4.4.1. Cell Designs and Performance

Li-ion cell development started in 1996 with the Stentor program. VES140 cells performed their first space flight in 2003 after having successfully passed the qualification in 2001 [10]. At the end of 2012, there were more than 70 satellites in orbit powered by VES Li-ion batteries. Most of them are GEO telecommunication satellites cumulating >1 MWh in orbit.

The current range of Saft Li-ion cells for satellites comprises four formats: VES16, VES100, VES140 and VES180 (Figure 14.17). These cell designs have been qualified for GEO, LEO and MEO missions.

This space-designed Li-ion cell range is based on positive electrodes containing lithium nickel cobalt aluminum oxide (NCA) that ensure long life thanks to the lithium excess—a specific characteristic provided by the NCA materials. By inserting excess Li^+ into the negative electrode during the first charge, the nickel-based oxide allows to benefit of an additional negative capacity, also called negative reserve. The energy or capacity degradation over the mission duration is then reduced drastically thanks to this negative lithium excess that acts as a reserve. In addition, NCA offers the highest specific energy compared to other positive active materials. Another important advantage of the NCA material for satellite applications is its very good stability during cycling. As shown in the following paragraphs, the real-time life test performed on VES140 has demonstrated 12 years with absolutely no degradation compared to the BOL energy.

The VES100, VES140 and VES180 cells (capacity of 26, 40 and 50 Ah) have the same 53 mm diameter with different heights (160–250 mm). The highest specific energy is provided by the VES180, i.e. 175 Wh/kg. Designed from an industrial cell dedicated to electric vehicle (EV) applications, the VES range has Al casing with specific space environment qualified terminals which guarantees a He leak rate lower than 10^{-7} cm^3 atm/s. The cell container design complies with the requirements of leak before burst. Individual

FIGURE 14.17 Saft Li-ion space cell range: VES16, VES100, VES140, VES180 and MPS cells. (For color version of this figure, the reader is referred to the online version of this book.)

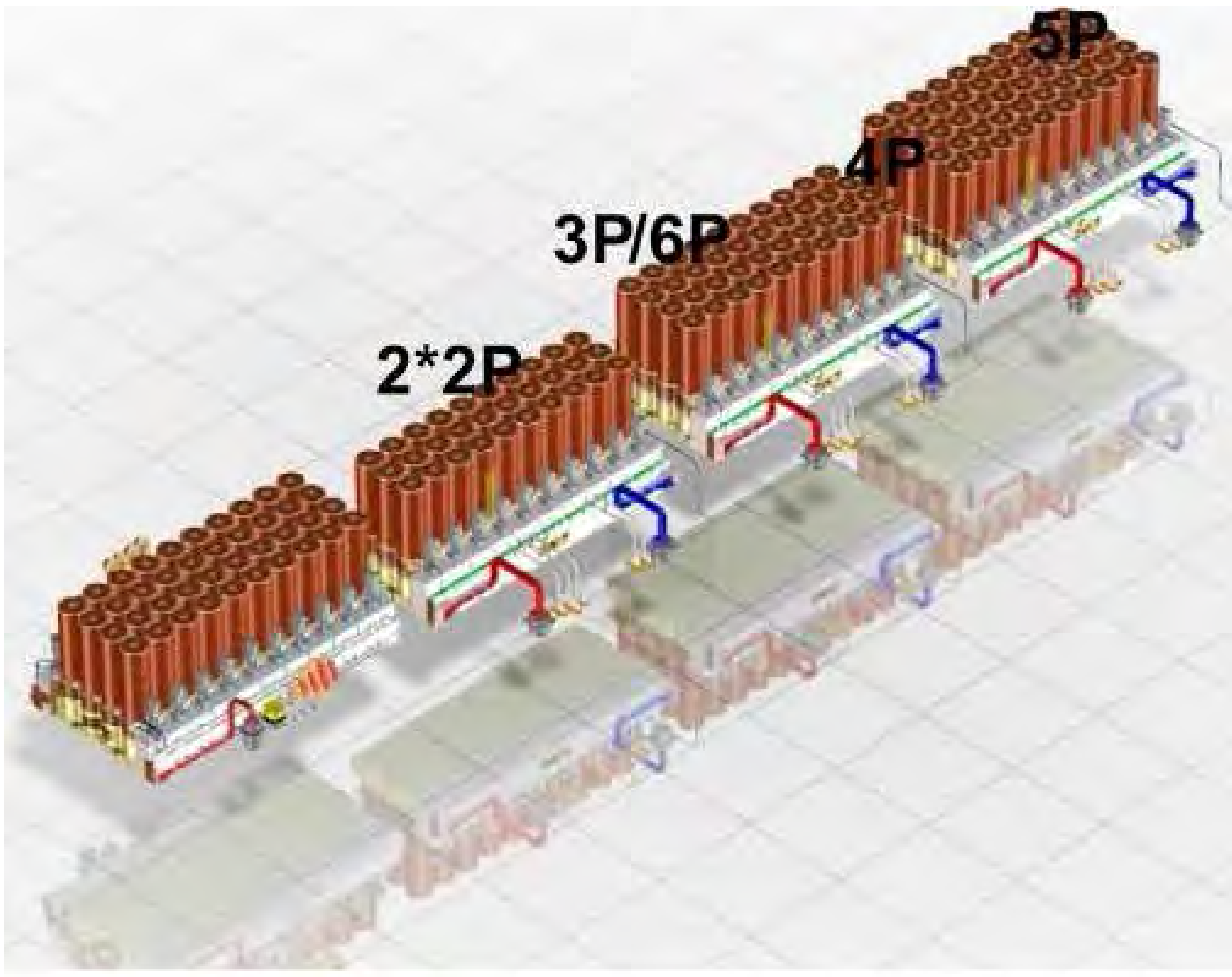

FIGURE 14.18 Example of VES batteries configurations. (For color version of this figure, the reader is referred to the online version of this book.)

a modular assembly approach. Bypass systems are implemented in Saft batteries to cope with cell failure and avoid risks for the full battery. The main requirements for bypass selection are: be compatible with derating rules, have no unmitigated single point failure when coupled to the battery, avoid open circuit on battery serial circuit and failure propagation leading to loss of mission or safety issue.

Moreover, Saft is proposing battery designs with integrated balancing system to optimize the available energy during the all battery's life. This is achieved by associating to the battery module a management system, named intelligent surveillance integrated system (ISIS). The main ISIS functions are: balancing (which optimizes battery life and available energy), bypass activation, cell package voltage telemetry supply and the disposal function to make the battery inert at the satellite's EOL.

An associated range of battery has been designed to make the VES16 cell suitable for small configurations (4S bus, 3P capacity) and large configurations (10S and up to 56P). Typical battery configurations using S-P topology are presented in Figure 14.19. This building block approach allows covering a large range of bus voltage and power. This battery range includes an individual simplified balancing system (SBS) to ensure lifetime, individual voltage telemetries, heaters and connectors.

4.4.3. Model

The satellite Li-ion model called SLIM is available to the space community to perform a battery selection and make a projection of the performance at EOL. The SLIM model [14]:

- Predicts the EOL parameters for LEO/MEO and GEO missions at the battery level
- Is based on electrochemical characteristics: energy, capacity, EMF, internal resistance, end of charge voltage, etc
- Is a macroscopic model based on energy (global at cell level)

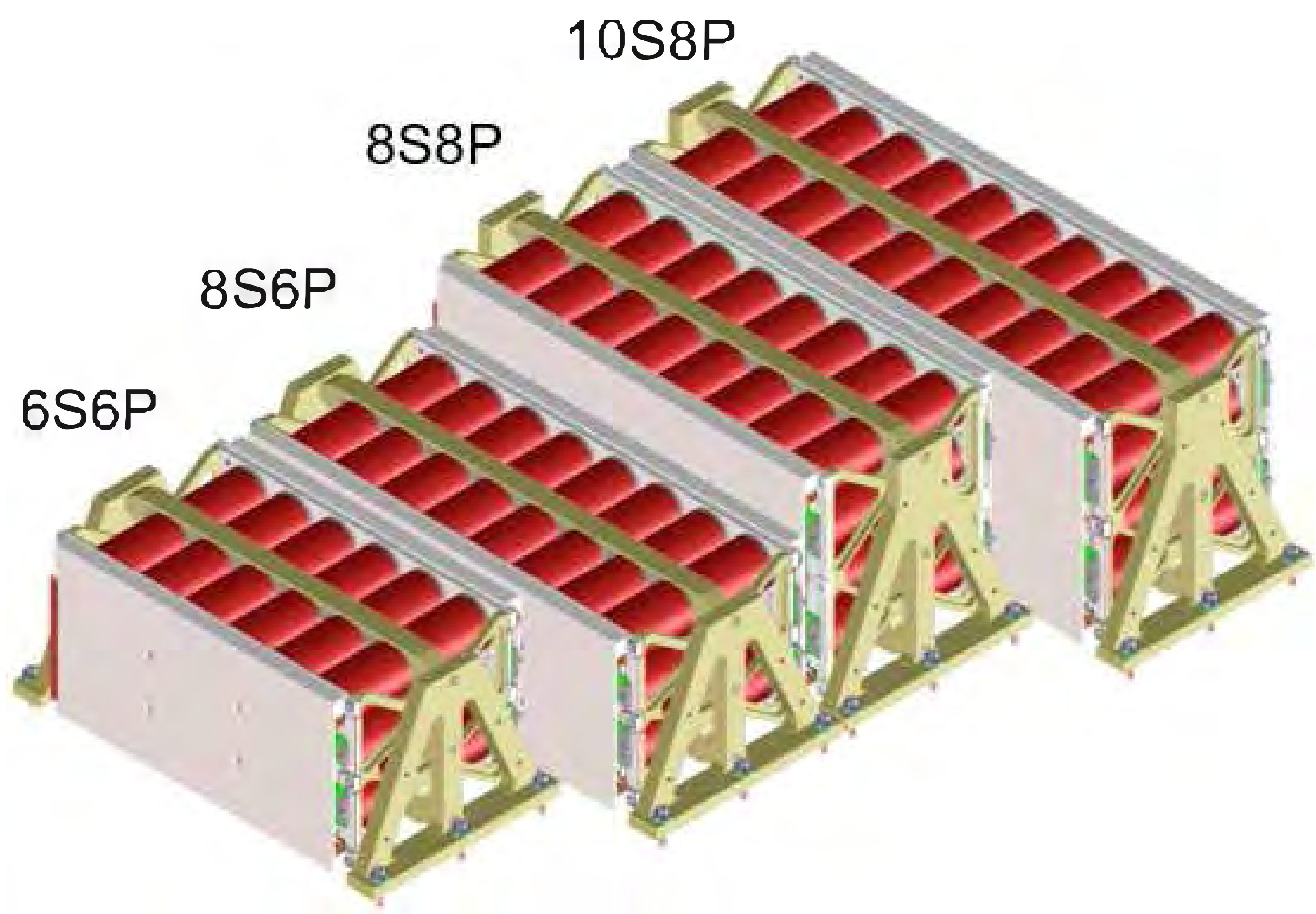

FIGURE 14.19 VES16 building blocks. (For color version of this figure, the reader is referred to the online version of this book.)

- Uses fading and calendar effects on energy and internal impedance vs. time, temperature, end of charge voltage, etc
- Uses mission figures: power, duration, DOD, end of charge (EOC) voltages, temperatures during eclipses and solstices, cell failures
- Gives cell and battery voltage profiles, energy evolution through the lifetime (nominal and failure cases).

The model outputs have been checked with the ground-life test results and in-orbit battery telemetry data showing a very good reliability and accuracy (<3% spread).

4.4.4. In-Orbit Experience

By the end of 2012, more than 90 satellites have been launched with Saft Li-ion batteries on-board cumulating ’1 MWh. The first successful launch was SMART 1 (2003) by the European Space Agency. The first GEO telecommunication satellite ever launched with Li-ion batteries was W3A for Eutelsat. Manufactured by Astrium, W3A is still powered by a 18.5 kWh Li-ion battery which exhibits no energy loss after >8 years in orbit. Sixty-five GEO telecommunication satellites have followed, thus forming the largest Li-ion battery fleet. In addition to Giove B, the first four Galileo satellites have been launched with VES batteries in October 2011 and November 2012 [15,16].

4.4.5. Summary

Since the 60s, Saft is a world leader in the battery market for satellites, having equipped more than 650 satellites for all mission types. Saft is the only space battery company to have mastered the three main electrochemical systems for satellites: Ni–Cd, Ni–H_2 and Li-ion. Thanks to the synergies with other Li-ion applications, satellite batteries will take