China-Brazil Earth Resource Satellite (CBERS) Battery Charging System

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Abstract*: The ever increasing complexity and integration of systems together with the explosive growth of electronics and computational communications have led to higher demands for energy, as recognized by the SAE ARP 4754 on complex or highly integrated systems. Electrical power conditioning and distribution is one of the vital functions in many types of systems, among which stands out the charging and discharging of batteries. In such systems, it's been known that incorrect handling can lead to thermal runway as already experienced in aerospace, aviation, automotive and portable consumer devices industries. In this article we intend to discuss and model a battery charging/discharging system currently in use in the CBERS (China-Brazil Earth Resource Satellite), to future develop an adaptive control that autonomously adjust control parameters as system degrades and operating conditions changes, in such a way that the thermal runway phenomenon is avoided, decreasing the risk of accidents and failures in that type of systems.*

Keywords*: Battery Charging, Satellite Power Supply.*

1 Introduction

Brazil has participated, over the years, in the development of remote sensing satellites, for imaging purposes, known as CBERS (China-Brazil Earth Resource Satellite). With a polar orbit of 778km of altitude, it takes around one hundred minutes to complete a revolution around the Earth, with an eclipse of about half an hour, resulting from the passage of the satellite through the Earth's shadow. Designed for a 3 years mission period, its power conditioning and distribution unit shall be able to provide, with high reliability, 1820W of continuous power to the spacecraft in a harsh environment of radiation-induced damaged on electronic components, large temperature variations in orbit and extreme vibrations during launch phase.

Figure 1- Artist conception of CBERS satellite.

CBERS3 satellite uses what is called hybrid topology for its Electrical Power Supply Subsystem (EPSS)[1]. A simplified block diagram of the Power Conditioning and Distribution Unit (PCDU) is shown in Figure 2. It is comprised of an energy source named Solar Array Generator (SAG), energy storage from Batteries (BAT), power control and distribution units represented by Battery Charge and Heating Controller (BCHC), Battery Discharge Regulator (BDR), SHUNT and DC/DC converters. The main subsystem functions are a) to convert the incident solar power into electrical power through a solar array generator, b) to store energy in batteries during illuminated periods for use during the eclipse and whenever peak power is demanded, c) to provide a regulated primary main bus, at the output of SHUNT equipment, taking power from the batteries or from the solar array generator, d) to provide secondary regulated buses to the various spacecraft payloads at the required voltage and power levels, e) to monitor and limit the batteries maximum charging voltage, f) to provide controlled heating power to the battery heaters, g) to provide firing power to the electro-explosive devices, h) to provide telemetries to assess the operation of the subsystem, i) to receive telecommands to change the status of the subsystem equipments.

In general, we can say that during sunlight the equipment SHUNT condition a fraction of the power generated by the SAG to provide the stand by consumption of the power bus and the equipment BCHC recharges the battery, by means of the remaining fraction of the solar array generator. It can also happen to the section of the solar generator connected to SHUNT to operate to its maximum capacity and provide part of power bus demand and the equipment BDR provides the complement, removing power from the solar array generator or battery. During eclipse, the BDR provides all the consumption of the satellite, drawing energy from batteries. In either situation above, conditioned power is delivered to the various payloads using DC/DC converters.

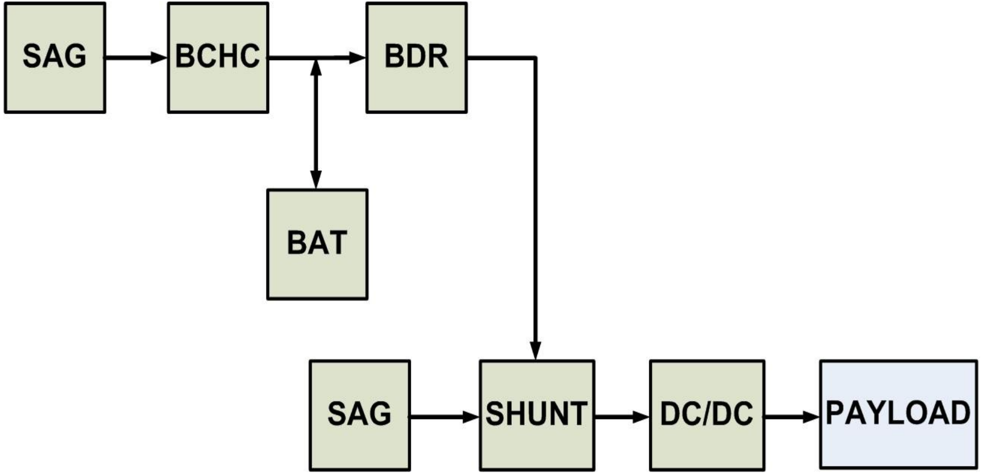

Figure 2 - CBERS power supply block diagram.

Battery performance is one of the most important factors limiting the lifetime of a space mission since it is subjected to extreme operating conditions. In the course of its use, the battery begins to deteriorate and jeopardize the mission. With degraded performance, the battery may not be able to supply other satellite subsystems and the payload, attitude control or onboard computer, resulting in failures of some subsystems, and consequently the deterioration of the mission and reduced life. Moreover, the short time available during the solar battery charge involves the use of fast chargers that use high current values, resulting, under certain conditions, overload and thermal batteries avalanches [2]. These facts lead us to an effort to better understand the various thermo-electric phenomena that exist in battery and affect their functioning, as well as seek ways and control strategies that allow greater autonomy on board of the satellite without the need for operator intervention in soil, which can take several hours before the satellite comes into visibility in the earth stations.

2 Battery charging and heating controller (BCHC)

The purpose of a battery charger is to provide the maximum charge to the battery without causing overcharging. Overcharging a battery, especially at high currents, will shorten its life, its coulomb capacity and dramatically increase its temperature which may cause physical damage to the battery and its surroundings. Thus, the proper use of chargers has been proved, over several decades of experience, one of the factors for prolonging the life of a battery whereas the manufacturing process still plays a major role in battery reliability. Moreover, it's been known that operating the batteries in ranges of low temperature can prolong its life as well as contribute to their better performance. Therefore, these facts call for a system that has both the battery charging and heating functions.
Several techniques for battery charging were studied, among which we highlight current limited, voltage limited, temperature limited, pressure limited and recharge ratio control[3]. These researches resulted in the development of the known temperature compensated end of charge voltages (V/T curves) for Nickel-Cadmium based systems in space applications [4]. Currently, a widely used method of charge is one that makes use of at least two modes of operations such as current limited followed by voltage limited. There are many ways to implement them electronically but this will not be discussed here. We just need to emphasize the behavior of the modes of operations. The transition from the first mode to the second one is defined by one of the V/T curves described above. This process can be viewed in Figure 3.

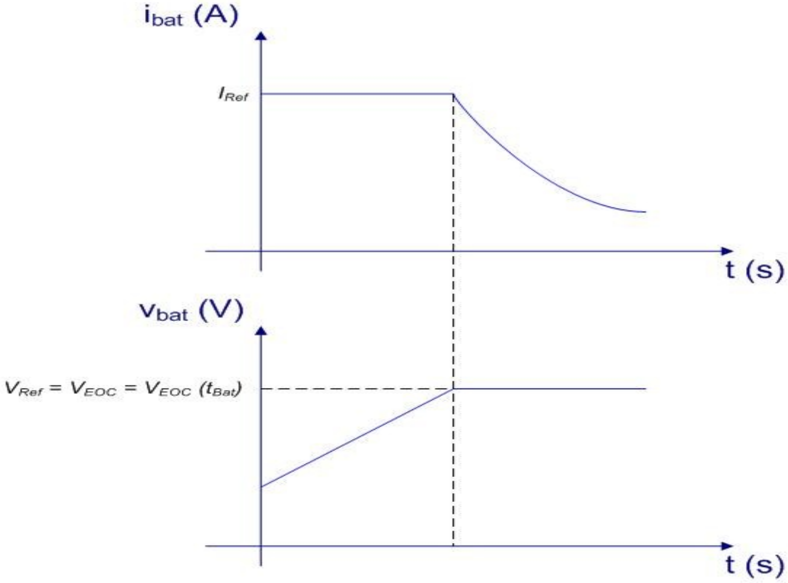

Figure 3 - Charging curves.

To keep the battery temperature within an appropriate range of temperature, it is coupled to a source and a drain of heat, represented respectively by a heater and a radiator (RAD). The power supplied by the heater and used to heat the battery come from equipment BCHC. Thermal greases are used to make thermal contact between the battery and radiator, preventing air bubbles. In the case of satellite CBERS, the heat applied by BCHC depends on the temperature of the battery and is such that above 10ºC no electrical power is applied to the heater and at 0ºC is applied a power named P_M . These temperature limits (0-10ºC) represent the range in which we want to keep the battery temperature. As the applied electric power to a resistor varies with the square of the voltage, the heat source has a parabolic curvature between these two extremes. There is also a saturation of this curve above 10 ºC and bellow -1ºC. The drain of heat through the radiator to deep space depends on its temperature and has also a non-linear relation because the heat radiated to space varies with the fourth power of its temperature.

As the battery passes from charge, overcharge and discharge reactions it goes simultaneously to an endothermic, exothermic and exothermic process, respectively. Thus we can distinguish three internal source of heat generation due to electrochemical processes[3]. The total heat is the sum of the heat generated by the charge of active battery material (endothermic process), the heat generated by the reaction of overcharge (exothermic process) and heat generated during discharge (exothermic process) as already defined in equations .

Figure 4 and Figure 5 shows diagrams for what has just been described.

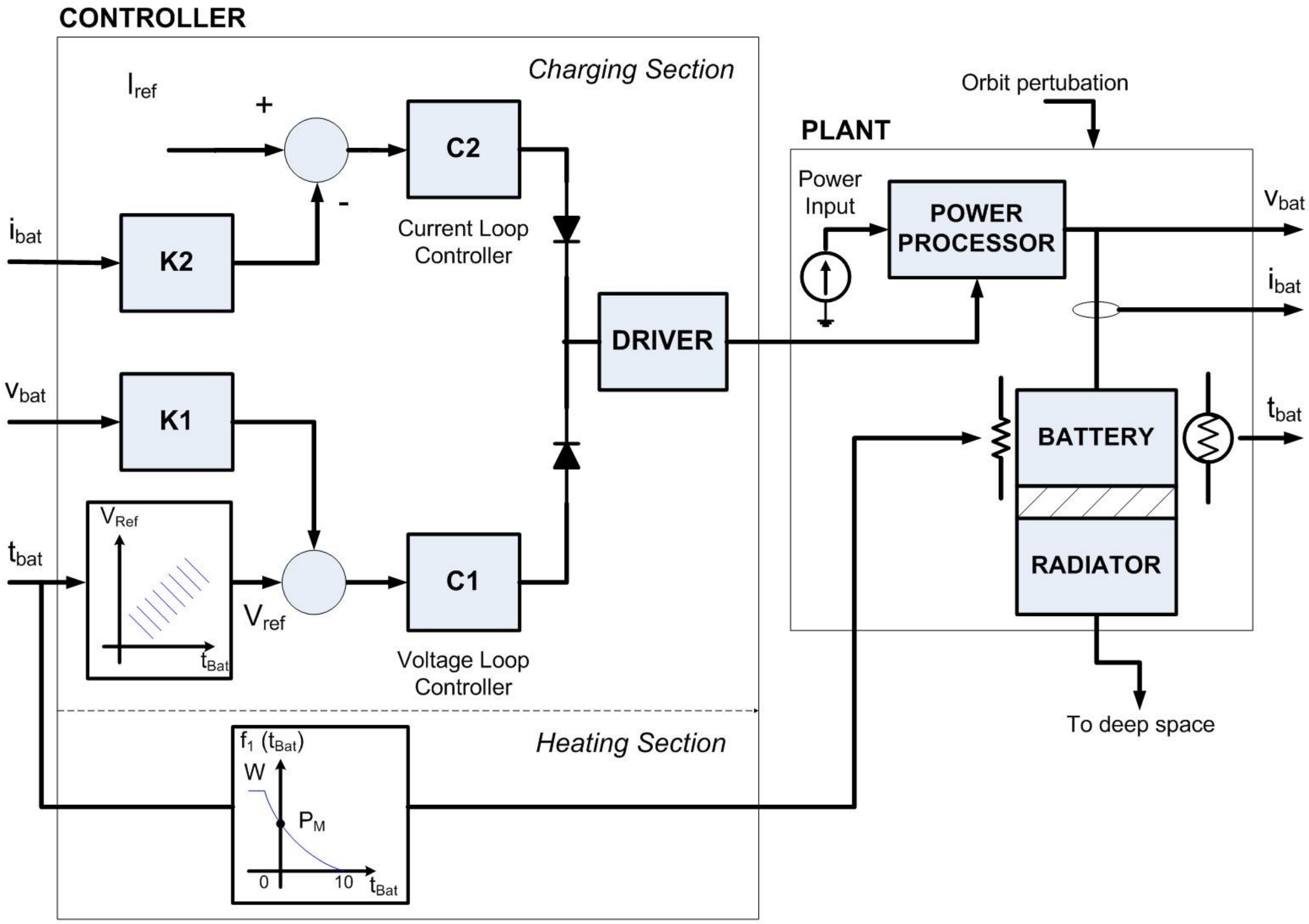

Figure 4- Battery heating and charging block diagram.

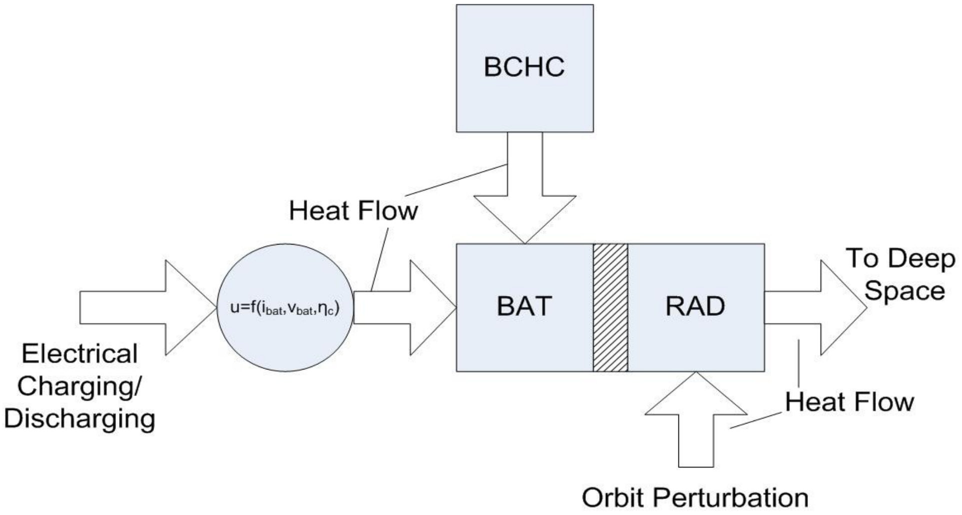

Figure 5- Diagram of battery heat flow.

3 Conclusion

In this article the CBERS satellite battery charging/discharging system was briefly presented. It was discussed how the system works during flight and it was presented the risk of battery thermal runway that exist in such system.

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5 References

1. Sullivan, D.O. Satellite Power System Topologies. ESA Journal, 13:77-88, 1989.
2. Ratnakumar, B.V. ; Timmerman, P. ; Stefano, S.D. Simulation of Temperature-Compensated Voltage Limit Curves for Aerospace Ni-Cd Batteries Using a First Principles Model. Journal of Power Sources, v.63, pp.157-165,1996.
3. Scott, W.R. ; Rusta, D.W. Sealed-Cell Nickel-Cadmium Battery Applications Manual. NASA Reference Publication 1052. Greenbelt, Maryland: GSFC, 1979.
4. Ford, F.E. ; Rao, G.M. ; Yi, T. Y. Handbook for Handling and Storage of Nickel-Cadmium Batteries: Lessons Learned. NASA Reference Publication 1326, p.10. Maryland: NASA, 1994.