Торайғыров университетінің хабаршысы
ҒЫЛЫМИ ЖУРНАЛЫ

НАУЧНЫЙ ЖУРНАЛ
Вестник Торайгыров университета

Торайғыров университетінің ХАБАРШЫСЫ

Энергетикалық сериясы

1997 жылдан бастап шығады

ВЕСТНИК Торайгыров университета

Энергетическая серия

Издается с 1997 года

ISSN 2710-3420

№ 4 (2022)

ПАВЛОДАР

НАУЧНЫЙ ЖУРНАЛ
Вестник Торайгыров университета

Энергетическая серия
выходит 4 раза в год

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания,
информационного агентства и сетевого издания
№ 14310-Ж
выдано
Министерство информации и общественного развития
Республики Казахстан
Тематическая направленность
публикация материалов в области электроэнергетики,
электротехнологии, автоматизации, автоматизированных и
информационных систем, электромеханики и теплоэнергетики

Подписной индекс – 76136

https://doi.org/10.48081/UJEG4973

SRSTI 89.25.35

doi.org/10.48081/MJYP3176

***D. M. Kalmanova**
L. N. Gumilyov Eurasian National University, Republic of Kazakhstan Astana,

DEVELOPMENT OF AN ENERGY SUPPLY SYSTEM BASED ON THE PROTOTYPE «KAZEOSAT – 2»

This article discusses the development of a prototype power supply system «KAZEOSAT -2» for which two types of load behaviour are modeled and described. In the first approach, the analysis focused on using load duty cycles to simulate the average power consumption per orbit in order to study the behaviour of the subsystem for various orbit scenarios. The second approach consisted in modeling the load switching behaviour taking into account the event of the mission flight sequence. The article also analyses the state of the energy balance based on the events of the mission flight sequence, as well as predicts the effect of power peaks on battery discharge behaviour. Busbar regulation was implemented, the converter block and converter efficiency were modeled using resistive resistance in parallel to its input ports. It is noted that the fill factor of the converter was controlled using a PI controller and a comparator, which measure the load voltage and compare it with the reference value.
Keywords: reliability, block diagram, modelling, block, subsystem

Introduction

The reliability block diagram is designed in such a way that it is possible to identify each element or function used in the product. Each block of the reliability flowchart n represents one element of the function contained in the element. The blocks in the diagram follow a logical order that refers to the sequence of events during the prescribed operation. The reliability scheme of the power supply system (PSS) is shown and described as follows [1].

Materials and methods

To fulfil the operational requirements of the SC subsystem, to determine the failures of the PSS and the selected environmental conditions, 7 sections of SC with 1 auxiliary section were required. Therefore, the SC subsystem will contain 8 sections of SC, provided that the failure of one section of SC will not lead to a system failure. Each section of SC contains three sequential blocks, which are a

SC module, an isolating diode (consists of a diode matrix that is used to isolate malfunctions, that is, blocking SC during shading periods and protecting the system from short circuit with shunting of the SC module in case of excess power) and a shunt regulator [consists of transistor matrix with a protective fuse, which is used for shunting exceeding the power of SC].

The battery subsystem used Li-Ion with 22 cells connected in series to maintain the bus voltage within the permissible range, provided that the failure of one section does not lead to a system failure. Each section will have one battery cell connected in parallel by a charge equalization unit to avoid charging and battery cell discharge malfunction [1].

For the power management and control subsystem, the microcontroller module (consisting of two parallel circuits) works as a backup module and the SM control module. SM consists of three sections of control circuits connected in a «2 out of 3» voting configuration for supervising the microcontroller module.

A reliability flowchart was generated from the subsystem specifications, failure modes and functional scheme in the following form: «2/8», «2/22», «2/3» they mean that the failure of one element is acceptable, but the failure of two or more elements leads to the failure of the subsystem.

Then these values were calculated in the MATLAB/Simulink model, which simulates the operation of a solar battery in orbit. The current generated by the matrix was used to power the battery and loads, generating data on the behaviour of the energy balance of the system. The EPS model is shown in Fig. 1, it consists of solar panels, a single-stage linear shunt regulator, a battery pack and four load buses: an unregulated bus, a 28 V bus, a 5 V bus and a 12 V bus.

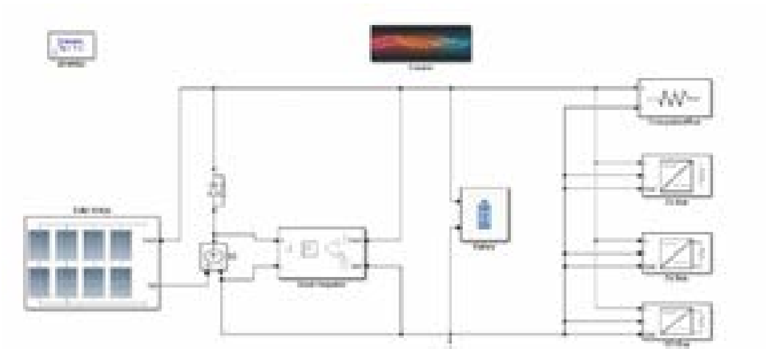

Figure 1 – EPS model

Two types of load behaviour were modeled. In the first approach, the analysis focused on using load duty cycles to simulate the average power consumption per orbit in order to study the behaviour of the subsystem for various orbit scenarios. In this case, load switching was neglected, and the power consumption for each bus was modeled based on its average consumption. The second approach consisted in modeling the load switching behaviour taking into account the event of the mission flight sequence. With this approach, it became possible to analyse the state of the energy balance in more detail based on the events of the mission flight sequence, as well as predict the effect of power peaks on battery discharge behaviour. Since the lifetime of the «KazEOSat-2» mission is long (about 7 years), the analysis discussed in the rest of this article suggests that the degradation of solar cells is very large (Ld ≈ 90%).

The «Solar panels» unit in Fig. 2 simulates the operation of «KazEOSat-2» batteries. It consists of input data with input-output curve points (i.e. Isc, Voc, Vmp and Imp) for each array (+X, -X, +Z and -Z) connected to a MATLAB function block that implements the equation model. 1, 2 and 3.

$$I = I_{sc}\left[1 - C_1\left(e^{\frac{V}{c_2 V_{oc}}}\right) - 1\right] \tag{1}$$

$$C_1 = \left(1 - \frac{I_{mp}}{I_{sc}}\right) e^{-\frac{V_{mp}}{c_2 V_{oc}}} \tag{2}$$

$$C_1 = \frac{\frac{V_{mp}}{V_{oc}} - 1}{\ln\left(1 - \frac{I_{mp}}{I_{sc}}\right)} \tag{3}$$

where: I_{sc} – current during short circuit;

V_{sc} – voltage during short circuit;

V_{mp} – maximum point voltage;

I_{mp} – maximum current point;

The total generated current was transmitted to the central bus, and its voltage was used in the feedback loop with the model, adding a voltage drop of 1.5 V in each matrix (Fig.2).

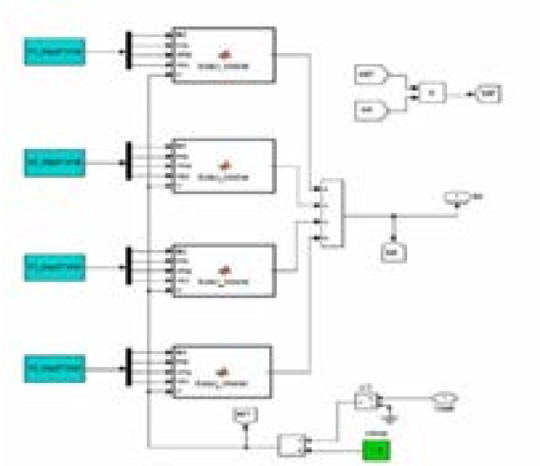

Figure 2 – STC parameters

The input of electrical data was duly taken into account, taking into account the angle of incidence of the sun and the operating temperatures in orbit. Thus, all solar cells are combined into an appropriate single array model for this particular simulation.

A single-stage PWM shunt controller was modeled as a comparator that compares the bus and the reference voltage (12 V), a PWM generator and a universal bridge unit (Fig. 3). The “PWM generator” unit was tuned to a frequency of 10 Hz and generates a two-level pulse using the comparator values as a reference modulating signal to power the unit «Universal Bridge». The reference voltage value is less than the maximum charging voltage allowed for the battery pack (i.e. 12.3 V).

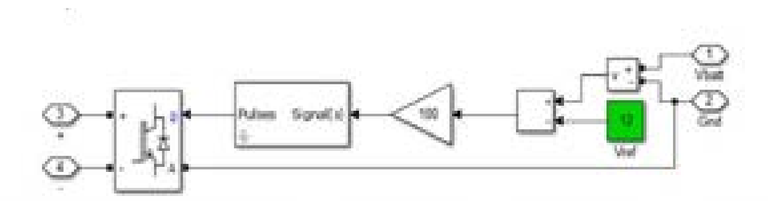

Figure 3 PWM generator and universal bridge unit

Results and discussion

The battery pack was implemented in the MATLAB model using the ‘Battery’ unit provided in the Simscape\Power Systems library (Fig. 4). The unit parameters were configured in accordance with the table of characteristics of the battery pack, that is, with a nominal voltage of 10.8 V (3 batteries of 3.6 V in series), with a nominal capacity of 15 Amp hour and a typical battery response time of 30 seconds. According to the previous analysis for the thermal subsystem «KazEOSat-2», the predicted operating temperature of the battery is from +13.5 °C to +13.8 °C. Therefore, the maximum value is +13.8 °C (i.e. 286.95 K) was set as a constant ambient temperature in the model.

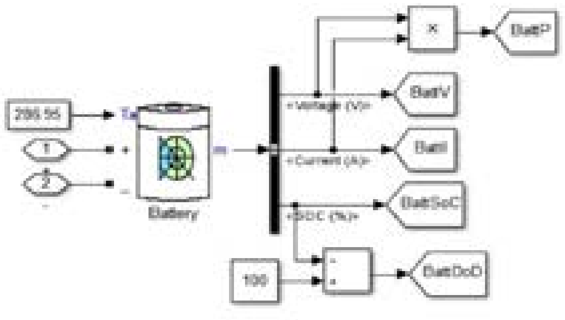

Figure 4 – MATLAB using the ‘Battery’ block

Bus regulation was implemented by connecting the ‘Two Quadrant DC/DC Converter’ unit (Fig.5) between an unregulated tire and regulated loads. The converter unit was modeled using a switching function model directly controlled by regulating the average on/off duty cycle (0 < D < 1) of switching, which ensures the fastest simulation possible. The fill factor of the converter was controlled using a PI controller and a comparator, which measure the load voltage and compare it with the reference value (Fig.5). The PI controller was configured in a continuous time domain [2].

The efficiency of the converter was modeled using a resistive resistance parallel to its input ports. The impedance consumes constant power and can be associated with fixed losses of the converter. It was implemented as a parameter of the “Current source limiter resistance” block, and its value is given by the formula.:

$$R = \frac{V_{butt}^2}{P_{reg-bus}(1-\eta_{cony})} \qquad (4)$$

where: $P_{reg\text{-}bus}$ – power of regulated bus;
η_{conv} – efficiency of converter;
V_{batt} – battery voltage.

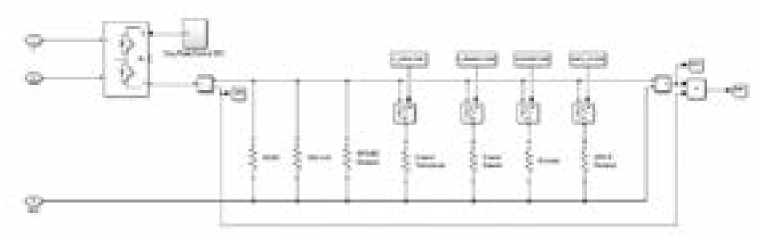

Figure 5 – MATLAB load model for a regulated 5V bus

Conclusions

Since most DC converters currently have an efficiency of more than 90 %, this value was used in the following analysis.

Loads are modeled as total resistance with constant consumption of active power. Figure 5 of the regulated bus shows that some loads were connected to the switch, which was controlled by external data provided by the MAT file. This data contains information about the on-off states of the load. Loads that were not connected to the switch were always on during the satellite flight. For an unregulated bus, the load was directly connected to the battery terminal, as can be seen in Figure 6.

The load of the 'Power Management Unit' on this bus simulates the internal consumption of the controller of the PSS.

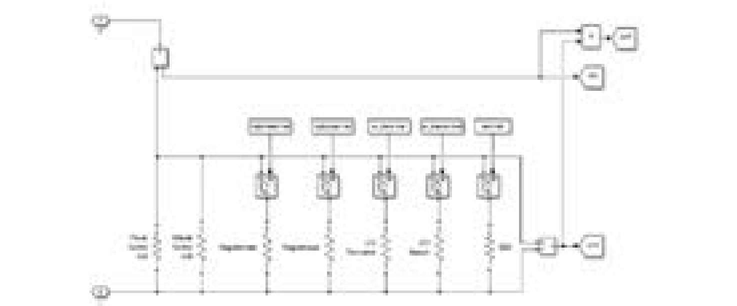

Figure 6 MATLAB load model for unregulated bus

For the first approach to modeling, that is, the analysis of average power consumption, the loads in the tires were replaced by a single impedance with active power consumption equal to the total average consumption of the bus.

REFERENCES

1 **Wang, Haosheng** Modeling and Simulation of Spacecraft Power System Based on Modelica / Haosheng Wang, Hongen Zhong. – Web of Conferences 233, 04033 (2021)

2 **Tishchenko, Anatoly K.** «Machines» / Anatoly K. Tishchenko, Eugeny M. Vasiljev, Artyom O. Tishchenko. – 8/64 –2020

3 **Swinerd, G.** Spacecraft systems engineering: edited by Peter Fortescue / Graham Swinerd, John Stark. – 4th ed. P. cm.

4 **Maral, G.** Satellite Communications Systems: Systems, Techniques and Technology / Gerard Maral, Michel Bousquet, Zhili Sun. - 6th Edition .– 2020

5 **Gordeev, К. G.** Kriterii vybora shemystabilizacii napryajeniya solnechnyh batarey dlya sistemy energosnabjeniya kosmicheskogo apparata [Criteria for choosing a solar battery voltage stabilization scheme for the spacecraft power supply system]: elektronnye I elektromehanicheskiye sistemy I ustroystva / К. G. Gordeev, Yu.A. Shinyakov, A. I. Chernyshov, V. O. Elman. – Sankt-Peterburg. nauch. tr. – Novosibirsk: Nauka, 2007. – 43-48 P. // Electronic and electromechanical systems and devices: St. Petersburg. scientific tr. – Novosibirsk : Science

6 **Flora, C.** Battery Program and Progress / Flora C., Neubauer J., Dembeck J., Pearson C. – The NASA EMU, 2009. – 30 p.

7 **Gruzdev, A. I.** Sostoyanie I perspektivy razvitiya proizvodstva vysokotechnologicheskih avtonomnyh istochnikov elektricheskoy energii v Rossii [Status and development prospects for the production of high-tech autonomous sources of electrical energy in Russia]: Elektrohimicheskaya energetika / Electrochemical energy / A. I. Gruzdev. – 2006 – T. 6. – № 1. – P. 3 – 29.

8 **Volkov, N. G.** Nadejnost elektrosnabjeniya. [Reliability of power supply]: Ucheb. posobie/ N. G. Volkov. – Tom.politech. un–ty.Томsк, 2003-140 p.

9 **Colombo, G.** Satellite Power System Simulation / G. Colombo, U. Grasseli. -1997

10 Oliveira de Magalhães, Renato Space Power Topology Selection and its System Level Modeling and Control / Renato Oliveira de Magalhães, Herbi Junior Pereira Moreira. – 2020

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1 Wang, Haosheng Modeling and Simulation of Spacecraft Power System Based on Modelica / Haosheng Wang, Hongen Zhong. – Web of Conferences 233, 04033 (2021)

2 **Tishchenko, Anatoly K.** «Machines» / Anatoly K. Tishchenko, Eugeny M. Vasiljev, Artyom O. Tishchenko. – 8/64 –2020

3 **Swinerd, G.** Spacecraft systems engineering: edited by Peter Fortescue / Graham Swinerd, John Stark. – 4th ed. p. cm.

4 **Maral, G.** Satellite Communications Systems: Systems, Techniques and Technology / Gerard Maral, Michel Bousquet, Zhili Sun. – 6th Edition .– 2020

5 **Гордеев, К. Г.** Критерии выбора схемы стабилизации напряжения солнечных батарей для системы электроснабжения космического аппарата: Электронные и электромеханические системы и устройства / К. Г. Гордеев, Ю. А. Шиняков, А. И. Чернышев, В. О. Эльман. -Санкт-Петербург: науч. тр., Новосибирск : Наука, 2007. – 43– 48 с.

6 **Flora, C.** Battery Program and Progress / Flora C., Neubauer J., Dembeck J., Pearson C. – The NASA EMU, 2009. – 30 p.

7 **Груздев, А. И.** Состояние и перспективы развития производства высокотехнологичных автономных источников электрической энергии в России / А. И. Груздев. - Электрохимическая энергетика, – 2006. – Т. 6. – № 1. – С. 3 – 29.

8 **Волков, Н. Г.,** Надежность электроснабжения. Учеб.пособие / Волков Н. Г. – Том.политех.ун– т. Томск, 2003–140 с.

9 **Colombo, G.** Satellite Power System Simulation / G. Colombo, U. Grasseli. -1997

10 Oliveira de Magalhães, Renato Space Power Topology Selection and its System Level Modeling and Control / Renato Oliveira de Magalhães, Herbi Junior Pereira Moreira. – 2020

Material received on 15.12.22

**Д. М. Калманова*

Л. Н. Гумилев атындағы Еуразия ұлттық университеті,
Қазақстан Республикасы, Астана қ.

«KAZEOSAT -2» ПРОТОТИПІ БОЙЫНША ЭЛЕКТРМЕН ҚАМТАМАСЫЗ ЕТУДІҢ ЖҮЙЕСІН ДАМЫТУ

Бұл мақалада «KAZEOSAT -2» прототипінің электрмен жабдықтау жүйесінің дамуы қарастырылады, ол үшін жүктеме әрекетінің екі түрі модельденеді және сипатталады. Бірінші тәсілде талдау әртүрлі орбиталық сценарийлер үшін ішкі жүйенің әрекетін зерттеу мақсатында орбитаға орташа қуат тұтынуды модельдеу *үшін жүктеменің жұмыс циклдерін пайдалануға бағытталған. Екінші тәсіл миссияның ұшу реті оқиғасын ескере отырып, жүктемені ауыстыру әрекетін модельдеу болды. Сондай-ақ, мақалада миссияның ұшу реттілігі оқиғаларына негізделген энергия балансының күйлері талданады және қуат шыңдарының батареяның зарядсыздану әрекетіне әсерін болжайды. Шина реттеуі жүзеге асырылды, түрлендіргіш блогы модельденді және түрлендіргіштің тиімділігі оның кіріс порттарымен параллельді резистивті кедергі арқылы модельденді. Конвертердің жұмыс циклі жүктеме кернеуін өлшейтін және оны анықтамалық мәнмен салыстыратын PI контроллері мен компаратордың көмегімен басқарылатыны атап өтілді.*

Кілтті сөздер: сенімділік, блок-схема, модельдеу, блок, ішкі жүйе

**Д. М. Калманова*
Евразийский национальный университет имени Л. Н. Гумилева,
Республика Казахстан, г. г. Астана

РАЗРАБОТКА СИСТЕМЫ ЭНЕРГОПИТАНИЯ НА ПРОТОТИПЕ «KAZEOSAT -2»

В данной статье рассматривается разработка системы энергопитания прототипа «KAZEOSAT -2» для которой смоделировано и описано два типа поведения нагрузки. В первом подходе анализ был сосредоточен на использовании рабочих циклов нагрузок для моделирования средней потребляемой мощности на орбиту, чтобы изучить поведение подсистемы для различных сценариев орбиты. Второй подход состоял в моделировании поведения переключения нагрузок с учетом события последовательности полетов миссии. Также в статье проанализированы состояния энергетического баланса на основе событий последовательности полета миссии, а также спрогнозировано влияние пиков мощности на поведение разряда батареи. Было реализовано регулирование шин, смоделирован блок преобразователя и эффективность преобразователя с использованием резистивного сопротивления параллельно его входным портам. Отмечено, что коэффициент заполнения преобразователя контролировался с помощью PI-контроллера и компаратора, которые измеряют напряжение нагрузки и сравнивают его с эталонным значением.

Ключевые слова: надежность, блок-схема, моделирование, блок, подсистема

Теруге 15.12.2022 ж. жіберілді. Басуға 30.12.2022 ж. қол қойылды.
Электронды баспа
3,44 Mb RAM
Шартты баспа табағы 23.59. Таралымы 300 дана. Бағасы келісім бойынша.
Компьютерде беттеген: А. К. Мыржикова
Корректор: А. Р. Омарова
Тапсырыс № 4019
Сдано в набор 15.12.2022 г. Подписано в печать 30.12.2022 г.
Электронное издание
3,44 Mb RAM
Усл. печ. л. 23.59. Тираж 300 экз. Цена договорная.
Компьютерная верстка: А. К. Мыржикова
Корректор: А. Р. Омарова, Д. А Кожас
Заказ № 4019

«Toraighyrov University» баспасынан басылып шығарылған
Торайғыров университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.

«Toraighyrov University» баспасы
Торайғыров университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.
67-36-69
E-mail: kereku@tou.edu.kz
www.vestnik-energy.tou.edu.kz