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Sizing of Lithium-ionCapacitor/Solar Array Hybrid Power Supplyto Electrify Micro-Satellites

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ABSTRACT

The electrical power subsystem is the heart of a satellite; it providesa permanent power source to all subsystems in the satellite.The power sources are either primary source or secondary source, primary power source is the main source that supplies power to satellite subsystems in sunlight period, and secondary power source is a back-up source that supplies the load during eclipse periods.This paper focuses on using multi-junction solar array as primary power source and the lithium ion capacitor as secondary power source. Size of solar array and lithium ion capacitor for micro-satellites power systemare presented. A case study and its simulation using Matlab/Simulink are analyzed. The results show that lithium-ion capacitor can be used as an energy storage alone or without need of chemical battery beside.

Keywords -*Solar array,lithium-ioncapacitors, lithium-ion batteries, sun angle, Sizing*

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Abbreviation:

SA	Solar Array
LIC	lithium-ion capacitor
LIB	lithium-ionbattery
LEO	Low Earth Orbit
EDLC	Electric Double Layer Capacitor
$\overline{P}_{consumed}$	daily average power consumed
$\overline{P}_{generated}$	daily average power generated
BCS	Body Coordinate System
OCS	Local Orbital Coordinate System
RAAN	Right Ascension of Ascending Node
LAN	Longitude of Ascending Node angle
ESR	Equivalent series resistance

Nomenclature:

P(t)	Generated power at any instant is given
S_0	Irradiance coefficient
η_T	Overall efficiency of power subsystem
A	SA area
$\overline{n}$	SA normal vector
$\overline{S}$	Sun vector direction
α	Sun angle; between $\overline{n}$ and $\overline{S}$
η_{SA}	SA efficiency of conversion
η_{PSS}	Power subsystem efficiency
K_{FF}	SA fill factor
K_{temp}	Temperature coefficient
K_{Deg}	Degradation coefficient
θ	Elevation angle; between the Z-axis and $\overline{n}$
Φ	Azimuth angle; between the X-axis and $\overline{n}$
ν	nu angle; between ($\overline{S}$), and the normal to the orbital plane (Y-axis)
β	Satellite in-orbit position angle; between $\overline{S}$ and the noon line.
i	Inclination angle; between the orbital plane and the equatorial plane
i(t)	i at any instant
i_0	Initial i at moment of launching
i'	Rate of change i
Ω	LAN angle; between X-axis, and the line of intersection between the orbital plane and the equatorial plane
Ω(t)	The LAN angle at any instant
Ω_0	Initial LAN at moment of launching

Ω'	Rate of change of LAN
Ψ	Longitude angle of the sun (RAAN); between X-axis, and the line of intersection between the ecliptic plane and the equatorial plane
$\Psi(t)$	The RAAN angle at any instant
Ψ_0	Initial RAAN at moment of launching
Ψ'	Rate of change of RAAN
ε	Inclination of the ecliptic plane to the equatorial plane (23.4523o)
$H(t)$	The attitude of the orbit at any instant
H_0	Initial altitude at moment of launching
H'	Rate of change of altitude
δ	Roll angle; rotation of the satellite around the X-axis
ϵ	Pitch angle; the rotation of the satellite around the Y-axis
μ	Yaw angle; the rotation of the satellite around the Z-axis
dv	Change in voltage from the Vmax to Vmin
V_{max}	Maximum working voltage
V_{min}	Minimum working voltage
I	Current withdraw by capacitor
dt	The discharge time corresponding to drawn current
C_{Total}	Total capacitance of the system
R_{Total}	Total resistance
V	Voltage drop caused by the ESR
C_{Cell}	Cell capacity
R_{Cell}	ESR of cell
P	Total numbers of parallel cells
S	Total numbers of series cells.

I. INTRODUCTION

A satellite consists of two main parts. The first one is called payload and the second is platform [1]. Payload is the satellite main purpose, andplatform contains communication, telemetry, on-board computer, electrical power and storage system and attitude and orbit control.Micro-Satellites have shown great capability in recent years in the field of remote sensing, such as earth imaging, disaster monitoring, military application, and deep space exploration. The small satellites have the abilityof re-visiting times for remote sensing missions and providing larger instantaneous coverage areas. The main problem in using the micro-satellite is the power generated not big enough to supply any device with high power for short duration like thrusters. In Low Earth Orbit (LEO)spacecraft where secondary source are typically cycled with a 100-min cycle periods consisting of a 65-min charge and a 35-min discharge [2].

Solar Array (SA) is the most widely and common source of electrical power in space. SA convert sunlight into electricity for Earth orbiting satellites. Power requirements in tens of watts to several kilowatts, and a life time from a few months to 15 years can be met with a SA. The output power of SA depends on temperature, space environment, irradiance, dirt, shadow, and so on. It produces energy according to its operational conditions, location, and environmental conditions [1].

Recently, the multi-junction solar array is used because it has higher efficiency and performance than silicon cell. It generates higher power compared to silicon cell, and has smaller temperature coefficient so it can also be used in interplanetary missions.[3,4].

Chemical batteries is the most realistic choice for energy storage device, because its performance is well-known, trusted, and used in many and many space missions. Now, the Lithium ion Batteries (LIBs) is the common secondary power source in satellites as its cell voltage is about 3.6 vwhich is much higher than NiCd and NiH_2 by three times, have a good temperature range,have a long cycle life, do not suffer from memory effect and have high specific energy above 130 Wh/Kg.[5]The disadvantage of using the LIB are it is strong dependent on the temperature and its performance deteriorated at low temperature so it have a negative impact on the thermal system. also is in order to keep the batteries functioning for the entire mission duration which contain more than 30,000 charging-discharge cycles, the Depth of Discharge (DoD) must be worked at low value about 30% as number of cycles of battery is inversely proportional with the DoD, so the power subsystem will use more number of cells to compensate the decrease in DoD. So this problem should be solved.

Today, super-capacitors(SCs) have become a good alternative to chemical batteries as rechargeable energy storage medium. Unlike batteries, super-capacitors provide very huge numbers of cycles (can reach to 1,000,000 cycles). In addition, the high specific power nature of super-capacitors will enable increase the payload and other subsystems power on board such as actuators and thrusters. Some additional benefits are also wide operating temperature range, and can easily measure the state of charge.

Super-Capacitors or ultra-capacitors also called electrochemical double layer capacitors are energy storage devices that store electric energy in the double layer between a high surface area electrode and an electrolyte[6]. As compared to batteries,there is no chemical reactions between the electrodes (not all SCs types) that is a purely physical phenomenon. Therefore, electrical energy storage produced in absence of any chemical reactions[7]. Due to the purely physical operation, the SC scan provide a large amount of cycling without any problem. Furthermore, the performance of SC with decreasing temperature does not deteriorate strongly as compared to the LIB [6]. SCs offer several advantages over secondary batteries, such as high power capability, and high charge-discharge efficiency, etc.[8]. However their low specific energy (range of 5 Wh/kg for cell) [9] limits their applications as secondary energy storage source. Here SCs are used to complement main energy sources, such as Solar array (SA), and batteries, when there is an instantaneous demand for relatively large power.

A lithium-ion capacitor (LIC) is hybrid capacitor that combines the features of SCs and lithium-ion batteries (LIBs), thus offering relatively large specific energy without losing the advantages of conventional SCs[10], and give higher discharge period.

Super-Capacitors are an energy storage material that have a very huge capacitance in hundreds and thousands farads, and high specific power [11].

They can be classified into three major types; Electric Double Layer Capacitor (EDLC), pseudo-capacitance and hybrid super-capacitors [12], as follows:

A. Electric Double Layer Capacitor (EDLC)

The energy is stored in the double layer formed at the electrode-electrolyte interface. Activated carbon is mainly used as the electrode material because it has low cost, and high surface area. EDLC is used in vehicles applications and it is the most common typethat has high specific power and low specific energy.

B. Pseudo-capacitor

Thiscapacitor uses oxidation-reduction reaction and stores the chargefaradaically by transferring of electron chargebetween the electrode and the electrolyte. A pseudo-capacitor has a chemical reaction at the electrode. Ituses metal oxide or conducting polymer as electrode materials. Its advantagesare having greater capacitance, and much higher specific energy than the EDLC. This technology is mainly in the research phase and is not commercially available [12].

C. Hybrid Capacitor

This capacitor has characteristicsof combination the features of LIB and EDLCs. The positive electrode has activated carbon and the negative electrode has carbon material that is doped with lithium ion. LIC is the most popular hybrid capacitors. The advantage is having much larger specific energy, the cell voltage is higher, and have large discharged time period. Sothe overall performance of LIC is better than EDLC [10].

II. SOLAR ARRAY SIZING

The sizing of SA means calculating the SA area needed that covers the power consumption.

The SA generated power at any instant is given by the following equation:

$$P(t) = S_0 \times \eta_T \times A \times \cos\alpha(t) \qquad (1)$$

$$\eta_T = \eta_{SA} \times \eta_{PSS} \times K_{FF} \times K_{\square emp} \times K_{Deg} \qquad (2)$$

Where $S_{\square}$ is irradiance coefficient, $\eta_{\square}$ is the overall efficiency, $\square$ is the SA area, $\square$ is the sun angle between the normal to SA vector ($\bar{n}$) and the direction of sun vector $(\bar{S})$, $\eta_{S\square}$ is the SA efficiency of conversion from light energy to electrical energy , $\eta_{P\square S}$ power subsystem efficiency, $K_{F\square}$ is the SA fill factor, $K_{te\square p}$ is the Temperature coefficient, and $K_{D\square g}$ is the degradation coefficient. In the design, the Power Supply Subsystem (PSS) must meet the requirement; where the daily average power generated is greater than the daily average power consumed at any moment during the lifetime $\bar{P}_{Generated} > \bar{P}_{Consumed}$ [13, 14].

Moreover, if the SA area is required for a given consumed power, we will re-arrange equation (1).

$$A = \frac{P}{S_0 \times \eta_T \times \cos(\alpha)} \qquad (3)$$

If the $S_{\square}$ P, and $\eta_{\square}$ remain unchanged, the SA area is affected only by sun angle. Therefore, the problem here is to find the value of sun angle and compute the SA sizing.

Since the dot product gives the angle between two vectors, therefore we will use it to find the sun angle value. So $\bar{n}$ and $\bar{S}$ is given by the following equation:

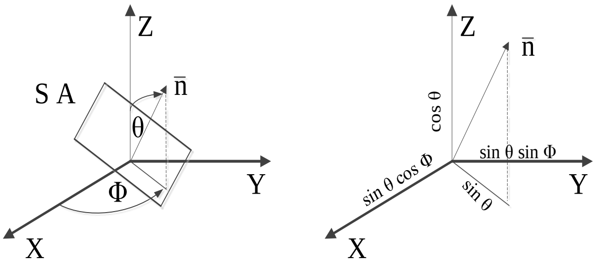
$$\bar{n}\cdot\bar{S} = |n||S|\cos(\alpha) \qquad (4)$$

Assume that the norm $|n|$ and $|S|$ are a unit vectors, and re-arrange the previous equation.

$$\cos(\alpha) = \bar{n}\cdot\bar{S} \qquad (5)$$

First, we have to calculate the values $\bar{n}$ and $\bar{S}$ then compute the sun angle.
Calculation of $\bar{n}$:
$\bar{n}$ will be calculated in Body Coordinate System (BCS) where selection of system axes is arbitrary according to the mission.
According to Fig. 1, $\bar{n}$ described in BCS:

$$\bar{n}_{BCS} = \sin(\theta)\cos(\phi)\underline{i} + \sin(\theta)\sin(\phi)\underline{j} + \cos(\theta)\underline{k} \qquad (6)$$



(a) (b)

Figure 1 (a) SA at an arbitrary position and (b) $\bar{n}$ in BCS

In matrix form

$$\bar{n}_{BCS} = \begin{bmatrix} \sin(\theta)\ \cos\llbracket(\emptyset\rrbracket) \\ \sin(\theta)\sin(\emptyset) \\ \cos(\theta) \end{bmatrix}\begin{bmatrix} \bar{i} \\ \bar{j} \\ \bar{k} \end{bmatrix} \qquad (7)$$

Where □ is the elevation angle between the Z-axis and $\bar{n}$, and $\emptyset$ is the azimuth angle between the X-axis and $\bar{n}$.
Calculation of $\bar{S}$:
$\bar{S}$ will calculate in Local Orbital Coordinate System (OCS) where selection of system axes are; the origin is located at the center of mass of the satellite, X-axis is the positive direction of orbital flight, Y-axis is the normal to orbital plane, and Z-axis is the direction from the satellite to the Earth[15]
According to Fig. (2), $\bar{S}$ described in OCS:

$$\bar{S}_{OCS} = -\sin(\nu)\sin(\beta)\bar{i} + \cos(\nu)\bar{j} + \sin(\nu)\cos(\beta)\bar{k} \qquad (8)$$

In matrix form

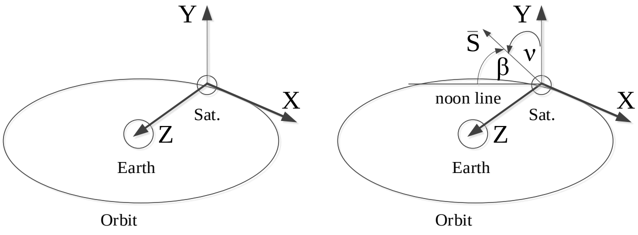
$$\bar{S}_{OCS} = \begin{bmatrix} -\sin(\nu)\sin(\beta) \\ \cos(\nu) \\ \sin(\nu)\cos(\beta) \end{bmatrix}\begin{bmatrix} \bar{i} \\ \bar{j} \\ \bar{k} \end{bmatrix} \qquad (9)$$

Where □ is angle between ($\bar{S}$), and the normal to the orbital plane (Y-axis), and □ is the satellite in-orbit position anglebetween $\bar{S}$ and the noon line.
The importance of ν is that, this angle shows us the worst-case day over the satellite lifetime. The ν angle is not to be confused with the sun angle (α), often used to define the sunlight incidence angle on the solar array, which

could be canted to catch the sun normally in case ν is not 90°. The power generation is proportional to cos (α), so when $\alpha$is 0° the power generation is maximum and 90° gives zero power.
The ν angle is given by the following equation:

$$\nu(t) = \frac{\pi}{2} \mp \sin^{-1}\begin{pmatrix} \sin i(t)\sin\Omega(t)\cos\psi(t) \\ +\sin\varepsilon\ \cos i(t)\sin\psi(t) \\ +\cos\varepsilon\ \sin i\,(t)\cos\Omega(t)\sin\psi(t) \end{pmatrix} \quad (10)$$

Where iis inclination angle of the orbital plane to the equatorial plane, Ω is longitude angle of ascending node (LAN)



(a) (b)

Figure 2 (a) OCS, (b) $\bar{S}$ in OCS

Fig.3, ψ is Longitude angle of the sun in ecliptic plane "Right Ascension of Ascending Node" (RAAN), and ε is inclination angle of the ecliptic plane to the equatorial plane Fig.4.

The inclination angle (i) at any instant, The LAN angle (Ω) at any instant, The RAAN angle (−) at any instant, the attitude of the orbit (H) at any instantare given by the following equations respectively :

$$i(t) = i_0 + i' \times t \quad (11)$$

$$\Omega(t) = \Omega_0 + \Omega' \times t \quad (12)$$

$$\psi(t) = \psi_0 + \psi' \times t \quad (13)$$

$$H(t) = H_0 + H' \times t \quad (14)$$

Where i_0 is inclination angle at moment of launching, and i' is rate of change inclination, Ω_0 is the initial LAN at moment of launching, Ω' is rate of change of LAN, ψ_0 is the initial RAAN at moment of launching, and ψ' rate change of RAAN, H_0 is the initial altitude at moment of launching, and H' is the rate of change of altitude.

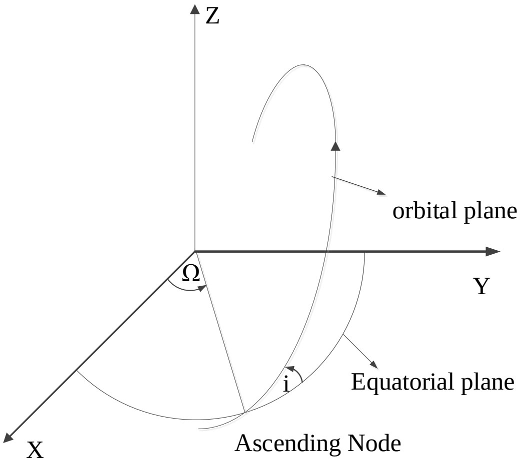


Figure 3 Orbital plane of Satellite

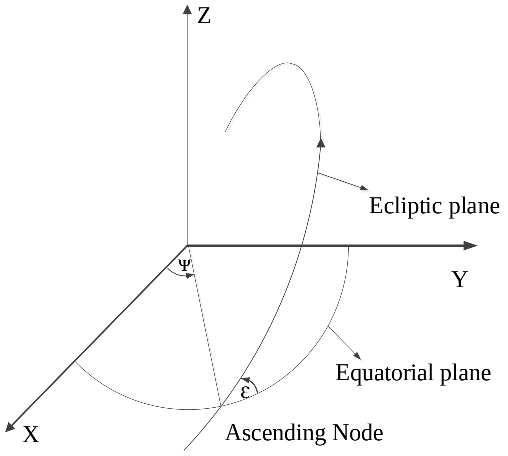


Figure 4 Ecliptic plane of sun

We will use rotation matrix to transform from BCS to OCS as $\overline{\mathrm{n}}$ is calculated in BCS and $\overline{\mathrm{S}}$ is calculated in OCS. The rotation matrices are given by the following equations:

$$R_X = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\delta) & -\sin(\delta) \\ 0 & \sin(\delta) & \cos(\delta) \end{bmatrix} \quad (15)$$

$$R_Y = \begin{bmatrix} \cos(\epsilon) & 0 & \sin(\epsilon) \\ 0 & 1 & 0 \\ -\sin(\epsilon) & 0 & \cos(\epsilon) \end{bmatrix} \quad (16)$$

$$R_Z = \begin{bmatrix} \cos(\mu) & \sin(\mu) & 0 \\ \sin(\mu) & \cos(\mu) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (17)$$

$$\bar{n}_{OCS} = R_Z R_Y R_X \bar{n}_{BCS} \quad (18)$$

Where δ is theroll angle; rotation of the satellite around the X-axis, ϵ is pitch angle; the rotation of the satellite around the Y-axis, and μ is yaw angle; the rotation of the satellite around the Z-axis. The multiplication order of matrices is important.

$\cos(\alpha)$ is called an illumination coefficient (K_{ill}), not used in the calculation directly but it need some modification e.g. if α > 90°, then cos (α) will be a negative value and since either power or area cannot be a negative values, therefore the working region of sun angle from 0° to 90° otherwise cos(α) will be zero.

III. SUPER-CAPACITOR SIZING

The SC voltage contain two components; a capacitive component represents the voltage change due to the change in energy within the SC, and a resistive component represents the voltage change due to the equivalent series resistance (ESR).
The capacitive component, the resistive component, and the SC total voltage components aregiven by the following equations respectively:

$$dv = I \times \frac{dt}{C_{Total}} \quad (19)$$

$$V = I \times R_{Total} \quad (20)$$

$$dv_{Total} = I \times \left(\frac{dt}{C_{Total}} + R_{To\square al}\right) \qquad (21)$$

Wheredv is change in voltage from the maximum voltage (V_{max}) to minimum voltage (V_{min}), I is the current, dt is the discharge time corresponding to withdraw current, C_{Total} is the total capacitance of the system, V is voltage drop caused by the internal resistance and R_{Total} is the total resistance.

The capacity of the module (C_{Total}), and the resistance of the module (R_{Total})aregiven by the following equations respectively:

$$C_{Total} = C_{Cell} \times \frac{P}{\square} \qquad (22)$$

$$R_{Total} = R_{Cell} \times \frac{S}{\square} \qquad (23)$$

Where $C_{Cell}$is cell capacity, $R_{Cell}$is the equivalent series resistance per cell, P is the number of parallel cells, and S is the number of series cells.
To determine numbers cells are required in series, divide the maximum applied voltage by the cell voltage.
To determine numbers cells are required in parallel, we will re-arrange the equation (20) to be:

$$P = I \times \frac{S}{dv\left(\frac{dt}{C_{Cell}} + R_{Cell}\right)} \qquad (24)$$

So, now we know the all parameters in sizing a bank of SC.There are different methods in sizing SC depending on using the previous equations either by using the energy in SC or by using the SC time constant or by ignoring the effect of ESR.

A. Energy in SC

This method works well for low power application where the loss due to ESR is minimal. Since the energy storage in SC is equal to ½ $C_{Total}V^2$, therefore the total capacitance is:

$$C_{\downarrow}\mathrm{Total} = 2E/((V_{\downarrow}\mathrm{max}{}^{\uparrow}2 - V_{\downarrow}\mathrm{min}{}^{\uparrow}2\ )\ ) \qquad (25)$$

Where E is energy of SC needed can be calculated from multiple the average power by working time.

B. SC time constant

We will assume SC time constant is equal 1 second or if we use the specific SC then, we will know the R_{Cell} and C_{Cell}. Since R×C=1, R=1/C, then use it in equation (20) to find C_{Total}.

C.*Ignore the ESR effect*

ESR to find the value of C_{Total} then use the equation (20) as a check for the design after choosing the proper SC cell. The total capacitance calculated by this method is

$$C_{Total} = I \times \frac{dt}{\square v} \qquad (26)$$

Note that the difference between these methods are small, the second, and third method did not take into account any losses due to ESR, we typically recommend oversizing the cell by adding a cell in series and parallel but not necessary.

IV. CASE STUDY

Now we will present the result in our case study.The case study based on using the Matlab, Mathcad, and STK software programs to simulate the behavior of power subsystem in satellite in the desired orbit. The SA is fixed around Y-axis,total numbers of panels are eight as shown in Fig.5.

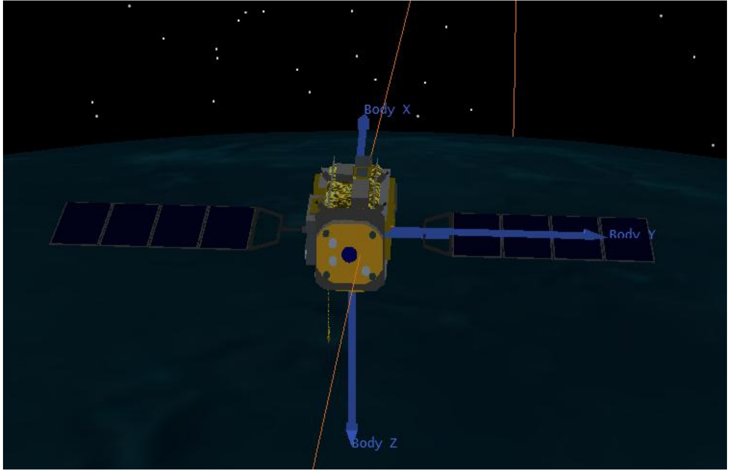


Figure 5 Satellite in the desired orbit

The results are based on some acceptable assumptions; the earth has spherical shape, the sun light is parallel and this lead to lack of penumbras, during study one orbit the sun, the earth, and the satellite assumed to be fixed during the whole revolution period, and the orbit has circular shape.

V. RESULTS

As shown in Fig. (3) the satellite has daily average power consumed ($P_{consumed}$) equal 81.58 w , and max power equal 233.8 w in duration 119.4 sec

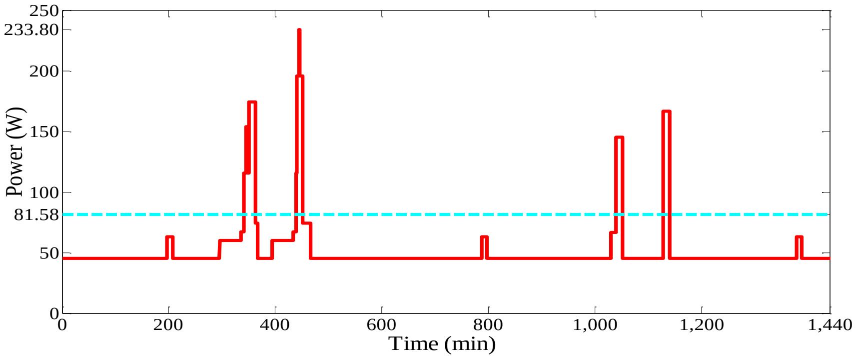


Figure 6 Load profile during a typical day

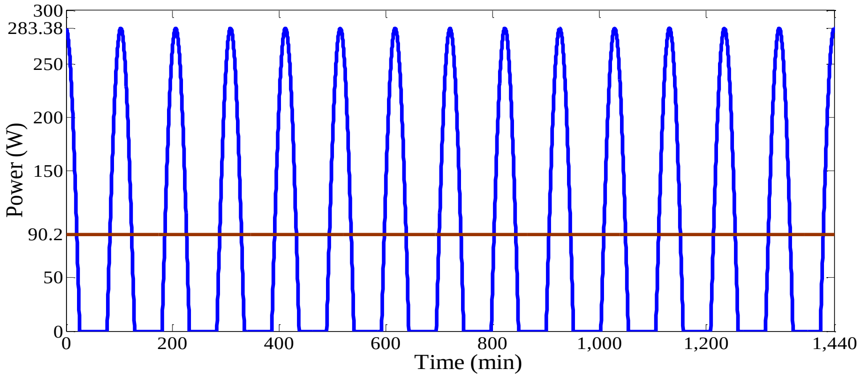


Figure 7 Generated power in typical day

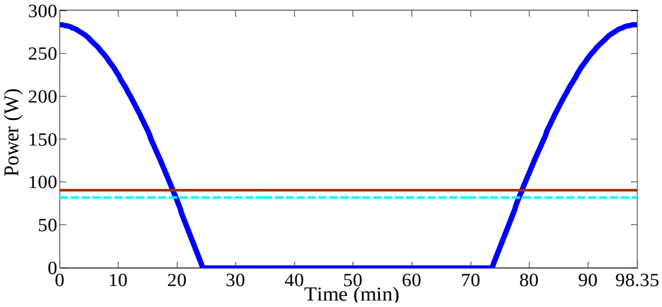


Figure 8 Generated power in one orbit

Solid line is average power generated, dotted line is average power consumed

The orbital inputs parameters shown in table (1) in appendix

A. SA sizing

The SA parameters is shown in table (2), and the SA data sheet in appendix (1).

Using equation (7) to find $\bar{n}_{B\square S}$, equations (11-14) to find ν angle, equation (9) to find $\bar{S}_{O\square S}$, then equation (18) to find $\bar{n}_{O\square S}$, at this step we know the value of values $\bar{n}$ and $\bar{S}$ so apply equation (5) to find the value of cos (α) and its correction factor as mentioned before it will 0.31.In equation(3), then area needed to generated 82W is equal to 1.36 m^2, then use the safety factor 10% then the daily average power generated ($P_{generated}$) equal 90.20 w which is larger than $P_{consumed}$by 10% and the max power equal 283.38 w which is larger than the max power consumed by 17.4% as shown in Fig. (7)

B. SC sizing

As shown in Fig. (7) or (8) the shadow duration is equal to half of total orbit duration. The SC parameters is shown in table (3), and the SA data sheet in appendix (2).

We will use the V_{cell} at 3.5 V, so S = 9, in equation (23) P =9 and add another one in case of cell failure, so P =10, I= $(I_{max}+I_{min})/2$, $I_{max}=P/V_{min}$, $I_{min}=P/V_{max}$, I=2.94 A, dv=$V_{max}-V_{min}$=4 V.

1) Energy in SC

In equation (25), C_{Total}=2376.21 F, calculate C_{Cell}= 2138.59F, so we will choose C_{Cell}=2300 F so calculate C_{Tolal} again it will be 2555.56F then make a check using equation (21) the dv new =3.4V <dv old ,so the design is accepted, the energy storage in SC is equal to 79.51Wh.

2) SC time constant

According to table (3), RC=1.38, in equation (21), C_{Total}=2172.28 F, C_{Cell}=1955.05 F, then choose C_{Cell}=2300 F it will give the same result as above.

3) Ignore the ESR effect

In equation (25), C_{Total}=2171.27 F, C_{Cell}=1954.14 F, then choose C_{Cell}=2300 F it will give the same result as above.

Note that at the beginning in design, there are difference between methods of design but at the end, the results are same. Now will check the whether this design can withstand during max current in max power duration. $I_{max}=P_{max}/V_{bus}$=8.36 A, dt =119.4 sec, therefore the dv=0.4 V, so the design is good.

VI. APPENDIX

Table 1 Orbital inputs parameters

Parameter	Value
Launching day	21/3/2014
H_0	680 Km
Maximum change in altitude	0 Km
Satellite lifetime (T_{life})	5 years
i_0	98.1115°
Maximum change in inclination	0 °
T_{LAN}	10.5 AM
elevation angle,θ	0°
azimuth angle,Φ	0°

Table 2SA parameters

Parameters	Value
$\overline{P}_{consumed}$	82 W
S_0	1360 W/m^2
SA efficiency, η_{SA}	29.5%
SA fill factor, K_{FF}	85%
SA efficiency of PSS, η_{PSS}	90%
Temperature coefficient, K_{Temp}	80%
Degradation coefficient, K_{Deg}	80%

Table 3SC parameters

Parameters	Value
$\overline{P}_{consumed}$	82 W
T_{shadow}	49.175 min
V_{max}	30 V
V_{min}	26 V
V_{bus}	28 V
V_{Cell}(rated)	3.8 V
C_{Cell}	2300 F
ESR_{Cell}	0.6 m Ω

Table 4 Solar array Emcore,ZTJ Photovoltaic cell, space photovoltaics

Parameter	Value
BOL Efficiency at Maximum Power Point	29.5%
V_{OC}	680 Km
J_{SC}	0 Km
V_{MP}	5 years
J_{MP}	98.1115°

Table 5Lithium ion capacitor Ultimo lithium ion capacitor (Prismatic series)

Parameter	Value
V_{Cell}(max.)	3.8 V
V_{Cell}(min.)	2.2 V
C_{Cell}	2300 F
ESR_{Cell}	0.6 m Ω
Specific energy	8 Wh/kg

VII. CONCLUSION

In this work, a power supply consists of solar array and Lithium-ion capacitor is designed to electrify micro-satellites. Solar Array is used to supply the loads and charging the storage source. Lithium-ion capacitor supplies the load in case of eclipse periods. A complete design for the SA is suggested based on the total consumed load power. A check is done to ensure that the generated power is more than the consumed power under any case whether in average or in maximum and during the eclipse duration. Super capacitor is designed based on the previous information. The results show that the LIC can supply the load properly by storing the sufficient energy during the day. The SCs in space application is look promising as it has huge number of cycles, wide temperature range, high efficiency, and its problem of specific energy can be overcome.

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