\sqrt{\frac{r3}{GMe}}$ = 1436.42minutes

$t_{sunlight}$ = 1367.318minutes, $t_{eclipse}$ = 69.102minutes

Solar efficiency– The maximum power radiated from solar cell is 460watts for geo-satellites.

To acquire the electrical energy, we need the solar cell and dimension of cells is 7680 2cm by 2cm solar cells divided equally among the 4 paddles, or 960 cells on each paddle face. So the capture area is $1.536m^2$.

The solar flux constant is 1358 w/m^2, there are some tolerance ± 5 percent., but the mean value of 1358 – 5= 1353W/m² is used. Hence by putting these values in the solar equation, we get 11.067% solar efficiency. By varying the maximum power condition the efficiency also changes. Hence by putting different power conditions we get different efficiencies. If Pmax= 42W then efficiency= 0.00913 and if Pmax=520watts then efficiency= 0.03003. By these values we will plot a graph of Pmax versus Efficiency for GEO satellite and analyse the result [9].

FOR LEO – Mass of earth= 5.972×1024kg, Radius of earth= 6378.14km, Radius of orbit= 6771km, altitude of satellite= 400km

Orbital velocity $V = \sqrt{\frac{GMe}{r}}$ = 7668.734m/s

Orbital period $T = 2\pi\sqrt{\frac{r3}{GMe}}$ = 1436.42minutes

$t_{sunlight}$ = 60minutes, $t_{eclipse}$ = 30minutes

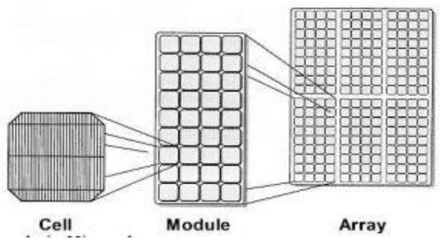

Figure 4. Photovoltaic Hierarchy

Design of photovoltaic cell:

It contain the semi contactors and resistance (series & shunt) and power source as current source, I_{ph}.

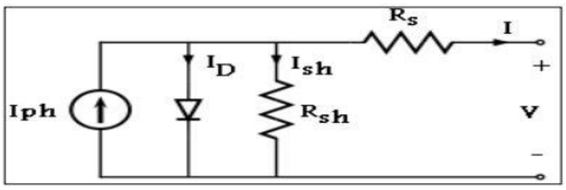

Figure 5. PV cell equivalent circuit

Solar efficiency – The maximum power radiated from solar cell is 2.310watts for Surya satellite. The energy harvesting subsystem collects energy from 12 solar cells. Cells are placed pair wise on all of the 6 sides of the satellite. The layout of the satellite is like that X= 2x(4cmx8cm), Y= 2x(4cmx6cm), Z= 2x(4cmx8cm). So, the capture area is 0.2112m². The value solar irradiance in solar equation is 1366W/m². Hence by putting these values in solar equation, we get 0.80% solar efficiency. By varying the maximum power condition the efficiency also changes [10]. Hence by putting different power conditions we get different efficiencies. If Pmax= 1.750watts then efficiency= 0.006061 and if Pmax=2.844watts then efficiency= 0.009857. By these values we will plot a graph of Pmax versus Efficiency for LEO satellite and analyse the result.

Table 1. Design parameters

Abbreviation	Parameter
v	Output voltage
R_{sh}	Shunt Resistance
I_{sh}	Shunt Resistance
R_s	Series Resistance
I_D	Diode current
I_{ph}	Current source

Photo voltaic Cell – The voltage generates by the Solar cell voltage between 0.5 volts to 0.8 volts it is based on solid state derives. For simulation, neglect the low voltage. It consist of nearly 36 to 72 cells. Arranged to give a shape of PV module. The design parameters shown in table 1.These modules can be connected in arranged and additionally corresponding to give a shape of PV board. The various parameters that PV cell relies on incorporate natural just as physical factors, for example, sun based radiation, surrounding temperature, arrangement resistor, shunt resistor, diode immersion current and so on. By differing these parameters, we can discover the conduct of PV cell in a satellite.

V. SIMULATION RESULTS AND DISCUSSION

The PV module is obtained from the Subsystems as shown above. By combining all the subsystems and putting the values of constant in callback, the I-V and P-V characteristics are shown in fig 6 with the help of graph.

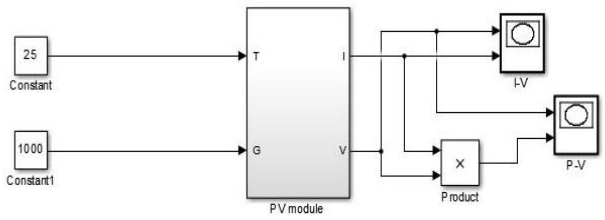

Figure 5. PV module

From the calculation of efficiency, the graphs plotted are:
The graph represents the different values of P_{max} which efficiency is calculated. When P_{max} = 460 watts, Efficiency is maximum 11.07%.

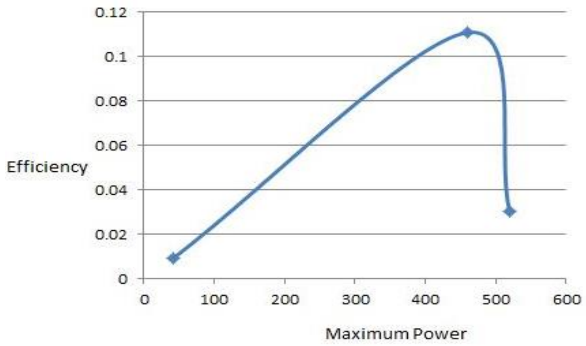

Figure 6. P_{max} versus efficiency

For GOES-13 satellite
X-axis: Maximum Power; Y-axis: Efficiency

For SS-1 Satellite (LEO Satellite): For SS-1 Satellite, P_{max} varies linearly with efficiency. Hence for maximum value of P_{max} 2.844watts, efficiency is maximum 0.90%.

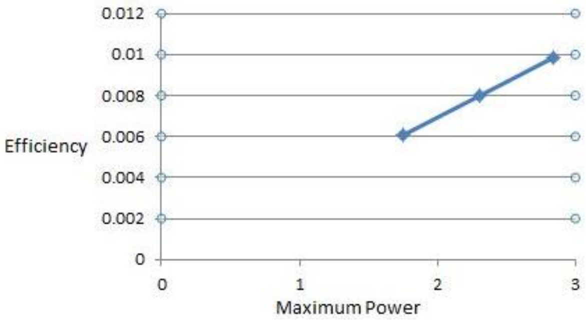

Figure 7. P_{max} versus efficiency

From the Simulink models we have generated I-V and P-V characteristics:

I-V characteristics:

X-axis: Current; Y-axis: Voltage

An OC – voltage and current charactertics, OC-Open circuit. For value of approx. 34A, the voltage is 8.2V.

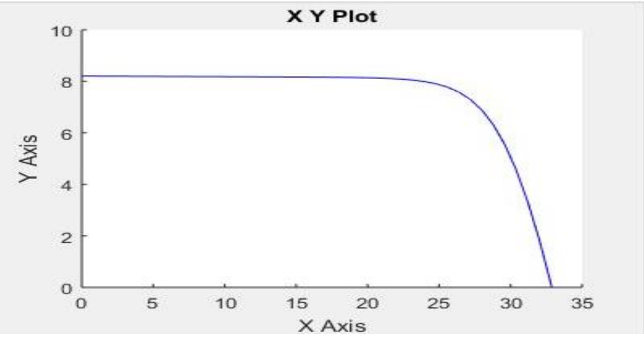

Fig. 8. Current versus voltage

P-V characteristics:

X-axis: Power; Y-axis: Voltage

P-V characteristics shows the maximum power point with respect to voltage for particular environmental conditions. The P-V graph shows linear change in power with respect to voltage up to MPP (maximum power point). The maximum power point value is 200watts for a voltage of 32 volts.

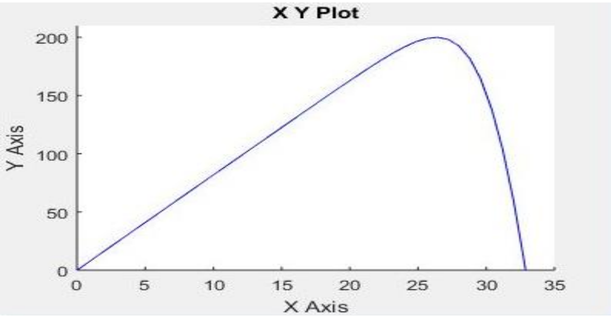

Fig. 9. Power versus voltage

VI. CONCLUSION AND FUTURE SCOPE

The graph of LEO Satellite varies linearly which means if maximum power increases then efficiency increases.

The graph of GEO Satellite varies parabolically which means it gives maximum power condition, which is 460watts, and for this maximum power, efficiency is maximum, which is 11.07%.

An I-V characteristic represents constant current in the range of open circuit voltage. For the given environmental condition, P-V characteristics shows the maximum power point with respect to voltage. The P-V graph gives linear change in power with respect to voltage up to MPP value 200w for 32v.

To predict the behaviour of PV cell we require a Matlab/SIMULINK model under different physical and environmental conditions. The maximum power point value is 200watts for a voltage of 32 volts.

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