ThalesAlenia Space
a Thales / Leonardo company

EDDA EUROPEAN DIRECT-DRIVE ARCHITECTURE

The project has received funding from the European Union's Horizon 2020 Space Research Program under Grand Agreement N°870470

DIRECT-DRIVE ARCHITECTURE FOR SOLAR ELECTRIC PROPULSION

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1 - INTRODUCTION

- /// Solar System exploration requires high power electric propulsion to move heavy payload over long distance
- /// Power systems will have to generate and distribute several tens of kW
- /// For inner planet of solar system, current approach is to use 100V solar array, MPPT converter and PPU with converter
  - / Mass, cost and dissipation will become more and more difficult to handle with power increase
- /// « Direct-Drive » for Solar Electric Propulsion intends to remove every converter between solar array and electric thruster
  - / Less dissipation, more power available, less mass and cost
  - / Direct drive is a virtuous circle, mandatory for Deep Space Exploration using SEP
- /// The Horizon 2020 project «European Direct-Drive Architecture » gathers a consortium that will study, manufacture and test a large representative mockup.

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2 - SOLAR ELECTRIC PROPULSION IN SOLAR SYSTEM

/// Solar flux decreases quickly with sun distance

/// Beyond the asteroïd belt, using solar array to power high power electric propulsion is **not reasonable**

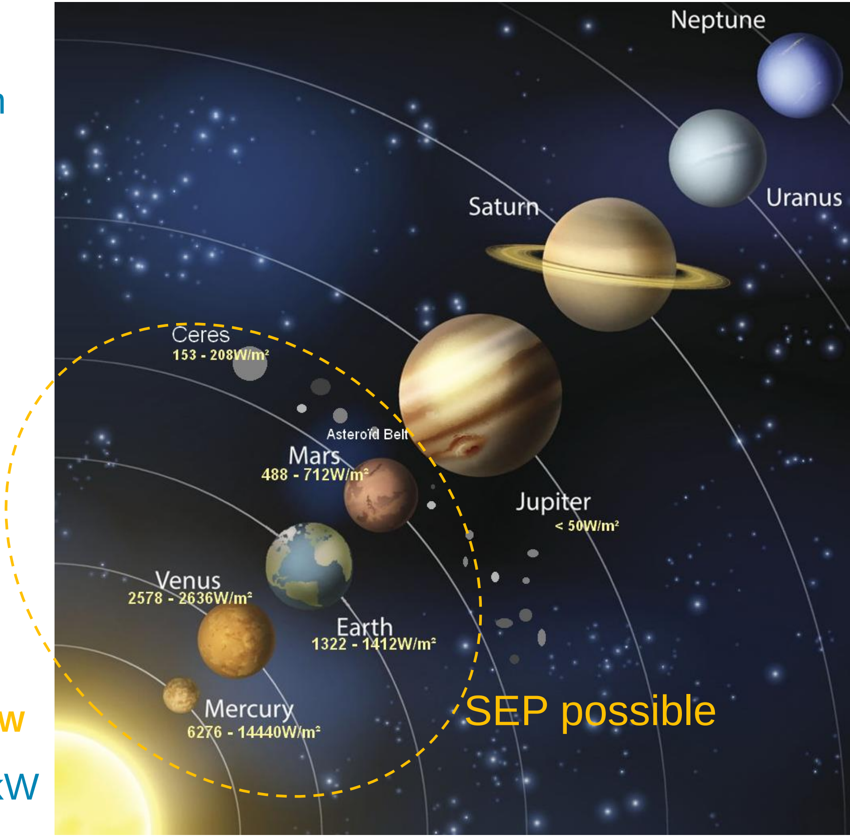
/// Past / current missions using SEP as main propulsion

- **Deep Space 1** : Asteroïd / **2.3kW**
- **Hayabusa 1**: Asteroïd / **350W**
- **Smart 1**: Moon / **1.4kW**
- **Dawn**: Vesta & Ceres / **2.5kW**
- **Hayabusa 2**: Asteroïd / **420W**
- **BepiColombo**: Mercury / **11kW**

/// Future missions

- **Power and Propulsion Element (PPE):** Moon / **~25kW**
- **Psyche:** Asteroïd / **4.5kW**
- **DART:** Asteroïd / **7.5kW**
- **Mars Sample Return (Earth Return Orbiter)** : Mars / **~30kW**
- **Asteroïd Retrieval Robotic Mission (*cancelled*) :** Asteroïd / **~30-50kW**

/// More and more missions to come using several tens of kW



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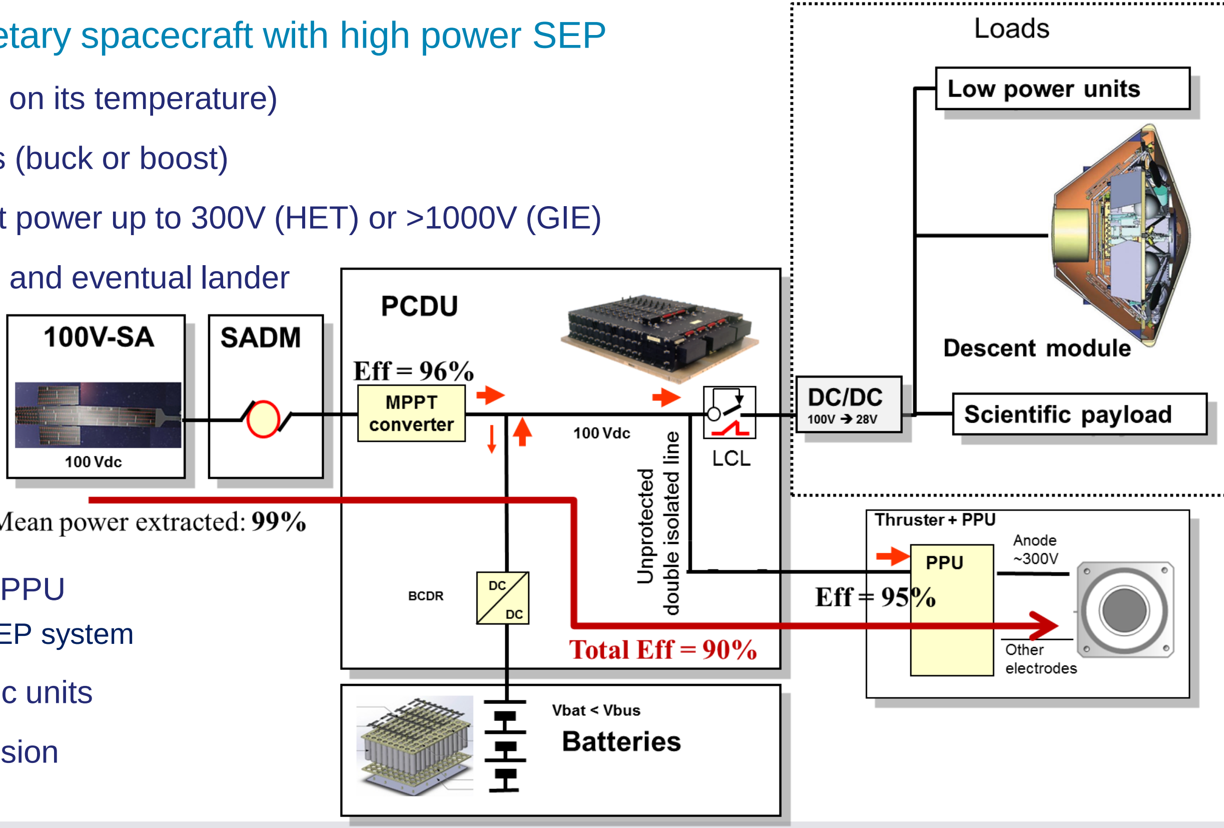
3 - CURRENT ELECTRICAL ARCHITECTURE

/// Standard architecture interplanetary spacecraft with high power SEP

- 100V - 130V Solar array (depending on its temperature)
- PCU or PCDU with MPPT converters (buck or boost)
- PPU to drive the thruster and convert power up to 300V (HET) or >1000V (GIE)
- Secondary bus for scientific payload, and eventual lander



/// Drawbacks:

- Thermal dissipation in both PCDU and PPU
  - Can reach more than 1kW for a 20kW SEP system
- High cost and mass for power electronic units
- Less power available for electric propulsion

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3 - CURRENT ELECTRICAL ARCHITECTURE

/// Example BepiColombo MTM (Mercury Transfer Module)

- Solar Array > 100V near earth (and at each eclipse exit) and down to 42V near Mercury
  - Power conditioning used as shunt when MPP voltage is >100V and as boost when MPP voltage is < 100V
- 100V « sun regulated » main power bus
  - No battery discharge regulator
- PPU are supplied through unprotected LCL (10A)
- 28V secondary bus

More information on: **BepiColombo MTM Power Conditioning And Distribution Unit, *Hansen Magnus Moberg,*** *presented at 9th ESPC (European Space Power Conference), 2011, Saint-Raphaël, France*

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4 - DIRECT DRIVE ARCHITECTURE

/// Description

- « Direct » connection of solar array with thruster anode
- Removal of PPU anode converter module, and increase of bus voltage until anode operating voltage (300V-500V for Hall Effect Thrusters and 300V-1000V for HEMPT)
- Past studies have shown feasibility of SA voltage and regulation at 300V and above

/// Interests

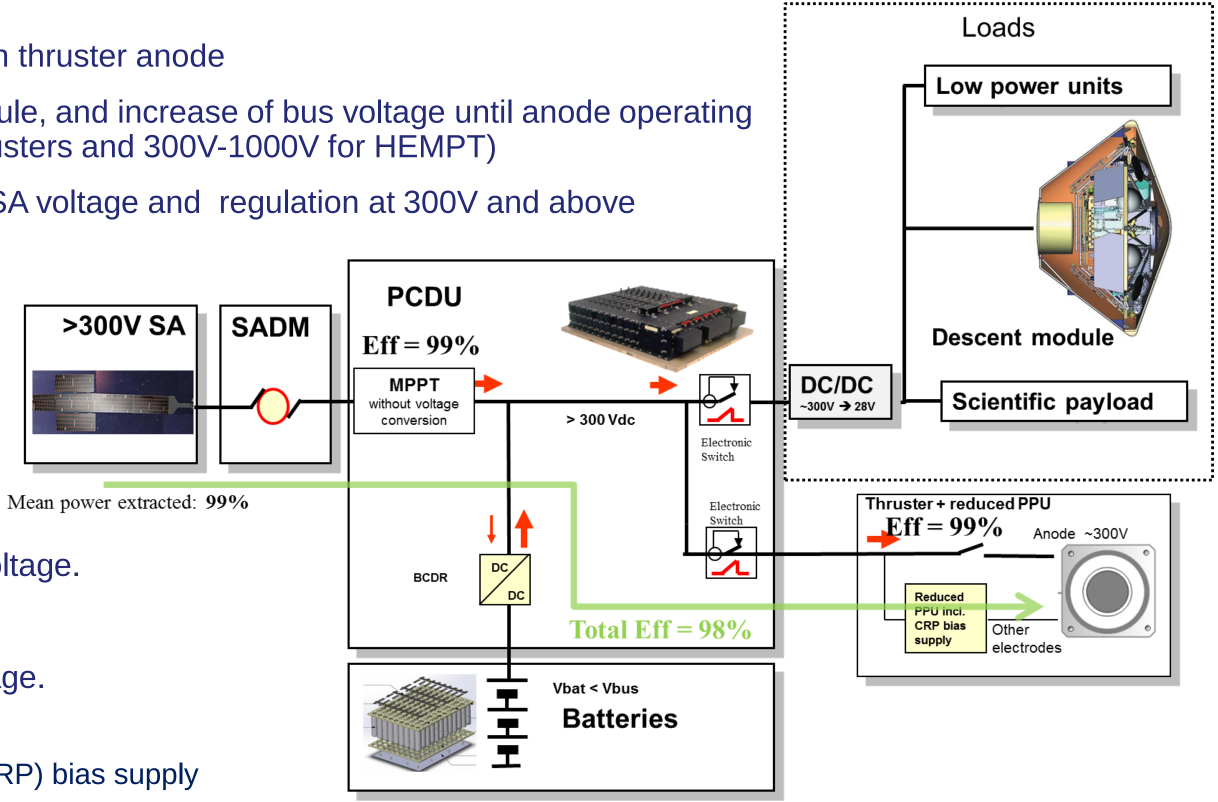
- Increased efficiency
- Less volume and cost
- Decreased thermal dissipation.

/// Drawbacks

- Primary bus voltage must fit thruster voltage.
- Modification of thruster operating

point has a direct impact on the bus voltage.

- No isolation between thruster and bus.
  - Need of Cathode Reference Potential (CRP) bias supply



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4 - DIRECT DRIVE ARCHITECTURE

/// Focus on « MPPT » technique without power/voltage conversion

- On interplanetary missions, solar array temperature is subject to large variation as sun distance is evolving
- Maximum Power Point Tracking is **mandatory** but various technique exist
- Most commonly used technique is to use an high efficient (95 to 96%) buck or boost power converter, and a MPPT algorithm which track the voltage of solar array MPP and apply this voltage at solar array input.

« Direct-drive » would not be complete if this power converter remains between solar array and thrusters

/// Principle of MPPT without conversion

- 2 solutions
  - Adaptation of the load current to equalize it with current of maximum power point of the solar array
    - **Thruster can adapt its Xenon flow rate to modify the requested current.**
  - Using a battery and its charge/discharge converter (BCDR) to adjust in real time a voltage on the bus corresponding to the voltage of maximum power point (Vmp) of solar array
- S3R cells are used in PCDU, leading to high efficiency of transfer (99%)

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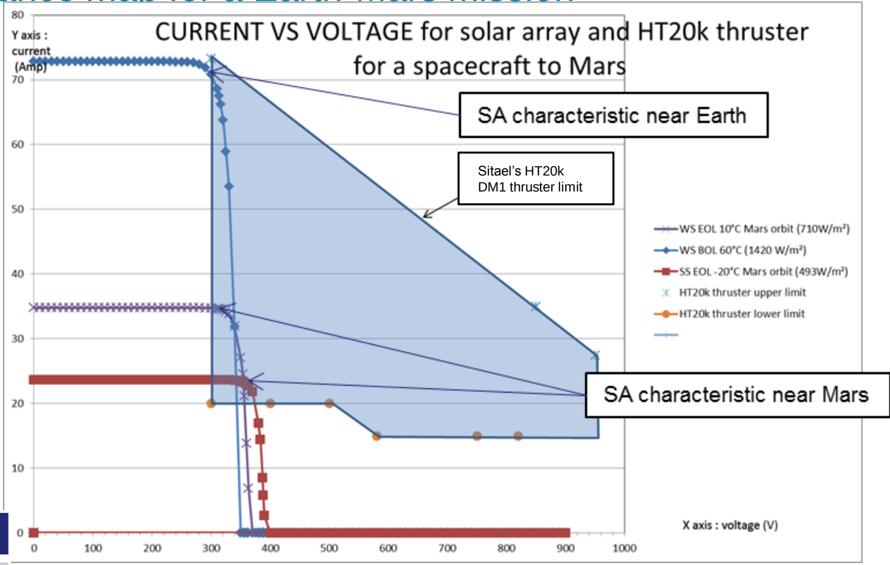
4 - DIRECT DRIVE ARCHITECTURE

/// Each electric thruster has its own « performance map » giving its limits in term of voltage and current

/// SA characteristic is always within the thruster performance map for a Earth-Mars mission



/// If it is not possible to keep SA MPP within performance map (too much variation of solar flux and temperature)

- Possibility to tilt the SA to reduce extremes values
  - Highly recommanded for missions to Mercury or closer to Sun to limit SA temperature
- In table below: several examples of 100m²/30kW (@1AU) solar array designed to stay within 300V-400V range (with different serie – parallel layout, but same surface)

	Vmp at Earth	Max Power at Earth	Vmp at targeted body	Max Power at targeted body	SA Layout
Earth-Ceres	300V (SA tilt = 60°)	17.5kW (SA tilt = 60°)	365V (SA tilt= 0°)	4.8kW (SA tilt= 0°)	100s300p
Earth-Mars	300V (SA tilt= 0°)	30kW (SA tilt= 0°)	383V (SA tilt= 0°)	13.5kW (SA tilt= 0°)	120s250p
Earth-Moon	300V (SA tilt= 0°)	30kW (SA tilt= 0°)	300V (SA tilt= 0°)	30kW (SA tilt= 0°)	120s250p
Earth-Venus	365V (SA tilt= 0°)	30kW (SA tilt= 0°)	310V (SA tilt= 0°)	49.8kW (SA tilt= 0°)	146s205p
Earth-Mercury	488V (SA tilt= 0°) But SA exploited at 400V max	30kW (SA tilt= 0°) But only 26.1kW extracted at 400V	300V (SA tilt= 70°)	60.8kW (SA tilt= 70°)	195s154p

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5 - STATE-OF-THE-ART OF DIRECT DRIVE ARCHITECTURE

/// State-of-the-art

- Studies have been done by NASA in the 70's but abandoned since only GIE was the use case: Bus voltage was too high (>1000V)
- In the 90's, with advent of HET, NASA has made new studies and breadboard
  - D2HET (Direct Drive Hall Effect Thruster)
  - National Direct-Drive testbed
- SITAEL also conducted a certain number of studies and thesis at EP subsystem level
- Thales Alenia Space conducted a H2020 in 2016-2017 to prove the feasibility of a high voltage bus (300V to 600V)
  - High-Voltage Electrical Power System Architecture: http://hv-epsa-h2020.eu/

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6 - EUROPEAN DIRECT-DRIVE ARCHITECTURE (EDDA)

/// Work to be performed within H2020 EDDA

EUROPEAN DIRECT-DRIVE ARCHITECTURE

- Objectives of the project
  1. **Increase PPU efficiency from 95% to 99%**
  2. **Enable MPPT without power conversion**
  3. **Reduce by half PPU mass and cost**
  4. **Having same direct-drive architecture for both Hall Effect Thrusters (HET) and High Efficiency Multistage Plasma Thruster (HEMPT).**
  5. **Increase TRL from TRL2 to TRL4 or 5**
- Website of the project: https://edda-h2020.eu/

Description of the mockup

- A High voltage Solar Array Simulator able to reproduce SA behavior in flight
- A battery simulator, using a DC/DC bidirectional power supply
- A PCU, including
  - Representative S3R ; BCDR (Battery charge and discharge regulator) ; Bus capacitance; Switches ; Control unit (with dSpace)
- Loads, with simple power resistors and input switch
- Direct-Drive Unit, including
  - CRP bias supply ; Filter unit ; Auxiliary supplies
- Gas supply, including
  - Gas tank ; Valve (provided by thruster manufacturers)
- Thrusters (provided by thruster manufacturers)
  - 2 x HT5k magnetically shielded from Sitael
  - 1 x HEMPT 30250 from Thales Deutschland

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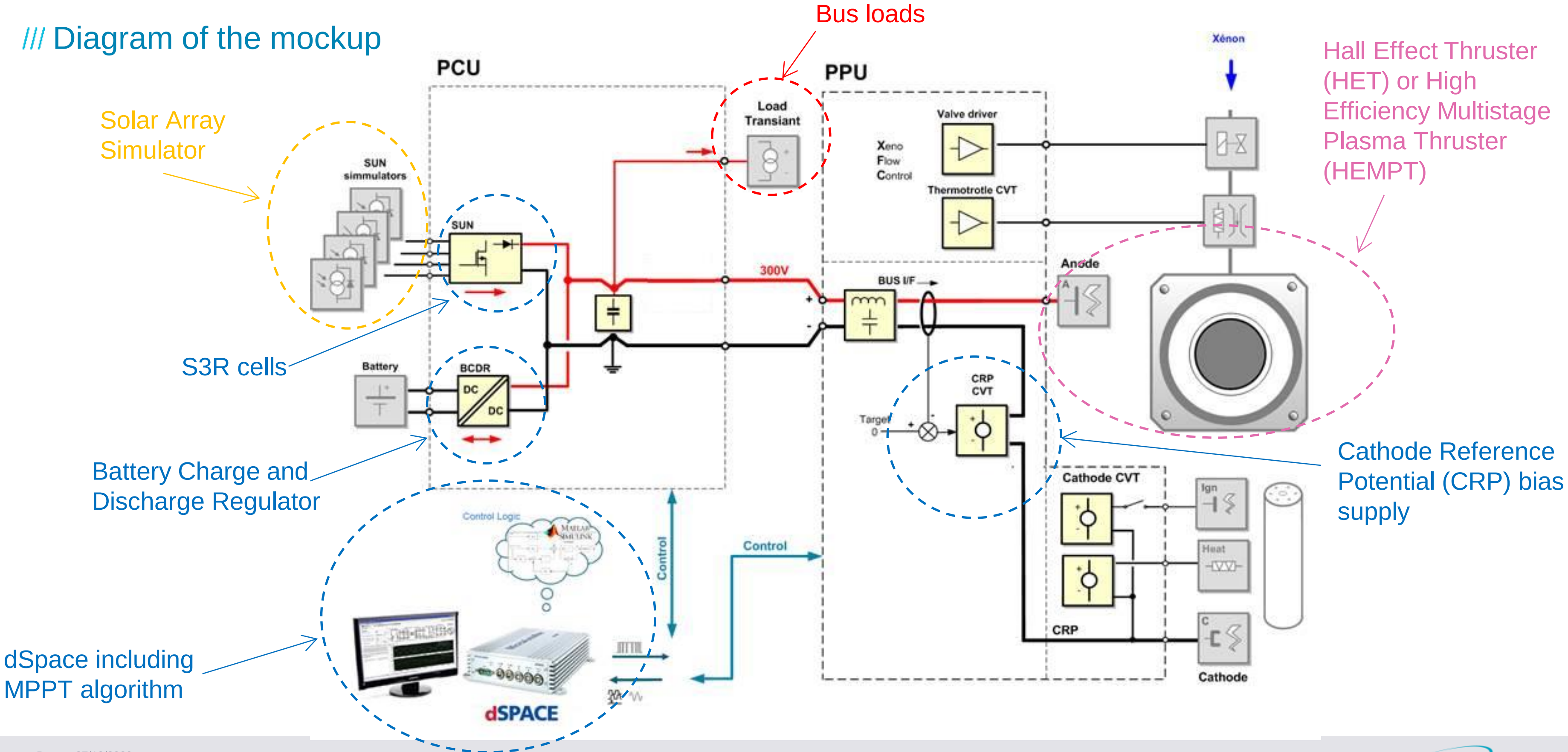
6 - EUROPEAN DIRECT-DRIVE ARCHITECTURE (EDDA)

/// Diagram of the mockup



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CONCLUSION

- /// Direct-Drive is mandatory for high power Solar Electric Propulsion
- /// Although restricted to 300V-class thruster (HET and HEMPT), the concept is fully applicable to higher voltage thruster (Gridded Ion Engine > 1000V)
  - Current state of technology do not allow to produce and distribute power at this voltage using solar arrays.
  - Although GIE are commonly used for deep space exploration (higher Isp), very high power electric propulsion (20kW-class thrusters, or more) will make use of HET or HEMPT which are less complex, in particular for this class of power
  - The use of direct-drive increase the efficiency of the overall propulsion system
- /// The H2020 EDDA project will allow to test a representative mockup for 5kW class thrusters. Conclusion of the study will be applicable to 20kW-class thrusters and beyond.

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