Estimation of Online Power Behavior in PHOENIX’s Electrical Power Subsystem

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Abstract: Research in space technology and small satellite development is getting more prosperous in recent year. The 2U CubeSat PHOENIX is developed at NCKU as a part of the QB50 mission, which will be launched in 2017. PHOENIX consists of several subsystems and one of the most critical one is the Electrical Power Subsystem (EPS), which provides, stores, distribute and controls the satellite’s electrical power. Prior to execute any mission, it is necessary to ensure that the power margin is sufficient. The paper provides a power system model to predict the online power behavior to avoid overloading. The purpose of the power system model is to maximize the mission performance and to prevent the CubeSat from entering the safe mode repeatedly, which interrupts the scientific mission operation. As a case study, the QB50p1 and QB50p2 of QB50 precursors, which are currently in orbit, are used in the analysis. The model is built up and verified based on the simulation software, PHOENIX’s data, and QB50 precursors’ data.

1. INTRODUCTION

The 2U CubeSat project PHOENIX, which will be launched to the ISS in 2017, is developed at NCKU as a part of the QB50 mission, which aims is study temporal and spatial variation of a number of key constituents and parameters in lower thermosphere with a network of about 40 CubeSats, separated by a few hundred kilometers and carrying scientific payloads. Fig.1 shows the PHOENIX’s model.

The power analysis must be considered in each design phase, but sometimes it still couldn’t guarantee that the power is enough or the satellite makes full use of the overall
energy. The power system model, divided into three parts: power generation, storage, and output management, utilizes the past data to modify the model and to predict the future trend. It provides the feasible opportunity to maximize mission performance.

2. ELECTRICAL POWER SUBSYSTEM (EPS)

The PHOENIX CubeSat utilizes a commercially-off-the-shelf (COTS) electrical power board (GomSpace NanoPower P31u) [1] to facilitate the hardware functions such as conversion, regulation, and distribution. All EPS hardware elements are space proven. The advanced triple-junction solar cells from EMCORE Corporation [2], which possess the high efficiency as 27.7%, are chosen and provide average power around 0.9W at maximum power point. Every surface of PHOENIX is body-mounted with solar cells except the +Z one, which is arranged for science payload – INMS. There are two on-board Lithium-Ion batteries with a total capacity of 2600mAh. The architecture of the system is composed of three photovoltaic (PV) power converters, self-locking switch and 3.3V/5V power regulator. The microcomputer on EPS board can monitor the status, including voltage, current and temperature as well as receiving command from on board data handling subsystem by I2C transmission. For the output, four subsystems and two scientific payloads match to different voltage value. In addition, the Killer-Separation Switch (KISS) design is applied to the system in order to enhance the stability. The EPS overall architecture is shown in Fig.2.

3. POWER GENERATION and CONSUMPTION

A CubeSat’s electrical power subsystem receives the power generated by the solar panels and regulates it to provide consistent and specified levels of power to overall subsystems. As to power demand, each subsystem (e.g., on-board computer, ADCS, transmitter…etc.) consumes power at different situation. In this paper, there discusses the power generation with many factors and consumption at nominal mode.

3.1 Photovoltaic electrical characteristics

Satellite at low-earth orbit has usually employed photovoltaic as their power source. Often, photovoltaics are the only real candidate for these low-power missions. Solar cells are a
well-known and steady source of power for a satellite but they are also affected by many parameters such as temperature, irradiation … etc. PHOENIX chose the III-V solar cells, which possess higher efficiency and usually adopt in the space filed, provided by Emcore (See Fig.3). The BJTM triple junction InGaP/InGaAs/Ge integrated with monolithic bypass diode protecting negative voltage generated from shading effect (See Fig.4).

The absorptivity of the solar cells is important to identify the ability of absorbing solar illumination. Also, another issue need to be aware that efficiency values for solar cells often indicate only to single cells. Therefore, it should consider losses inherent to cells assembly to scale the efficiency adequately. Table 1 shows the specification of PHOENIX’s solar cell.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Emcore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>3.13g</td>
</tr>
<tr>
<td>Dimension</td>
<td>63.41 x 38.63 mm²</td>
</tr>
<tr>
<td>Area</td>
<td>24.5cm²</td>
</tr>
<tr>
<td>Absorptivity</td>
<td>90%</td>
</tr>
<tr>
<td>Assembly degradation</td>
<td>85%</td>
</tr>
<tr>
<td>Electrical Parameters</td>
<td>AM0 (135.3 mW/cm²)</td>
</tr>
<tr>
<td>BOL Efficiency at Maximum Power Point</td>
<td>27.7%</td>
</tr>
<tr>
<td>Voc (Open-Circuit Voltage)</td>
<td>2.67V</td>
</tr>
<tr>
<td>Isc (Short-Circuit Current)</td>
<td>0.41A</td>
</tr>
<tr>
<td>Vmp (Maximum Power Point Voltage)</td>
<td>2.34V</td>
</tr>
<tr>
<td>Imp(Maximum Power Point Current)</td>
<td>0.38A</td>
</tr>
<tr>
<td>FF(Fill Factor)</td>
<td>83.7%</td>
</tr>
<tr>
<td>Temperature Coefficients</td>
<td>28°C</td>
</tr>
<tr>
<td>ΔVoc/ΔT</td>
<td>-6mV/°C</td>
</tr>
</tbody>
</table>
Solar cells are quite sensitive to temperature. When temperature of PV module is increased, open-circuit voltage, power and efficiency are decreased and short-circuit current is increased slightly. The Fig.5 presents that the solar cell enjoys cold sunny environment.°C

| \( \Delta I_{sc}/\Delta T \) | 0.29 mA/°C |
| \( \Delta V_{ref}/\Delta T \) | -6 mV/°C |
| \( \Delta I_{pp}/\Delta T \) | 0.25 mA/°C |
| \( \text{Eff}/\Delta T \) | -0.064%/°C |

Therefore, the characteristic can be describe with temperature difference \( \Delta T \) by following equations and Table 1 [4].

\[
V_{pp} = V_{ppref} - \alpha(T_{ref} - T) \tag{1}
\]

\[
I_{pp} = I_{ppref} - \beta(T_{ref} - T) \tag{2}
\]

\[
P_{pp} = P_{ppref} \times \gamma(T_{ref} - T) \tag{3}
\]

### 3.2 Battery charge regulator

PHOENIX uses the boost converter as the battery charge regulator (BCR) to charge battery with two mode: Constant Current (CC) and Constant Voltage (CV). In addition, BCR integrated with Maximum Power Point Tracking (MPPT) to harvest the maximum power derive from the illuminated cells. However, the efficient issue is concerned to consider how to be the optimal connection of solar cells reducing the loss. According to [5], the configuration is one string with two solar cells in series connection.

### 3.3 Albedo contribution

The albedo is correction term that describes the irradiation which is reflect by the surface of earth[6]. The albedo rate in the LEO depends on the season, weather and topographic...
feature so the paper collected and analyzed albedo data within three years from NASA database which match each value for every latitude and longitude.

### 3.3 Power generation

Since PHOENIX’s attitude will stabilize moderately after deployment and the power generation of the satellite is higher in the tumbling state, the model doesn’t consider the rotational scenario. When the incident light is perpendicular to the surface of the solar cells, the cells get the maximum energy flux around 1360W/m². The software System Tool Kits (STK) from Analytical Graphics Inc. (AGI) provides the solar panel tool to calculate the power for incident light in space environment.

To compute the electrical power captured by the solar panel array at a given point in time, STK applies the following power equation:

\[
P = A \lambda \cos(\alpha)
\]

where \(A\) is the area of solar cells array (m²), \(\lambda\) is solar constant using average value around 1360W/m², \(\alpha\) is the angle of PV module with respect to the incident light.

![Fig.6 Panel and EPS temperature of QB50 precursor](image)

About the thermal issue, this paper exploits the data of QB50 precursors [7] to simulate the variation of temperature in space environment shown in Fig.6. Due to ADCS in each QB50 satellite, each panel sustains different temperature range and deviation causing all panels presenting different performance. Fig.7 depicts the architecture of power generation.
model. First, the model exploits the STK to combine the four parameters, which is solar panels, orbit, absorptivity and assembly degradation, especially the most crucial factor as the orbital and solar panels. Second, three correction terms make the model more accurate. Some of them increase or decrease the power. Consequently, total seven parameters form the model with a step by step flow, not a single one of these parameters can be omitted. The model simulates that the generated power of PHOENIX is 2.1W which is quite close the real condition comparing to other CubeSat.

3.2 Energy storage

Li-ion batteries are served for energy storage in PHOENIX. Since different C-rate and temperature correspond to the different performance, the methodology of fuzzy logic is applied to model the Li-ion batteries[8]. Before using the fuzzy rules, the sophisticated experiments are performed to get the characteristics of the batteries[9]. There uses the ∆V’s variation to temperature and C-rate represented by fuzzy rules which could model the battery dynamics accurately.

![Fig.8 The ΔV curves at different C-rate](image)

![Fig.9 The ΔV curves at different temperature](image)

4. POWER SYSTEM MODEL

According to the above discussions, the power system model estimates how much the power could be used. In the development stage, the power consumption for each subsystem and payloads is available through a series of tests. Using the developed graphical user interface for the power system model, the graph shown on the Fig.11 is obtained. PHOENIX can thus switch to safe mode on the basis of voltage value, so the power model can estimate not only the power generation and consumption, but also voltage of the batteries.
5. CONCLUSIONS

The paper investigates the design of a power simulation and monitoring software for better utilization of satellite power to fulfill mission operation. With the power system model, the CubeSat can operate semi-autonomously. The telecommand sequences for ground station can thus become less frequently and the frequency of interrupts due to low power condition can be reduced.

6. References