Electrical Passivation Needs for Zero Debris

Clean Space Days 2024

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Content

1. Conflicts with the power system
2. Rationale for Passivation implementation
3. Passivation Requirements overview
4. Current state of the technique
5. Challenges
6. Future needs

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Conflicts with the power subsystem

- ECSS-E-ST-20C Space engineering Electrical and electronic

The power subsytem of a spacecraft shall be able to generate, store, condition, distribute and monitor the electrical power used by the spacecraft throughout all the mission phases and in the presence of all environments actually encountered

- Typical power subsystem SRD related requirements

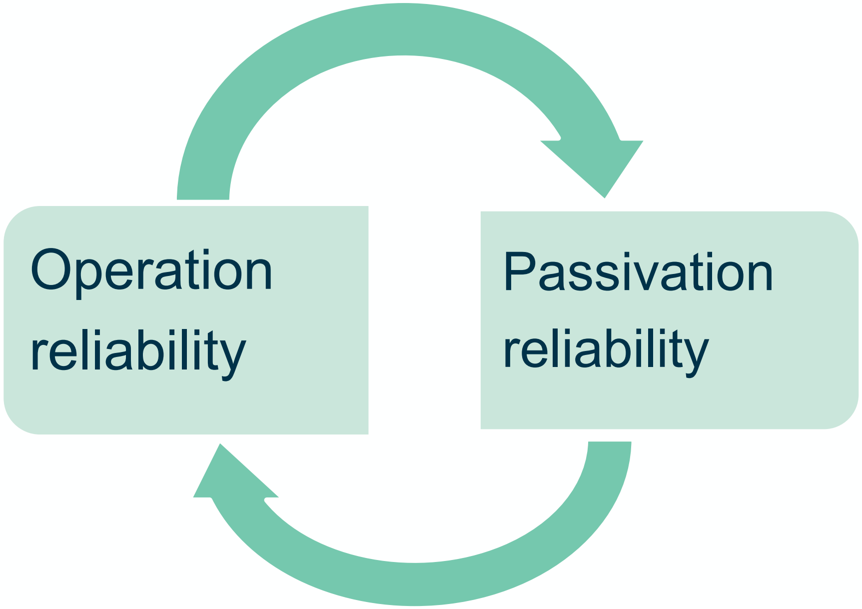
The power subsytem shall be capable of operating continuously after any single failure, considering all operational conditions and contingency situations

In case of a dead-bus scenario, the power subsystem shall be capable of autonomously recover all its full functionality and to build enough energy reserve to reach a safe mode

Conflicts with the power subsystem

And now, on top of that…

Passivation command to kill the power of the spacecraft



Content

Rationale for Passivation implementation

- Is a spacecraft eletrical passivation really needed?

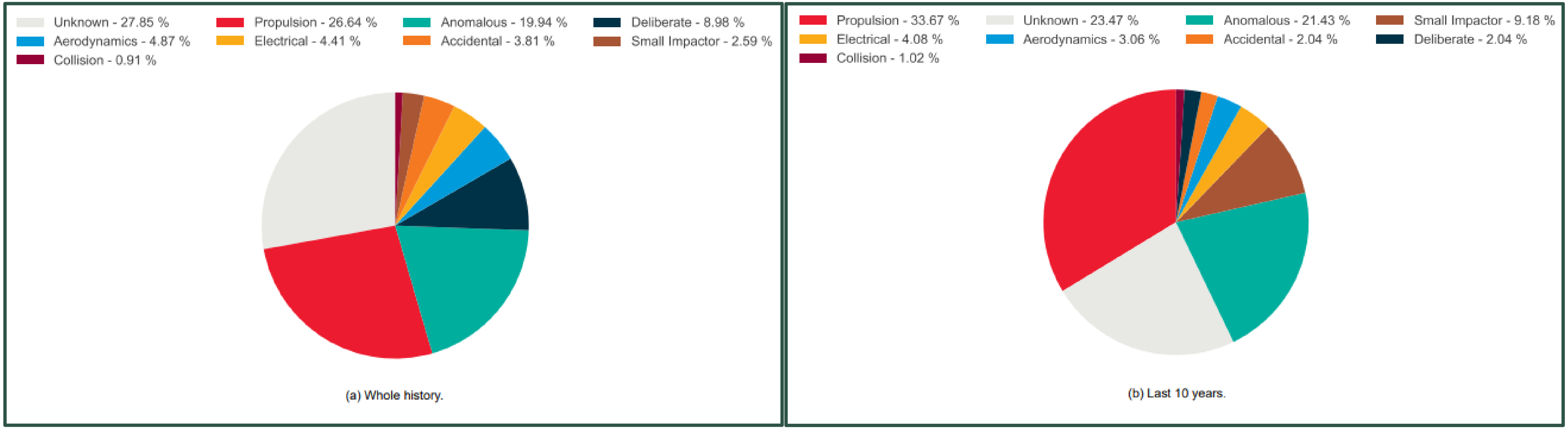


Fig. Event causes and their relative share for all past fragmentation events up to April 23

Source: ESA's Annual Space Environment Report Sept. 2023

Rationale for Passivation implementation

- At least two spacecraft created fragmentation events within the last 10 years due to the batteries

- No Li-Ion battery explosions in orbit so far

- However, risk with this batteries is still there

Rationale for Passivation implementation

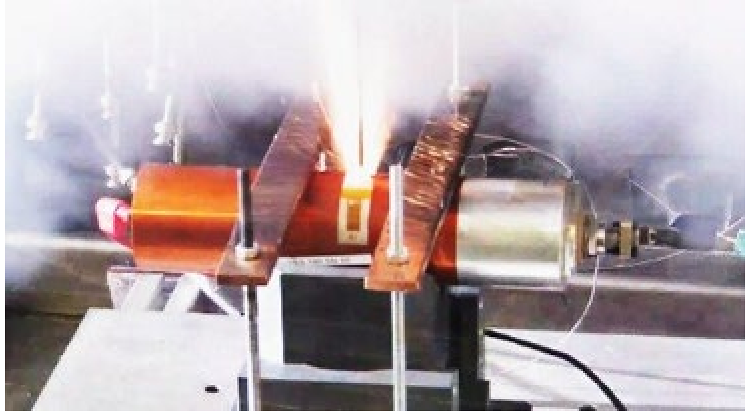
- Alert EA-2020-EEE-1-A, Active

Internal safety device on Li-Ion cell not preventing catastrophic event during battery overcharge

- Abuse Test Activity on Li-Ion cells / batteries confirming the risk

Batt. Module explosion

Micrometeorid impact test



Internal short-circuit test

And many more funny tests…

Rationale for Passivation implementation

Content

Passivation Requirements overview

- ESSB-ST-U-007 Iss1 ESA Space Debris Mitigation Requirements

5.3.2.2a
A spacecraft or launch vehicle orbital stage operating in Earth orbit shall include passivation capabilities

Always!!

5.3.2.2b
A spacecraft or launch vehicle orbital stage operating in Earth orbit shall passivated before the end of life unless a successful controlled re-entry is performed

Just if no re-entry

5.3.2.2c
A spacecraft or launch vehicle orbital stage operating in Earth orbit shall be designed to guarantee a probability of successful passivation through to the end of life of:

1) **At least 0.90**
2) **At least 0.95, when operating in the LEO protected region in an orbit with a natural orbital decay duration longer than 25 years**
3) **At least 0.95, when GEO protected region**

Passivation reliabilty

Passivation Requirements overview

- ESSB-ST-U-007 Iss1 ESA Space Debris Mitigation Requirements

5.3.2.2d
The passivation shall be executed by one of the following means, in order of preference:
1) **Permanently and irreversibly deplete and prevent future loading**
2) **Demonstrate that a safe level is reached**

How to passivate

Content

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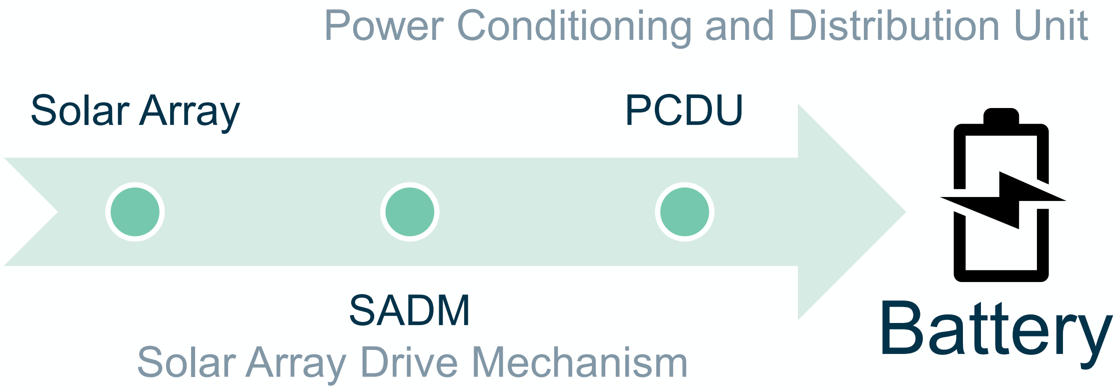
Current state of the technique

Power path from the energy source to the battery in a typical spacecraft

Fig. LSTM. Earth Observation satellite in LEO



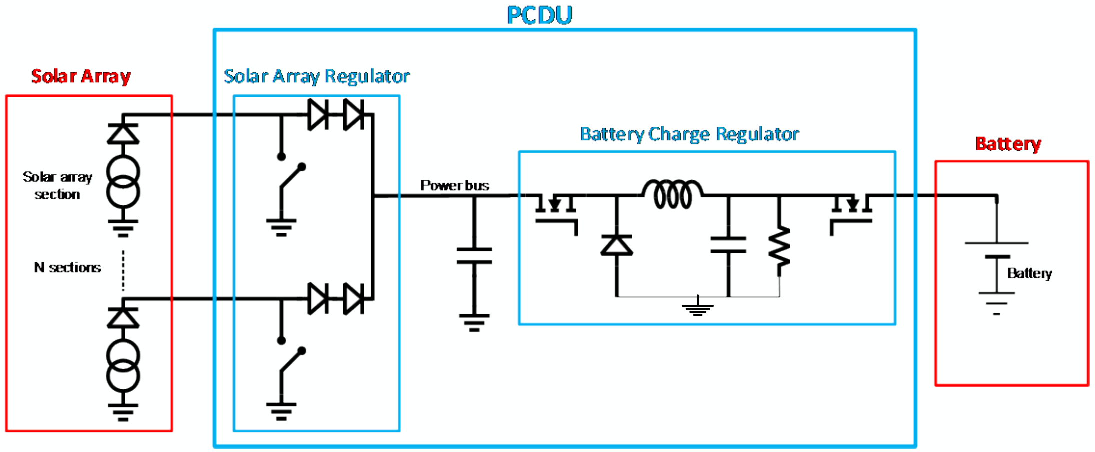


Fig. Reduced block diagram of a power subsystem example

Current state of the technique

1. Disconnect the battery from the source of energy (Solar Array) to prevent future loadings

Most common solution (today) is to use HW already existing along the power path to interrumpt the transfer of power from the solar array to the battery:

- **Example 1 (old): By opening the battery relay connection inside the PCDU**
- **Example 2: By opening the switches of the solar array regulator converter or by shunting the switches of the solar array sequential synchronous shunt regulator inside the PCDU**

More robustness is provided to the passivation function if it acts on several circuitry inside the PCDU, e.g.:

- **The above-mentioned switches**
- **Disconnecting PCDU auxiliary supplies**
- **Inhibiting the PCDU MEA (Main Error Amplifier) signal to request 0 power to the subsystem**

Even more robustness is achieved if additional switches are introduced (e.g. short-circuiting solar arrays to ground via high power relays

Ideally not directly in the power path

Current state of the technique

2. Deplete completely or discharge the battery to low State Of Charge (SOC) within aceptable risks

Option A
Connect the battery to a discharge network in order to achieved a controlled depletion of the battery

Option B
Discharge the battery as much as posible with the main bus normal loads. Once the battery is disconnected, discharge slowly the battery with the leakages on the power system (leakage discharge current towards PCDU, battery shelf-discharge…)

Current state of the technique

Most used switching devices

Relays

MOSFETs

GaNFETs

Content

Challenges

Limitations in the devices used

Relays	MOSFETs	GaNFETs
• Low current capability when conmuting • Mass & Area for high power relays • Shock & Magnetic Interactions	• Radiation effects at End of Life • Temperature ratings and temperature cycling effects	• Radiation effects • Temperature ratings and temperature cycling effects

Challenges

Reliability figure requested for passivation activation challenging in some conditions (lifetime, radiation, temperature…)

Compromise between passivation activation reliability figure and high reliability for nominal operation (risk of unintentional passivation, complexity to provide hiRel to both functions…)

Solutions are mission specific and spacecraft's platform specific. A generic bullet proof solution for all spacecrafts and missions is inconceivable with the current state of the art

In occasions, hard to justify the solution selected with reliable data:

- No life test cycling data on the switches used under the temperature ranges and radiation expected
- No sufficient data for thermal runaway at battery module level at a given SOC
- Need of relying on electronics for a very extended temperature range once thermal control is lost

In the last recent year several activities have been implemented by ESA in collaboration with industry to face these challenges and improve the weakness areas

Content

Future needs

Things to come…

Passivation activation

- Reliability figure for passivation activation to be increase even further

Keep passivation after EoL

- Reliability figure for keeping the spacecraft passivated after EoL to be requested

Need of a dedicated passivation device?

- Not an aside function for the current power units, but a main function of a dedicated power unit

Need of a mechanical / chemical solution?

- If future requests move into this direction… Maybe electronics are not sufficient

The end… Thank you!