A Study of Lightweight Dynamic Algorithm of Power Management System for Small Satellite Applications

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Abstract: This paper presents the study of the lightweight dynamic algorithm of a power management for a small LEO satellite application such the CubeSat. The work was proposed in connection with a rule-based decision method and scheduling. Here, the functional payloads of the satellite tasks were considered consisting of electric power units, attitude controller modules, and environmental space systems. The functions of the main systems in the satellite operation were scheduled at the work process and the scheduling of the mission tasks were relied on decision-making rules. It shows that the lightweight dynamic algorithm was aimed to optimize the state-of-charge (SoC) of batteries. The study of the proposed work was based on a simulation to understand the energy behavior and also consider the battery usage.

Keywords: dynamic algorithm; power management; battery management; small satellite

1. Introduction

Power management system (PMS) in a satellite application has played a rule in design of the small-size configuration [1]. Due to mass and volume limitation, the satellite components were considered in a design depending on a mission purpose. The Cubesat is a type of a small satellite that is represented in size scales [2]. Its utilization has a benefit in a space mission, for example, a geographic exploration. One of the key subsystems is a PMS module that delivers the electrical energy to payload consumers [3]. The tasks of the PMS are designed by operating on an effective work policy [4]. The design of an electrical power system (EPS) depends on the technical specifications and functional requirements of the satellite operation. The part of a PMS unit is potential and necessary to deal with a solar energy harvest by interacting with solar planar units and satellite payload consumption. In order to enlarge a satellite lifespan, the PMS operation has to take into account the battery utilization dealt with the efficiency and performance. In addition, the issue of the power shortage was monitored to prevent the fault of a satellite operation. The EPS controller is an embedded on-board computer working on programming which can be approached by applying an algorithmic management [5]. In that, dynamic programming can be used to develop a management trajectory to achieve the effectiveness of the EPS operation. However, the hardware architecture for a small satellite application gives the constraint of a processing resource leading to the infeasible solution to implement a complex algorithm. Here, the aim of this work is to study the energy characteristics for a small LEO satellite application. The operation of a power management system is concentrated to enhance the battery efficiency and performance [6]. The lightweight dynamic algorithm is developed under the solar energy harvesting and the control of satellite payloads. The modeling and algorithm are demonstrated in Section 2. The results and discussion are given in Section 3. The summary is reported in Section 4.

2. Modeling and Algorithm

The modeling and algorithm of the PMS were illustrated according to the LEO satellite operation of which the orbit period is 92 mins. The electrical energy harvest, power storage and load consumption was considered to model the PMS characteristic. Figure 1 shows the energy profile that the ten periods of the orbits depicted. It shows the energy response as a function of time including a sun and eclipse phase with 55 mins and 37 mins respectively. In this study, the payloads and functional units for the photography space mission were studied of which the power budget was listed in Table 1. The satellite payloads were concerned with energy budgets including a telecommunication, attitude controller and functional loads.

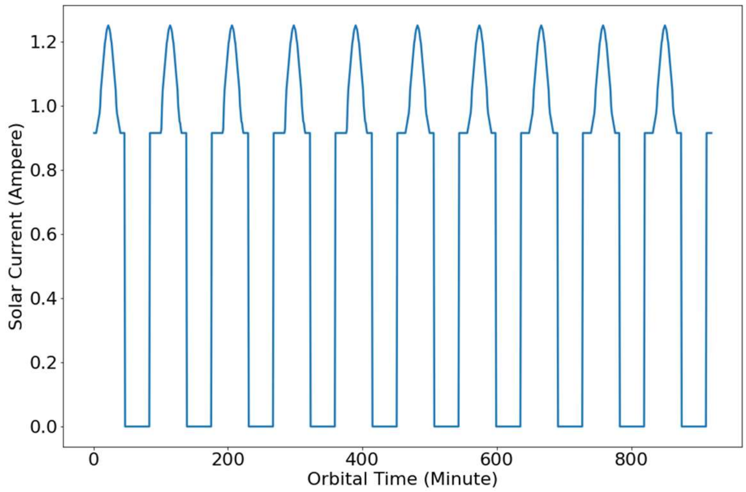

Figure 1. The current profile of the energy harvesting with a solar module

Table 1. The power budgets of the electrical payloads.

Tasks	Operating Time (Min)	Normalized Time/Orbit (Min.)	Avg. Current Consumption (A/Min)
Comm. (Rx)	92	1	0.005
Comm. (Tx)	12	0.13	0.25
Heater	37	0.402	0.338
OBC Controller Unit	92	1	0.2
Attitude Controller	81	0.88	0.115
EPS	92	1	0.711
Camera Module	48	0.552	0.092
payload#1	27	0.293	0.1
payload#2	28	0.304	0.1
payload#3	30	0.326	0.2

Based on the decision rule approach [7], the algorithm of a power management was designed in order to optimize the battery characteristics. The decision variables consist of the state-of-charge (SoC) which is under the uncertain parameter in context of the consumption scheduling. The problem involves the satellite lifetime depended on the battery characteristics. The decision set includes the available amount of electrical energy average power consumption rate and operational time of active jobs leading to that of the objective function maximizes the SoC percentage (%SoC).

```
Algorithm: Dynamic Power Management
SelectPowerSource()
    If %SoC < 100 & PV > Sum of all LoadPower Then Charge State
    Else if %SoC < 100 & PV > Sum (LoadPower)
        No charge and bypass the power from PV to operate satellite system
    Else if PV < Sum(LoadPower)
        Combine power from solar and battery to operate satellite system
TimeBlockChecking()
    For t = 0 to end of job[j]
        SelectPowerSource()
        Calculate the SoC at time t
        If %SoC > threshold Then Increment t
        Else Return false
    End For
Return true
Loop Begin
    For i = 0 to N      #N is a number of running jobs
        Power consumption = sum(LoadPower[i]);
            If job[j] request to start Then
                If job[j] in the list of a compulsory operation Then Enable job[j]
            Else TimeBlockChecking()
                    If %SoC > threshold Then Enable job[j]
                    Else Disable job[j]
        SelectPowerSource()
End Loop
```

3. Results and Discussion

In order to understand the management process in a satellite operation, the proposed algorithm was implemented and simulated carried out to observe the characteristics of the battery. To start with the initial state, the SoC was set of 100% in the beginning. Fig 2 shows the simulated results of the SoC responses plotted as a function of the operating time. The orbital period spends nine cycles as the total of 828 minutes. The electrical specification of the battery was provided by a manufacturer given in a range of the capacity of an electrical current of 1.5 to 5 ampere hour (Ah). The parametric study was performed to illustrate the SoC response with the 8.2 volt battery power related to a minimum (1.5 Ah) and maximum (5 Ah) of the electrical current. The SoC plots depict in comparison to the baseline SoC (without an algorithm) and the optimized SoC (with the algorithm). It reports the near-unity state which is approximately achieved of 94.32% and 94.86% with regard to the 5 Ah and 1.5 Ah respectively, on average over the observed orbital time. The management of the satellite operation was focused on scheduling of the highest priority of the satellite control functions whereas the space mission with a camera module was considered depending on a discrete period as occasion.

As a result, the characteristic of the SoC response was obviously improved when applying the dynamic algorithm in a management process. This means that the performance of batteries can contribute to the lifespan of a satellite, and also design of a miniaturized satellite.

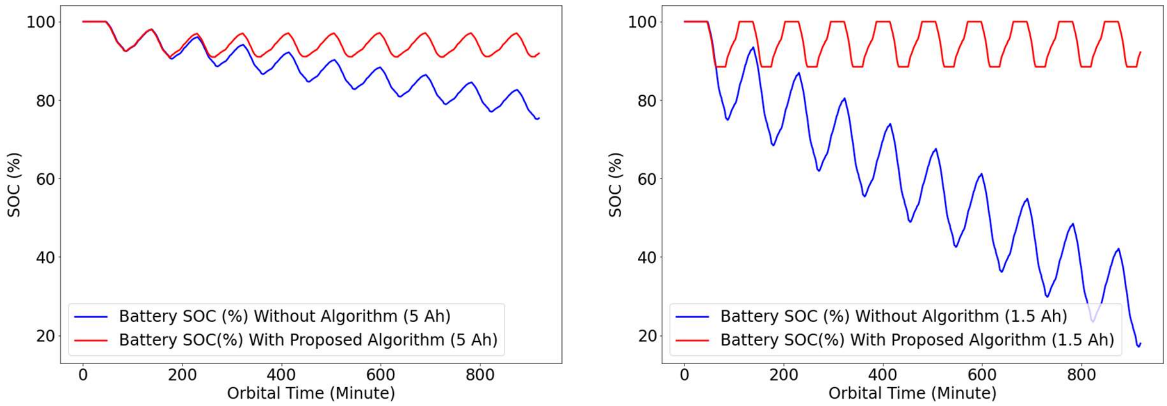

Figure 2. The characteristics of the SoC of the battery without/with the optimized algorithm

4. Conclusions

The dynamic algorithm for power management in a small satellite application has been successfully demonstrated in order to deal with the variable energy storage and payload consumption. The proposed study illustrates rechargeable battery usage by scheduling the energy-collected and distributed routine in operation. It clearly allows the strategy of the power management working on a linear decision rule as a simple effective approach. The primary factors of power management consist of the control of the state-of-charge (SoC) of batteries and the consumption characteristics of the payload satellite interfaces taken into account. The energy profile was modeled based on the LEO operation in this study. The benefit is obtained and also useful to reflect the design factors in a small satellite.

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