Development of Lithium Ion Power System for Satelite

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The lithium ion battery emerged in the commercial market in 1991 and introduced new technology advantages over its energy storage predecessors. Lightweight, high energy density and low maintenance are among the key advantages that it offers. Ten years after its debut, lithium ion secondary battery makes its first orbit around the Earth.

Since then, lithium ion is considered the next milestone in rechargeable batteries. In order to be at the forefront of space technology, it is critical that we work towards achieving this technical know-how and prepare ourselves for the challenges ahead. The power system is proposed to be as efficient as it can be so that modularity can be achieved.

The system consists of the Battery Charge Regulator (BCR), Battery Control Module (BCM) and Cell Balancing Circuit (CBC). Each of the module design is kept modular and independent of each other. This approach is selected so that the module can be customised to the specific requirements of different satellites.

BCR employs a buck type switching converter to charge the battery, while BCM uses analogue and digital control to monitor the battery charge and discharge current. In order to ensure the maximum lifetime of the battery, CBC is employed. The cell's voltage deviation in lithium ion battery pack is kept at a low rate of 2% in order to utilise its capacity to the fullest.

The advantages of the lithium ion battery seem promising for satellite applications, while cell manufacturing technology keeps advancing. Hence, to be at the forefront of space technology, Astronautic Technology (M) Sdn Bhd (ATSB) is pursuing the use of the lithium ion power system for the satellite to take advantage of its benefits.

1.0 INTRODUCTION

ATSB is currently developing the lithium ion battery power system for spacecraft use. The power system development shall be designed to be as efficient as it can be so that modularity can be achieved. The development objectives of the Lithium Ion battery charger system are:

- To encourage in-house development capabilities
- To develop a lithium ion battery charger system for space application. The system can be customised to suit future mission undertaking.
- To keep the design at modular based for expansion and design flexibility
- The baseline is to develop charger system for +28V bus voltage, 600W power handling capacity.

2.0 OVERVIEW

2.1. Lithium Ion battery history

- The first non-rechargeable commercial lithium metal battery was introduced in the 1970s. The technology seemed promising at that time because it provided high energy and mass density compared to other energy storage.
- In the early 1980s, attempts to commercialise rechargeable lithium metal failed due to instability and safety issues. The cells tend to explode when overcharged with high current.
- The unstable lithium metal was replaced with non-metallic lithium (carbon based) that consists of lithium ions. Although the energy density is lower compared to lithium metal, it is safer provided that precautions are taken during charging/discharging.
- In 1991, Sony started producing its 18650 rechargeable lithium ion cells for commercial use.
- In 2000, the first space-qualified lithium ion battery pack built from Sony's 18650 cells were flown on board the STRV satellite.

2.2. Why lithium ion?

The key factors that lithium ion technology offers are:

- High volume energy density, Wh/l – twice that of nickel cadmium
- High mass energy density, Wh/kg – less weight for the same energy
- High voltage per cell, 3.6V – one lithium ion cell equivalent to three NiCd cells
- Linear discharge curve – fuel gauging potential
- Low maintenance – no scheduling cycling required
- No voltage depression due to repetitive cycling – NiCd symptoms eliminated
- Low self-discharge, almost half of NiCd – long storage/shelf life
- Environmental friendly, lead and cadmium free – NiCd manufacturing plant slowly reduced or moved, strict regulations from the government

However, for all the benefits that it offers, the penalties for such a system are:

- Monitoring and protection circuit needed – to maintain voltage, current and temperature within the safety limit
- Moderate discharge current – parallel configuration needed for higher load current
- Single cell monitoring required – highly reactive lithium material may combust/explode if charged or discharged at a very high rate

2.3. Comparison with other battery

Figure 1 shows the energy density comparison between the lithium ion battery and other commercial batteries. From the figure, lithium ion clearly has an advantage over other types of batteries. Although lithium polymer (Li-Poly) packs a higher energy density, the manufacturing technology is still new and is unable to deliver uniformity between cells.

2.4. Potential and heritage in space application

The various advantages of lithium ion make it a potential candidate as a future energy storage device in space applications replacing the already proven nickel cadmium. As stated before, the following are the advantages:

- High volume energy density (Wh/l) – less space required to achieve a specific amount of energy. Space is critical especially in small but high powered spacecraft.
- High mass energy density (Wh/kg) – keeping the spacecraft's mass down.
- High voltage per cell – lower cell count in a pack. Only eight cells of lithium ion is needed for a 28V battery pack compared to 24 cells in NiCd.
- Low maintenance – no scheduled cycling needed. Scheduled cycling can disrupt the spacecraft's ability to provide timely activities (imaging, data downloading)
- Low self discharge – long storage/shelf life. With its low self-discharge, which is almost half of NiCd, maintenance is easy in case of launch delay. Less maintenance equals to less charge/discharge, which equals to longer battery life.

3.0 LITHIUM ION BATTERY POWER SYSTEM DEVELOPMENT

The baseline specifications for the development are that the power system shall cater to a spacecraft with +28V bus voltage and 600W power handling capacity. The baseline was selected from the perspective of upgrading the current RazakSAT™

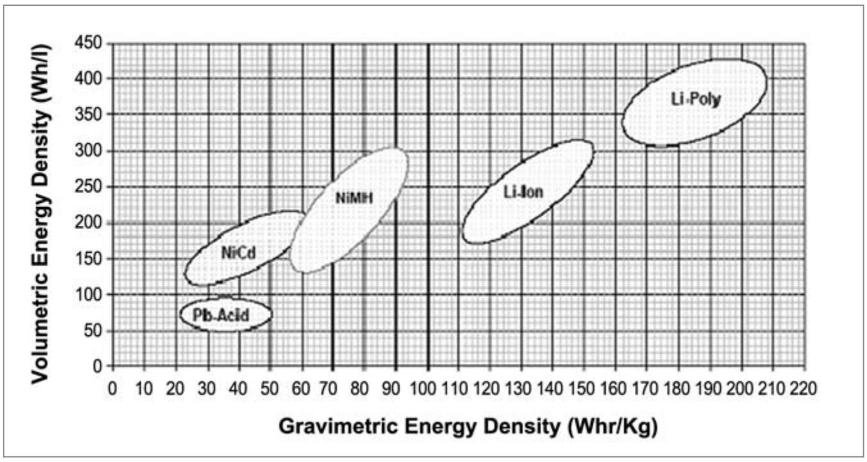

Figure 1: Lithium ion comparison (volumetric and gravimetric) [1]

Table 1: Space-qualified lithium ion comparisons [2]

	NiCd	NiH_2	Li-Ion	System Impact
Energy density (Wh/kg)	30	60	125	Weight saving
Energy efficiency (%)	72	70	96	Reduction of charge power: solar panel
Thermal power (scale: 1-10)	8	10	3	Reduction of radiator, heater pipes sizes
Self discharge (%/day)	1	10	0.3	No trickle and charge at launch pad
Temperature range (°C)	0 — 40	-20 — 30	10 — 30	Management at ambient
Voltage depression	Yes	Yes	No	No recondition
Energy gauge/monitor	No	Pressure	Voltage	Observable state of charge
Charge management	CC[1]	CC[1]	CCCV[1] + Balance	Parts increase
Modularity	No	No	Yes	One cell design, ability to put cells in parallel

CC = Constant current   CV = Constant voltage

Table 2: Lithium ion heritages in space [3]

Program	Customer	Launch	Energy (Wh)	Satelites
STRV 1d	DERA UK	Nov 2000	100	1
Rosetta	Matra Marconi Space	2003	1069.2	1
Roland	CNES	2003	73	1
Roland-2	CNES	2003	148.6	1
Mars Express	Matra Marconi Space	2003	518.4	1
Beagle2	Matra Marconi Space	2003	291.6	1
PROBA	ESA	July 2001	194.4	1
SCI SAT	CSA	2002	388.8	1
Microsat Bus	CNES	2003	345.6	4
ESSAIM	ASTRIUM	NA	NA	4
New Millenium ST5	NASA	2003	54	3
				Total: 19

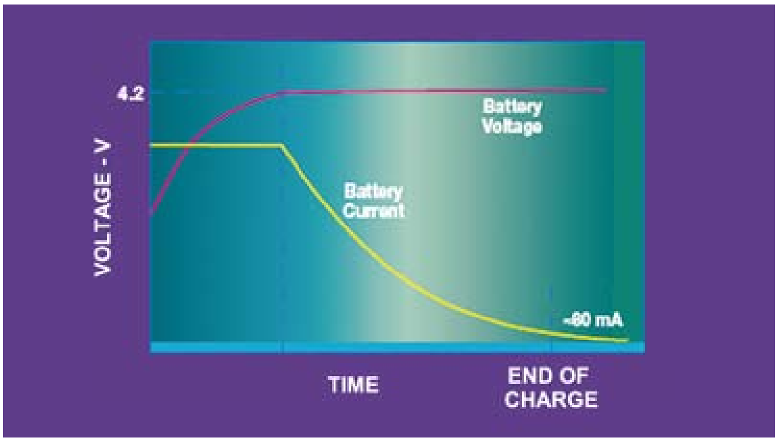

Figure 2: Lithium ion charge characteristics [4]

Figure 4: Battery charge regulator

power system for future missions.

Lithium Ion battery charger system development:

- The objective is to develop a lithium ion battery charger system for space application. The system can be tailored to suit future missions undertaking.
- The baseline is to develop charger system for +28V bus voltage, 600W power handling capacity.

3.1. System overview

The proposed system will consist of a Battery Charge Regulator (BCR) rated at 600W, Battery Control Module (BCM), Cell Balancing Circuit (CBC), Power Supply Module (PSM) and 20Ah lithium ion battery pack. Details of each module are described as follows.

3.1.1. Battery charge regulator

The Battery Charge Regulator regulates the charging current to the battery and supplies electrical power to the load during the sunlit period. The constant current-constant voltage (CCCV) method is selected for charging the lithium ion battery. Constant voltage must be regulated precisely to avoid affecting the charging capacity or overcharging. The nominal charging current for the lithium ion battery will be set between 0.5C to 1C and a full charge voltage (FCV) of 4.2V for each cell.

Figure 2 shows the charge characteristics of the lithium ion battery. In order to charge the battery efficiently, the charger will charge with constant current until the battery reaches an 80% state of charge (SOC). The charger will change to constant voltage preset at 4.2V and the charge current will be slowly tapered down. This is due to the fact that lithium ion cannot accept trickle overcharge as nickel cadmium does. The tapered charge current will be slowly reduced to 0.03C for about two hours. At this point, the battery is charged to its full capacity.

Table 3: Battery charge regulator specifications

Parameters	Specifications	Remark
Charger type	Buck type	
Capacity	> 600W	
Redundancy	Yes	Cold Standby
Efficiency	> 95%	
Over current limit	0.5C	Battery dependant
Control method	PPT and CC to CV	CV (32.8V)

3.1.2. Battery control module (BCM)

Battery Control Module (BCM) monitors and controls the status of the battery. It monitors the charging and discharging current/voltage. The battery pack temperature is also monitored. BCM controls the constant current (CC) charging the battery for approximately 50 minutes (from 0% capacity) until it reaches 4.2V. Full charge is achieved when the battery reaches the upper voltage threshold, the current drops and levels off at about 3% of the nominal rating (0.03C). BCM will ensure that the battery will be charged within these parameters.

Among the BCM's capabilities are:

- Over current limit (1C)
- Over discharge current limit
- Over voltage limit (4.2V)
- Over discharge voltage limit (cut-off 3.0V)
- Constant current (0 - 80%)
- Constant voltage (80 - 100%)
- Temperature control (0 – 40°C)
- Battery capacity timer

3.1.3. Cell balancing circuit

Overcharging lithium ion will cause damage to its active material. BCM will ensure that overcharging does not occur to the battery. However, a lithium ion battery pack is made up of several cells to achieve its desired voltage. The cell tends to deviate after a certain amount of time. This deviation is caused by several factors that will not be discussed here. [5]

This cell deviation or cell imbalance affects other types of battery as well such as lead acid and NiCd. In the case of lead acid, the cell imbalance can be treated by using controlled overcharge. However, lithium ion cannot tolerate prolong overcharge without causing damage to itself.

A trade off study between different cell balancing methods is currently being performed. There are several balancing methods to consider, each with its own advantages and disadvantages. In general, cell balancing methods are divided into active and passive methods.

The right method or a combination of methods is needed to apply the cell balancing technique onboard a spacecraft. These methods shall take into account the requirements and limitations faced when designing a system for a satellite power system. The next step is to select and test the conceptual Cell Balancing Circuit based on the method selected.

3.1.4. Lithium ion battery power system architecture

- The system consists of a solar array simulator capable of supplying 600W, Battery Charger Regulator (BCR) rated at 600W, Battery Control Module (BCM), Cell Balancing Circuit (CBC) and a 20Ah lithium ion battery pack.

- The battery pack will provide +28V unregulated bus ranging from 24V to 32.8V. The battery pack topology will be 8s x 2p to achieve 20Ah capacity.

3.2. Development plan

The development is as below:

1. Lithium ion characteristics
   - Search and collect materials
   - Study and review
   - Comprehensive report

2. Lithium ion battery
   - Commercial cells
     - Assembly and testing
   - Commercial cells
     - Cell protection
     - Assembly and testing

3. Charger system (Battery Charge Regulator)
   - Power converter study
   - Buck converter study
   - RazakSAT™ BCR study
   - Appropriate design sizing
   - Manufacture and test

4. Controller system (Battery Control Module)
   - Control scheme requirements
   - Analog based control system
     1. Test and verify
   - Microcontroller based control system
     1. Test and verify

5. Power supply board
   - Test and verify

6. Cell balancing system
   - Test and verify

7. Battery packing
   - Purchase and select (screen) cells
   - Cell level characteristics testing
   - Battery protection circuits
   - Battery level characteristics testing
   - Integration testing with charger and controller

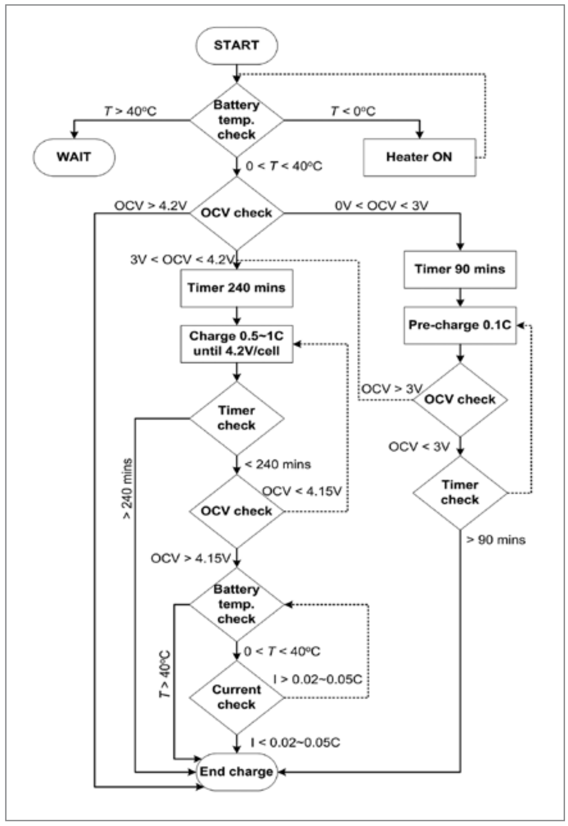

Figure 5 - Battery control module flowchart

Table 4 – Battery control module specifications

Specifications	Requirement	Remark
Current Range	TBD	Battery dependant
PPT	Analogue Method	
	Digital Method	μ controller based
PPT Error	< 2%	
Solar Panel Voltage and Current TLM	SP Voltage (0 ~70V) SP Current (0 ~10A)	
Over Voltage Protection	32.8V	4.1V (per Cell)
Under voltage Protection	24V	3V (per Cell)
ADC	10bits	Voltage, Current and Temperature monitoring
DAC	8bits	BCR Control

Table 5: Cell balancing methods

Methods		Advantages	Disadvantages
Passive	Charge shunting using capacitor	• Fixed rate switching	• slow charge transfer • large capacitor for high current
	Energy converter using transformer	• Fixed rate switching	• Fixed rate switching
Active	Charge shunting using resistor	• Minimum parts • Easy implementat ion	• Power dissipate at high current • Thermal control

Table 6: Cell balancing circuit specifications

Specifications	Requirement	Remark
Balancing Error	> 2%	Charge shuttling (TBD)
Cell Monitoring	8 cells	28V bus voltage

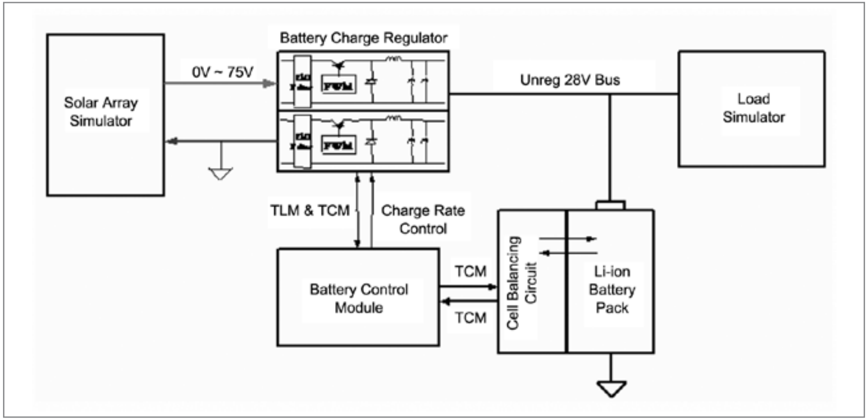

Figure 6: Lithium ion battery power system architecture

3.3. Conclusions

The main driver for this project is the knowledge and experience gained for the engineers involved. The test results conducted for qualifying the system for space application will be published in order to create awareness and get feedback from the respective community.

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