OPALIS DESCRIPTION

	Nom et sigle	Date et signature
Prepared and approved by	**Christian ELISABELAR DTN/TVO/3CE**	04/10/2024 Signature numérique de Christian ELISABELAR Date : 2024.10.04 09:44:23 +02'00'

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Summary

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Summary: This document is the User Manual of OPALIS, and gives some descriptions of the power architecture used by the tool and the modeling of each component.

Modifications

Version	Date	Version of OPALIS
1.0	September 2024	OPALIS 2.3.0

Documents

Reference		Document Title
RD01	DCT/DA/PA-2009.0021267	CIC DATA EXCHANGE PROTOCOL V2.0

Terms, definitions and abbreviations

Acronym / abbreviation	Definition
AM0	Air Mass Zero. This is solar radiation above the Earth's atmosphere.
BCD	Battery Charger Discharger
DET	Direct Energy Transfer
DB	Distribution Box or Distribution Converter
DOD	Depth Of Discharge
HMI	Man-Machine Interface
LEO	Low Earth Orbit
MPP(T)	Maximum Power Point (Tracking)
NRB	Non-Regulated Bus
S3R	Sequential Switching Shunt Regulator
OCP	Open Circuit Point
SA	Solar Array
SAR	Solar Array Regulator
SADM	Solar Array Drive Mechanism
SCP	Short Circuit Point
SOC	State Of Charge
VBNR	Primary Bus Voltage

SUMMARY

1 OPALIS OVERVIEW

The OPALIS software is a simulator of spacecraft power system. It is used for pre-sizing purposes and quick tests of power supply system.

For instance, OPALIS enables to define the global efficiency of the power system and to compute the battery state of charge during a simulation.

The global architecture of the power system simulated by OPALIS is composed (see figure 01) by:

- Solar Array SA sections
- Harness from SA to SAR
- Solar Array Regulator SAR
- Battery Charger and Discharger BCD
- Harness from BCD to Battery
- Battery
- Harness from Primary Bus to Distribution Box
- Distribution Box DB
- Spacecraft Power consumption

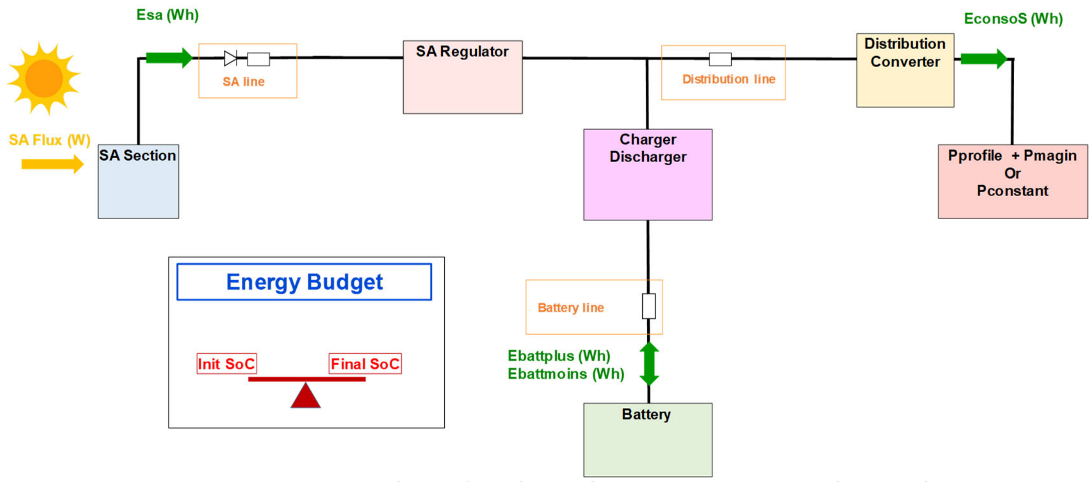


Figure 1: Simplified OPALIS architecture Power Supply Chain

OPALIS simulation is able to provide different energies transferred from SA to Spacecraft and exchanged by the battery.

Sizing of SA, battery and all components can be verified by the energy balance, when the final SOC is equal or better than the initial one.

There are three types of inputs:

- The static inputs are the parameters needed to describe all the equipments used.
- The simulation inputs allow the initialization of the test run.
- The ephemerides of the power consumption and of the various flows received by the solar array.

All of these data need to be manually filled by the user in the OPALIS human-machine interface.

Thanks to this, OPALIS is able to plot the evolution the main variables of a spacecraft power supply system as a function of time.

There are two versions of OPALIS:

OPALIS SIMPLE: It is a very preliminary sizing of the power supply, and it gives an idea of SA surface and battery capacity needed.

OPALIS ADVANCE: Where all components of the hardware architecture of the power chain is defined precisely, and where it is possible to simulate different types of regulation and control.

2 OPALIS ADVANCE

2.1 OPALIS ADVANCE ARCHITECTURE

The global architecture of OPALIS in figure 2 shows the hardware of the power system and the associated control loop.

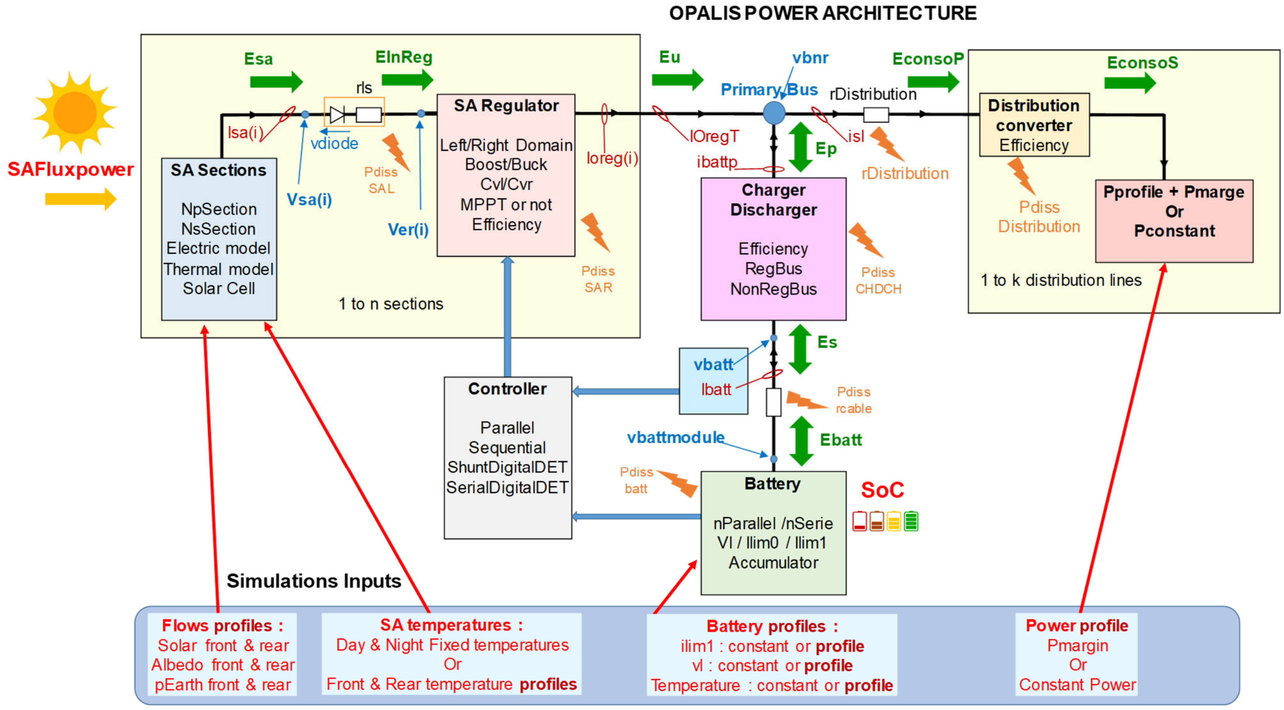


Figure 2: OPALIS Architecture

In order to simulate a large panel of application, the architecture gives the following implementations:
- The Primary Bus that is the central electrical power node of the architecture.
- One to n sections composed by SA + diode, harness + SAR.
- Battery section composed by the battery module, battery harness, the BCD.
- One to k Distribution lines each composed by a DCDC converter and a power consumption.
- The Controller, that compares the battery current and voltage with the input references, and generates the command of the SAR through a Proportional Integer Regulator.

In addition to the hardware architecture, OPALIS simulates the operation of the power supply chain as a function of time.

Therefore, a definition of the simulation duration is needed, typically several orbits.

In one side, OPALIS needs the solar fluxes on the SAs to operate. These fluxes can be generated by the spacecraft mission, depending on the orbit, attitude, maneuvers, and SA geometric implementation.

In the opposite side of the power chain, the power consumption of the spacecraft shall be provided.

2.2 DESCRIPTION OF OPALIS COMPONENTS

2.2.1 SOLAR ARRAY

The SA is composed by several sections. The number of sections is from 1 to n.

Each section is composed by an association of Ns solar cells in series and Np in parallel. OPALIS takes into account the connections of solar cells in the sections.

The operator can add SA sections in the OPALIS HMI.

The number of solar cells in series Ns shall be adjusted with the voltage at the input of SAR. This is called SA voltage adaptation. An assembly of Ns solar cells in series is called a string.

The number of strings in parallel is determined by the global current (power) delivered by a SA sections.

2.2.1.1 SA ELECTRICAL MODEL

The electrical model of the solar cells used in OPALIS is characterized by an exponential equation, where the delivered current depends on the voltage across the cell, the temperature and the solar flux intensity.

The current is given with a standard solar flux spectrum **AM0 = 1366W/m²**.

The operating voltage of the SA section and then of the solar cell is imposed by the SAR. The control of the SAR consists in setting its input voltage **Ver** that is connected to the SA section Vsa through a diode and harness.

The current delivered by a solar cell **Isa** at reference temperature and an AM0 solar flux is the following:

$$Isa = ki10 + discsa * (Temp - Tref) + ki2 * exp(ki3 * (kvt * (Tref - Temp) + Vsa))$$

With:

- Tref: reference temperature (used to establish the solar cell model), in °C
- Temp: actual temperature during the solar cells use, in °C
- discsa: temperature coefficient used to calculate the variation of the current value in short-circuit at a given temperature compared with the value established at the reference temperature, this parameter also takes into account networking coefficient and solar cell degradation, in A/°C
- ki10: short-circuit current value (Isc) at T=tref, in A
- ki2: parameter used for the SA current modelling, in A
- ki3: parameter used for the SA current modelling, in V-1
- kvt: variation of the open-circuit voltage (Voc) with regards to the temperature, in V/°C
- Vsa: SA section output voltage (upstream of its associated regulator), in V

The parameters in green depend on the type of solar cells used, they have to be filled in the "simulation" tab.

Note:

The "Tref" parameter corresponds to the reference temperature, that is the temperature used to establish the model.

The SA current is usually not computed from the nominal temperature of the solar cells. It is recommended to calculate it from a reference temperature closer to the actual operating temperature ("Temp"). Hence, the model will be more robust to temperature variations during the actual use of the solar array (despite these variations the model will still be representative).

Voltage at the maximum power point for the temperature Temp:

$$Vpmsa = Vpmsa0 + kvt * (Temp - Tref)$$

With:

Vpmsa0: voltage (in Volt) at Pmax for Temp = Tref

Note:

A possibility is to determine by calculation the three main points of the curve Isa(Vsa):

- at Isc (short-circuit)
- at Pmax
- at Voc (open-circuit)

Then, the coefficients ki2 and ki3 have to be adjusted so that the curve meets those previously calculated points.

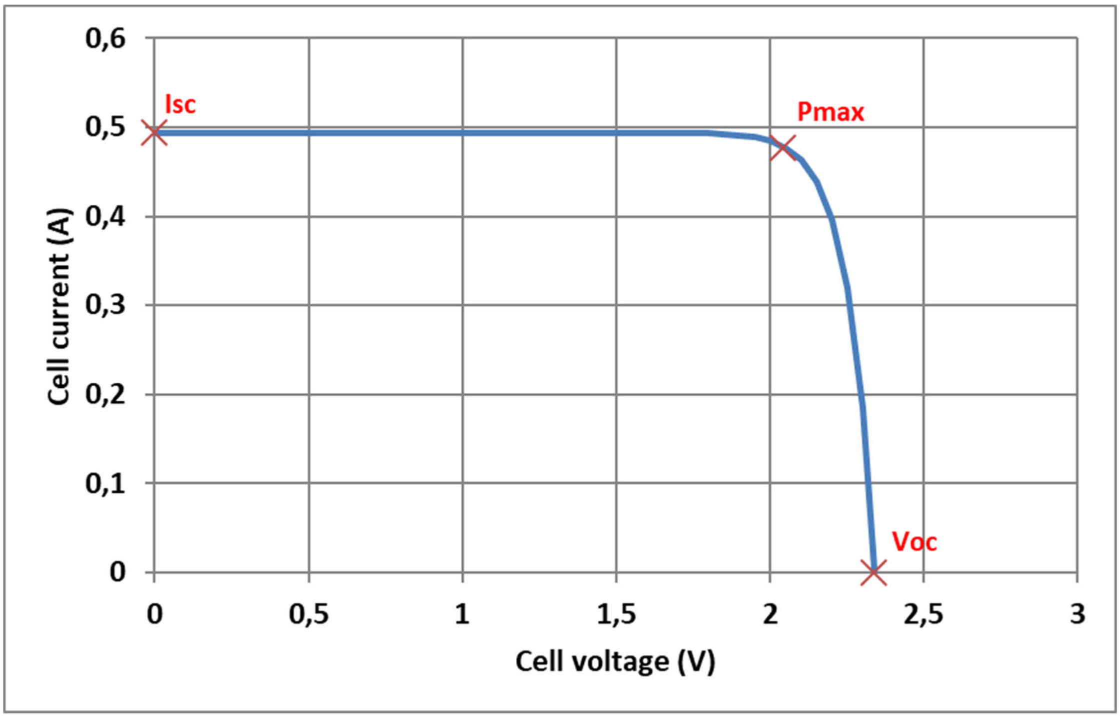


Figure 3: Typical I(V) solar cell curve

The real current **Isa** produced during OPALIS simulation for each SA section is calculated with an Isa model using Ns & Np solar cells, the direct solar flux, and the albedo flux received by the panel, while also taking into account the front panel temperature Temp and the SA voltage applied **Vsa**.

2.2.1.2 SA THERMAL MODELS

The SA thermal model is composed by 2 thermal nodes, one on the front face of the panel and one on the rear face. Between them the thermal transfer is made by conduction. Thermal exchanges with the environment is made by radiation.

The SA temperature is determined by the thermal balance of all the fluxes received and emitted.

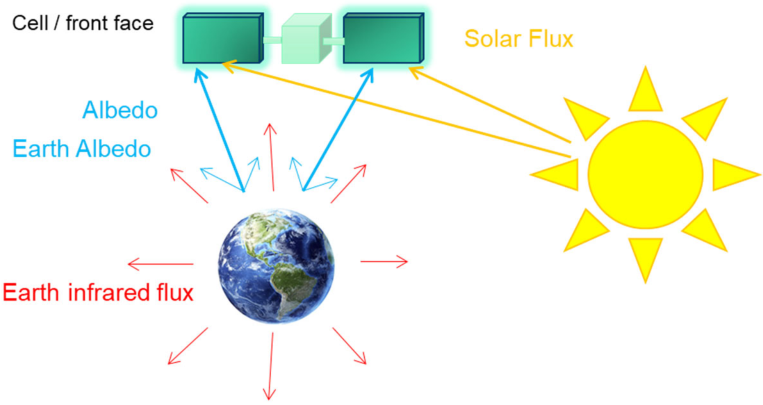


Figure 4: SA thermal fluxes

The fluxes received by the SA panel in front face and in rear are:

- Front Face Direct solar flux
- Rear Face Direct solar flux
- Front Face Earth Albedo flux
- Rear Face Earth Albedo flux
- Front Face Earth Infrared flux
- Rear Face Earth Infrared flux
- Rear face Satellite Infrared flux (In case of body mounted SA panel)

From the fluxes received, the power received is calculated with respect to the surface absorbance **Alpha**.

$$\mathbf{P_{receivedfront} = \Sigma Flux_{receivedfront} \;.\; A_{sa} \;.\; Alpha_{front}}$$

$$\mathbf{P_{receivedfrear} = \Sigma Flux_{receivedrear} \;.\; A_{sa} \;.\; Alpha_{rear} + P_{conduction}}$$

The fluxes emitted by the SA panel in front face and rear face are:

- Front Face Infrared emitted flux
- Rear Face Infrared emitted flux
- Electrical power extracted by the photovoltaic convertion.

The thermal power emitted $\mathbf{P_{emitted}}$ is calculated with the surface emittance **Epsilon**.

$$\mathbf{P_{emittedfront} = Epsilon_{front} \;.\; KB \;.\; A_{sa}.\; T^4 + P_{conduction} + P_{saelec}}$$

$$\mathbf{P_{emittedrear} = Epsilon_{rear} \;.\; KB \;.\; A_{sa}.\; T^4}$$

Where **KB** is the Stefan-Boltzmann constant (5,670 3 × 10^{-8} W m^{-2} K^{-4}).

In case of a body mounted SA panel, the rear face exchange is calculated by:

$$\mathbf{P_{emittedrear} = Epsilon_{rear} \,.\, KB \,.\, A_{sa} .\, (T_{rear}^4 - T_{satellite}^4)}$$

The thermal power transferred from front face to rear face of the SA section is defined as:

$$\mathbf{P_{conduction} = A_{sa} \,.\, (T_{front} - T_{rear}) \,.\, ThCond}$$

The electrical power transferred to the spacecraft $\mathbf{P_{saelec}}$ is calculated with the solar cell efficiency and its electrical model.

For each SA section, the thermal model needs the following parameters:

- Front and rear Absorptivity: $\mathbf{Alpha_{Front}}$, $\mathbf{Alpha_{Rear}}$
- Front and Rear Emissivity: $\mathbf{Epsilon_{Front}}$, $\mathbf{Epsilon_{Rear}}$
- The thermal conductance **ThCond** from front to rear face of the panel
- The thermal capacitance of the panel **ThCapa**
- The Sa section area: $\mathbf{A_{sa}}$

The temperatures are calculated at each simulation step:

$$\mathbf{DeltaT_{front}(n) = timeStep \,.\, [\Sigma P_{receivedfront}(n) - \Sigma P_{emittedfront}(n)] \,/\, ThCapa_{front} \,/\, A_{sa}}$$

$$\mathbf{T_{front}(n) = T_{front}(n\text{-}1) + DeltaT_{front}(n)}$$

$$\mathbf{DeltaT_{rear}(n) = timeStep \,.\, [\Sigma P_{receivedrear}(n) - \Sigma P_{emittedrear}(n)] \,/\, ThCapa_{rear} \,/\, A_{sa}}$$

$$\mathbf{T_{rear}(n) = T_{rear}(n\text{-}1) + DeltaT_{rear}(n)}$$

Where **timeStep** is the calculation time step in OPALIS.

The thermal capacitance is arbitrarily distributed considering the mass distribution of the panel:

$$\mathbf{ThCapa_{front} = 0{,}7 \,.\, ThCapa}$$

$$\mathbf{ThCapa_{rear} = 0{,}3 \,.\, ThCapa}$$

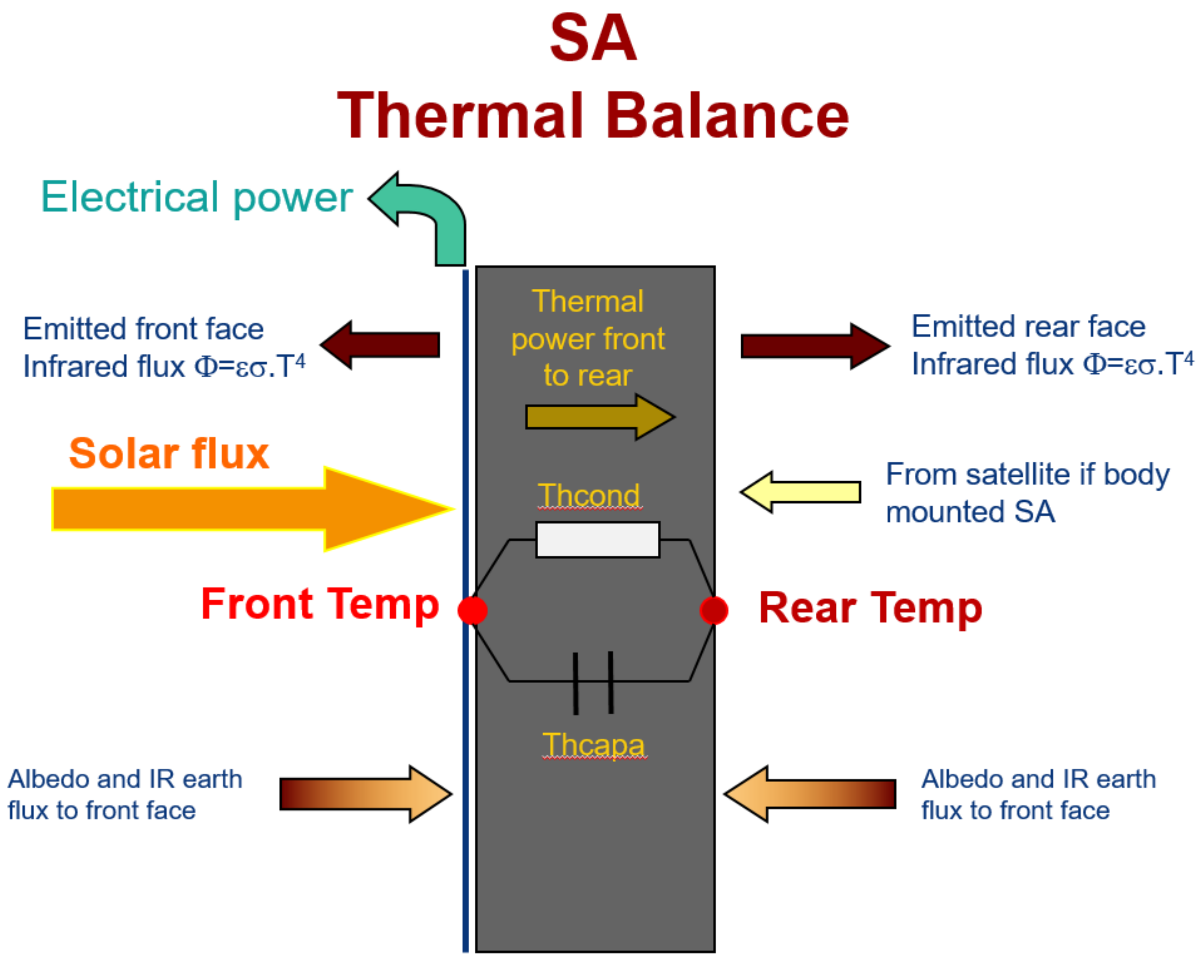


Figure 5: SA thermal bamance

The following tables give typical values of thermal parameters:

OPALIS	Heat capacitance	Thermal conductivity AV/AR
	J/K/m²	W/K/m²
panneau 2cm NIDA ALU et reseau cellules	3900	100
panneau PCB 5mm et réseau cellules	7400	50
panneau ALU 3mm et reseau cellules	4000	33000

material	Absorptivity	IR Emissivity
Nickel noir	0,92	0,4
Or poli	0,23	0,03
Aluminium poli	0,12	0,04
Peinture noire	0,98	0,91
Peinture blanche SG122FD	0,2	0,88
OSR OCLI	0,08	0,81
SPL XTE	0,88	0,85
AZUR 4G30	0,91	?
face AV cellules GS MYEV	0,831	0,851
face AR GS MYEV	0,94	0,876
MLI noire	0,98	0,91
SPL XTJ	0,9	0,85

Deployed panels

In OPALIS, when the SA panels are deployed, the rear face looks into deep space. In this case, the radiative thermal exchanges on the rear face are performed with respect to the deep space's cold temperature of -273°C.

Body mounted Panels

In OPALIS, when the SA panels are body mounted, the rear face coincides with the satellite body. In this case, the radiative thermal exchanges are performed with a rear face temperature that is equal to the satellite temperature, and the thermal flux from satellite to the body mounted SA panel is a portion of the power dissipated by the satellite. In OPALIS the portion taken into account is 1/6 of the satellite consumption.

OPALIS SA thermal models choice

In OPALIS, it is possible to choose 4 global thermal models of the SA section:

- Reduced
- Albedo and pEarth profiles
- Fixed Day and Night Temperatures
- Front and Back Temperature Profiles

For the **« Reduced »** model the solar flux is set by the profile entered in the "Input" tab, however the albedo and the terrestrial infrared are calculated from fixed values ("Albedo" and "Earth radiation") filled in the "Simulation" tab. The calculations, made for each section, are as follows:

$$\mathbf{Flux_{albedofront} = SolarFlux \, . \, kalbedo \, / \, \pi}$$
$$\mathbf{Flux_{albedorear} = SolarFlux \, . \, kalbedo \, / \, \pi}$$
$$\mathbf{Flux_{earthfront} = EarthRadiationFlux \, / \, \pi}$$
$$\mathbf{Flux_{earthrear} = EarthRadiationFlux \, / \, \pi}$$

With:
Kalbedo is a coefficient defined as the proportion of the SolarFlux Constant that is reflected by Earth, (about 410W/m² / 1366W/m² = 30% in case of LEO).
EarthRadiation is the black body emission of Earth, (about 246W/m² in LEO).

The **AM0** (Air Mass zero) value of the solar constant is **1366W/m²**.

The typical value of an average Albedo in LEO is 410W/m².
The typical value of an average Albedo in GEO is 2,6W/m².

The typical value of an average earth radiation in LEO is 246W/m².
The typical value of an average earth radiation in GEO is 5,5W/m².

The model "**Albedo and pEarth profiles**" takes into account all of the flux ephemeris (illumination, albedo and terrestrial infrared power) entered in the "Input" tab. This is the most accurate model.

The model "**Fixed Day and Night Temperatures**" considers only the temperature values set in the "Simulation" tab by the "Day temperature" and "Night temperature" parameters.

With the model "**Front and Back Temperatures Profiles**", the SA temperatures are directly the values from the input profiles.

2.2.1.3 SA MODEL LIMITATION

OPALIS does not take into account partial shadowing, nor partial field of view between deep space and spacecraft body.
There is only one thermal node on each SA face. For more precision, it is possible to break down a big SA section on several sections with dedicated thermal parameters.

2.2.2 SA LINE

Each SA section is connected to the SAR true harness and blocking diode. OPALIS takes into account the voltage drops across the diode **Vdiode** and the resistance **rls** of the section line.

2.2.3 SA VOLTAGE ADAPTATION

The voltage of power bus **Vbnr** shall be well matched with the SA voltage.

In the following example, there are 3 SA strings from Ns=8 to Ns=10 cells. The voltages that give the maximum power are then different. In case of DET the voltage polarization imposed by the input of the SAR shall cross the Isa(Vsa) curves near the MPP.
In our example Ns=8 is too short and Ns=10 is too long.
This adaptation shall be made considering the EOL characteristics of the SA and the operating SA temperature.
The bus voltage **Vbnr** is adjusted to the battery voltage for a non regulated bus, or to the **VBus** in case of a regulated bus.

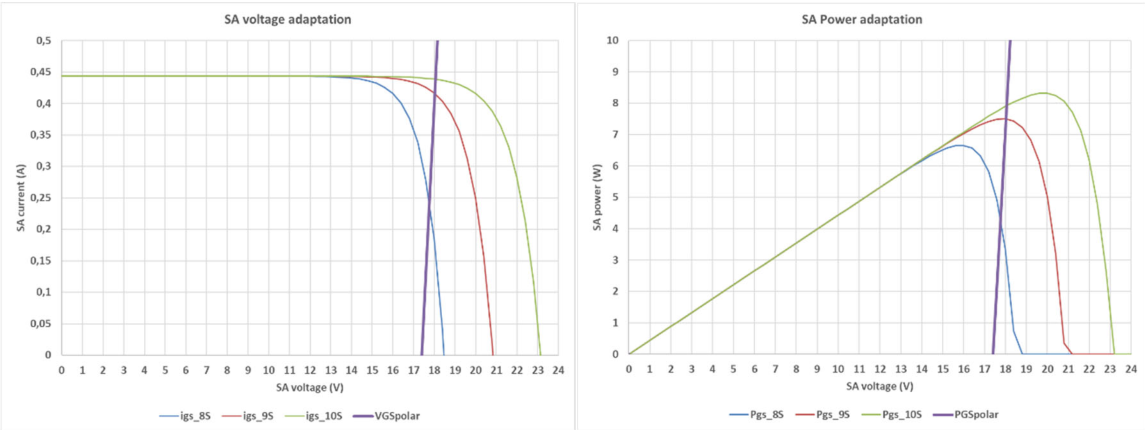


Figure 6: SA voltage adaptation with power bus

The transformation ratio from input to output of the SAR for the voltage adaptation has to be considered if the power architecture uses a SAR with a DCDC converter.

See 2.2.4 : Solar array regulator for SAR.

2.2.4 SOLAR ARRAY REGULATOR

The SAR is the power device that is able to regulate the power transfer from the SA section to the primary power bus.

In OPALIS, the SAR imposes its input voltage **Ver** and then the operating voltage of the SA section **Vsa**.

For an optimized operation the voltage of the SA shall be as close as possible to the MPP (see figure 7). The so-called voltage adaptation shall be made preferably at the EOL conditions and at the sunlight operating temperature.

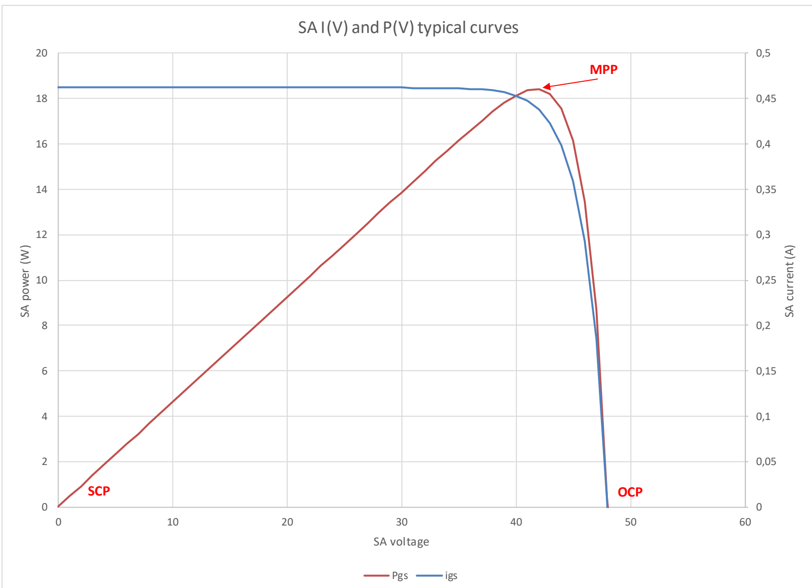


Figure 7: SA I(V) typical curves

Given the SA typical curve in figure 7, there are two possibilities to regulate or control the power from the SA:

- In the **left domain** of the characteristics, from the SCP to the MPP: from 0W (short circuit) to maximum power of the SA section.
- In the **right domain**, from MPP to OCP: from maximum power of the SA section to 0W (open circuit).

There are different topologies of power converter for the SAR:

- DET: Direct Energy Transfer where the SAR is a simple switch connecting or not the SA section to the primary bus.
- DC/DC converter (typically a PWM converter) where the input voltage can be adjusted continuously from 0W to full power. Depending on the topologies involved, the MPP point can be accessible or not.

For each domain of regulation, there are several classes of SAR power converter.

For the **left domain**:

- **DET SHUNT**: There is a controlled switch in parallel that can short-circuit the SA section when no power is transferred, and a diode in series when the SA section is connected to the primary bus.
- **BOOST converter**: This converter is only a booster; the input voltage of the SAR is always lower than the primary bus. If the primary bus voltage is higher than the MPP voltage, then the MPPT is possible.
- **CVleft**: The input voltage can be lower or higher than the primary bus and then, by a good voltage adaptation, the MPPT is possible.

For the **right domain**:

- **DET SERIAL**: There is a controlled switch in series. If the switch is open, the SA is in open circuit and no power is transferred. If the switch is closed, the SA section is connected to the primary bus.
- **BUCK converter**: With this converter, the input voltage of the SAR is always higher than the primary bus. If the primary bus voltage is lower than the MPP voltage, then the MPPT is possible.
- **CVright**: The input voltage can be lower or higher than the primary bus and then, by a good voltage adaptation, the MPPT is possible.

SOLAR ARRAY CONTROL

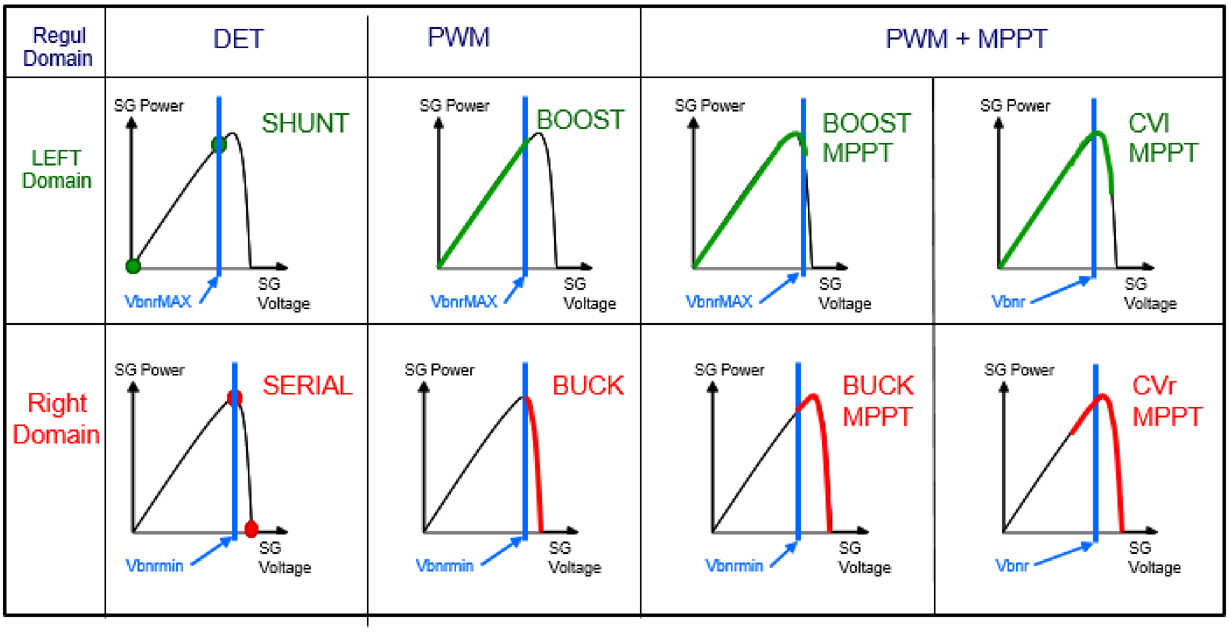


Figure 8: SAR operating ranges

In OPALIS, there is the possibility of choosing any of those eight configurations.

The input voltage order of the SAR is sent by the controller module. The details of how to control each SAR configuration is described in chapter 2.2.11 : controller.

Thanks to this voltage order, the SAR sets its input voltage as requested by the controller. The power transfer is thus controlled.
The SAR power transfer has an efficiency. The model of this efficiency is described in chapter2.2.12 : Efficiency model.

Input SAR voltage clipping

The input voltage of the SAR **Ver** respects the orders provided from the control loops (VL, Ilim or MPPT). However, it shall be limited by the specific topology of the SAR converter. The voltage clippings are function of the SAR topology:

- DET SHUNT, BOOST, BOOST MPPT: 0 < Ver < Vbnr/efficiency
- DET SERIAL, BUCK, BUCK MPPT: Vbnr/efficiency < Ver < 2 . VSAocmax
- CVIMPPT, CVrMPPT: 0 < Ver < 2 . VSAocmax

VSAocmax is the maximum SA section voltage. A factor of 2 is taken to account for a limit in the voltage sizing of the converter.

2.2.5 BCD

The BCD (Battery Charger Discharge) is used only when the regulated voltage option is chosen.

When the battery is directly connected to the primary bus, the voltage **Vbnr** depends on the battery SOC. This is the case of the so-called NON REGULATED BUS.

When the power architecture is a REGULATED BUS, the BCD makes the interface between the battery and the primary bus. In this case, the voltage **Vbnr** is regulated with a given value. OPALIS automatically regulates the primary voltage following the order **VBus**.

Here, there are also two efficiency curves for the power transfer during charge and discharge. See chapter 2.2.12 Efficiency model.

2.2.6 BATTERY HARNESS

Battery harness is modeled by a single equivalent resistance **Rcable** in interface with the battery module.

2.2.7 BATTERY MODULE

A battery is composed of several accumulators connected in series and in parallel.
The electrical model used to simulate an accumulator is detailed hereafter:

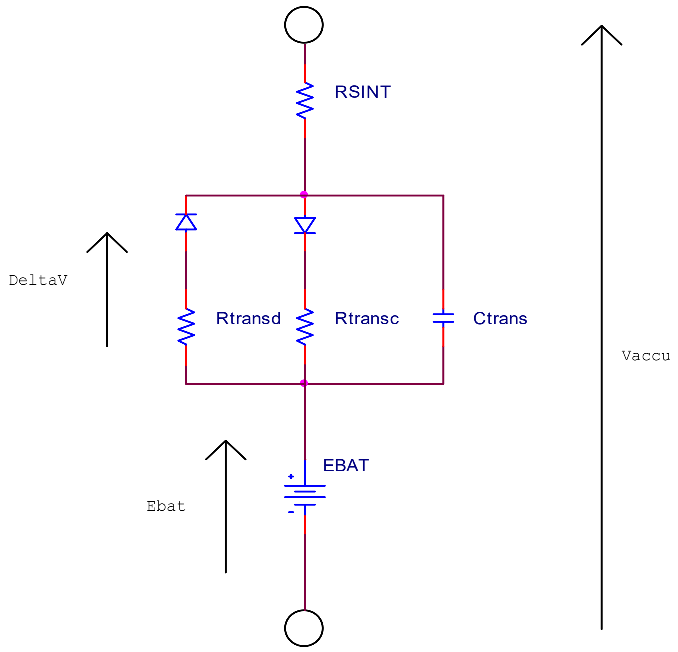


Figure 9: Electrical schematic of the battery model

With:

$$Ebat = ebat0 + ebat1 * SOC + ebat2 * SOC^2 + ebat3 * SOC^3 + ebat4 * SOC^4$$

$$Rsint = rsint0 + rsint1 * Ebat + rsint2 * exp(rsint3 * (Ebat - rsint4))$$

$$RtransD = dint0 + dint1 * SOC + dint2 * SOC^2 + dint3 * SOC^3 + dint4 * SOC^4$$

$$RtransC = dintch$$

$$Ctrans = tau$$

The parameters in green depend on the type of accumulators used, they have to be filled in the simulation parameters.

The parameters ebat[0..4], rsint[0..4], dint[0..4], dintch and tau could be determined from the curves of the datasheet of the accumulator or from measurement performed on this accumulator. The coefficients are deducted from the extrapolation of these curves.

The other parameters needed for OPALIS initialization regarding the battery model are listed hereafter:
capaBatNom: nominal capacity of the battery (nameplate).
capaBat and **ebatEffective**: effective capacity and effective energy of the battery which consider degradation and depend on the lifetime, the number of cycle and the cycled DOD.

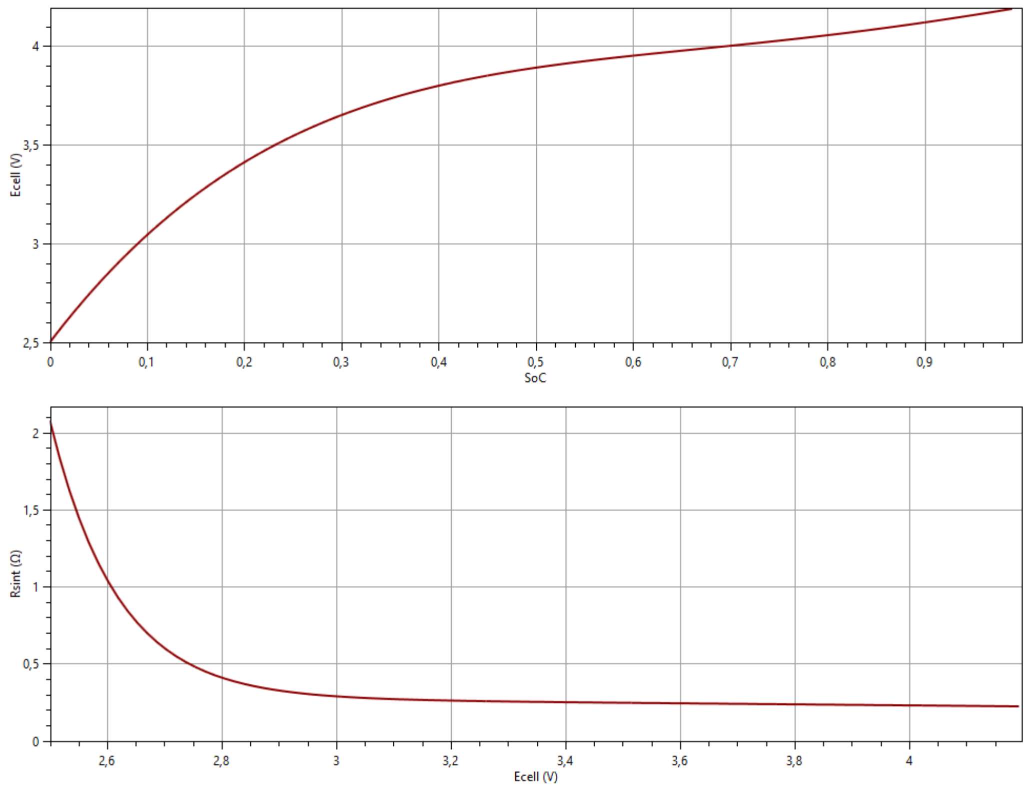


Figure 10: Ebat(SoC) and Rsint(Ebat) for a 18650HC accumulator

2.2.8 DISTRIBUTION HARNESS

Distribution harness is modeled by a single equivalent resistance **Rdistribution** between primary bus and distribution devices.

2.2.9 DISTRIBUTION CONVERTER

The distribution converter can act as a DCDC converter, a distribution switch, or a current limiter depending on the need.
For energy budget purposes, the distribution converter in OPALIS is modeled with a power transfer efficiency. See chapter 2.2.12 Efficiency model.

2.2.10 SPACECRAFT POWER CONSUMPTION

This module defines the power consumption of the satellite or spacecraft.

On each distribution section, it is possible to give a power profile as a function of time defined for all the simulation duration as an input. It is possible to add a constant power margin.

If there is no known power profile on the distribution lines, OPALIS gives the possibility to define a constant power without margin on each distribution line.

2.2.11 CONTROLLER

The rule of the controller is:

- Compare the battery voltage **Vbatt** with the battery taper voltage VL
- Compare the battery charge current **Ibatt** during charge with the limitation ILIM
- Execute a stable and accurate regulation of VL and ILIM
- Execute MPPT
- Generate the SAR input voltage orders

Battery voltage and current limitations
The regulation loops for battery voltage and current use proportional and integrated correctors.
The figure 11 represents, in a simplified form, the control of the regulator converter:

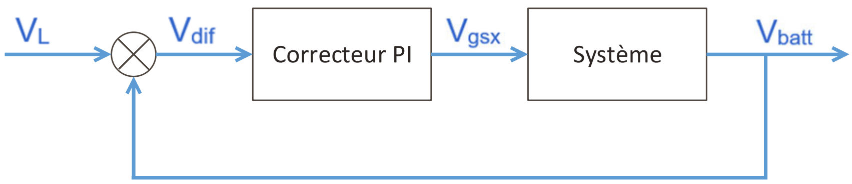


Figure 11: Simplified diagram of the regulation

The voltage error between the reference value V_L and the measured battery voltage V_{batt} is computed as follows, along with the current error between the reference value Ilim and the battery current Ibatt.

In case of a shunt regulator (left domain): $V_{dif} = V_L - V_{batt}$ and $I_{dif} = I_{lim} - I_{batt}$
In case of a series regulator (right domain): $V_{dif} = V_{batt} - V_L$ and $I_{dif} = I_{batt} - I_{lim}$

The value of the control voltage V_{gsxv} is set with the following equation:

$$V_{gsxv} = V_{gsxv} + g_a(V_{dif} - V_{difm}) + g_b \times timeStep \times V_{difm}$$
$$V_{gsxi} = V_{gsxi} + g_{ai}(I_{dif} - I_{difm}) + g_{bi} \times timeStep \times I_{difm}$$

V_{difm} and I_{difm} are the value of V_{dif} and I_{dif} at the previous time step.

The parameters timeStep, g_a and g_b have to be filled by the user:

timeStep: calculation time step of OPALIS (typically 0.1s)
ga, gbBoost, gbBuck for battery voltage regulation
gai, gbiBoost, gbiBuck for battery charge current limitation

The typical values for the regulation parameters are:

Paramer	Ga	GbBOOST	GbBUCK
Value	0.3	5	5

It is recommended to not change these values.

After the proportional and integral control, OPALIS generates a global order Vgx that represents the power to be transferred from SA sections to the primary bus during simulation.

Vgsx = min [vgxv ; vgsxi]

Because OPALIS gives the possibilities to choose SAR topologies, SA control domains (left or right), MPPT or not, DET or DCDC converter, OPALIS processes the global reference Vgsx to evaluate the input voltage order for each SAR.

Parallel control: the order voltage is shared in a balanced way on each SAR.

Sequential control: the reference voltage is addressed sequentially, SA section by SA section. In this case, the number of SA sections transferring power depends on the order.

After the parallel or sequential process, OPALIS generates the real input voltage order for each SAR.

DET control

DET: this option is naturally sequential.
It is a hysteresis control on the battery voltage and current, which are compared with VL and ILIM.
The parameters of hysteresis control are:

- **Delta VBus**: positive or negative delta voltage applied on battery voltage difference
- **Delta Ibatt**: positive or negative delta current applied on battery current difference
- **DET step**: The time step (s) when the hysteresis comparison is made, the process is made every DET step. This is to simulate a digital regulation frequency at 1/DETstep (Hz).

MPPT

The MPPT is made by applying a Vgx order that can polarize the SA section at its MPP. The battery voltage and current limitations have the priority over MPPT.

2.2.12 EFFICIENCY MODEL

The efficiency model is based on the typical circuit of figure 12.
The efficiency on the power transfer from input (IN) to output (OUT) is:
Efficiency = Pout / Pin

The losses can be decomposed in three parts:

- Parallel losses than are constant for a given input voltage and are characterized by a parallel resistor.
- Serial losses proportional to the transferred power, these correspond to a constant voltage drop (like a diode).
- Serial losses that are proportional to the square of the transferred power, these correspond to a series resistor.

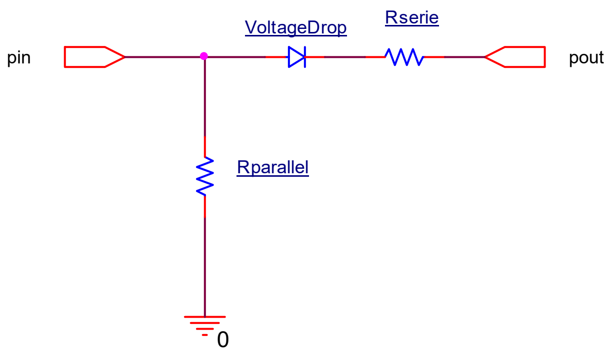


Figure 12: Typical circuit for an efficiency model

More generally, it is possible to write the input power **Pin** like:

$$Pin = Pout + a + b.Pout + c.Pout^2$$

To be compatible for all converter, a relative power is used in OPALIS. For that, OPALIS needs to know the sizing power of the converter **Pdim**, and we have to be sure that the real power transferred through the converter is lower than **Pdim**.

$$p = Pout / Pdim$$

with

$$0 <= p <= 1$$
$$pin = p + a + b.p + c.p^2$$
$$B = 1 + b$$
$$pin = a + B.p + c.p^2$$

$$efficiency = p / pin = p / (a + B.p + c.p^2)$$

In OPALIS IHM 4 parameters which describe the efficiency curve are needed :

- Pdim: sizing power converter or maximum power transferred
- RendementMAX: the maximum efficiency between p=0 and p=Pdim
- Rendement1: The efficiency for p=1 (Pout = Pdim)
- p0: point which defines the slope at the origin of the efficiency curve. p0 is the value of p when the slope crosses an efficiency = 1.

From these parameters, OPALIS computes before simulation running the value of a, b and c.

The following examples illustrate the model.

Generic example :

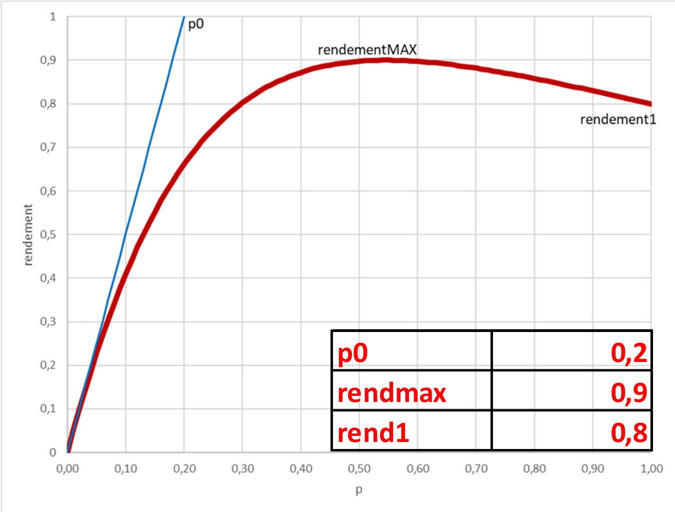


Figure 13: Generic efficiency curve

RendementMAX < 1
Rendement1 < 1
Rendement1 <= RendementMAX
p0 < 1

Example of a constant efficiency :

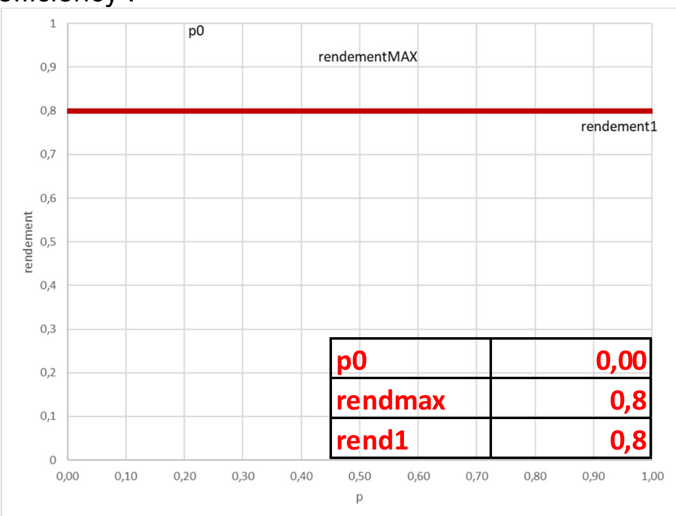


Figure 14: Constant efficiency curve

Example of an efficiency of only serial losses:

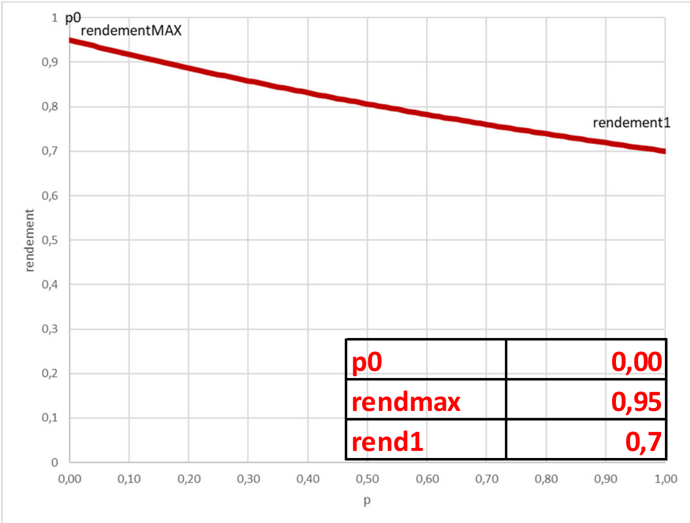


Figure 15: Only serial losses efficiency curve

Example of only parallel losses:

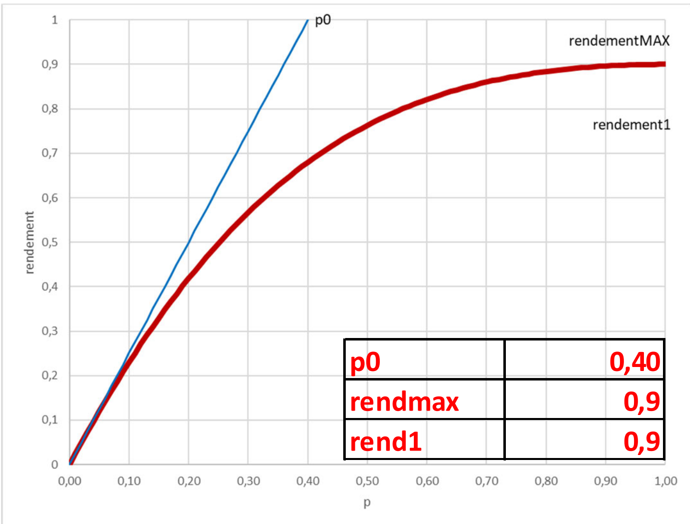


Figure 16: Only parallel losses efficiency curve

Others examples:

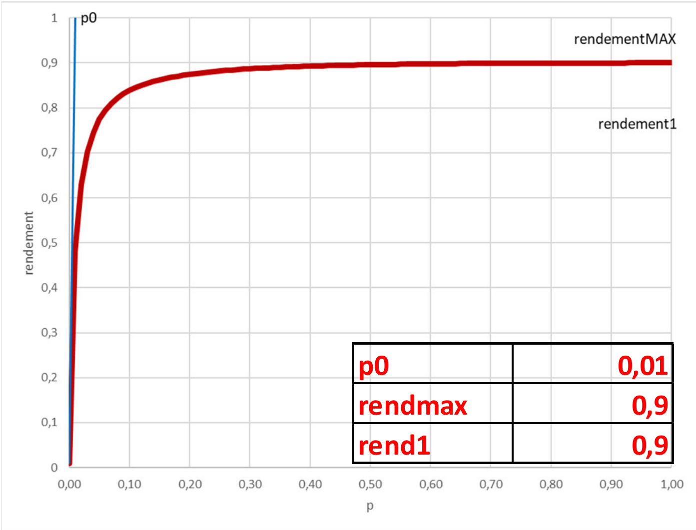


Figure 17: Efficiency curve 1

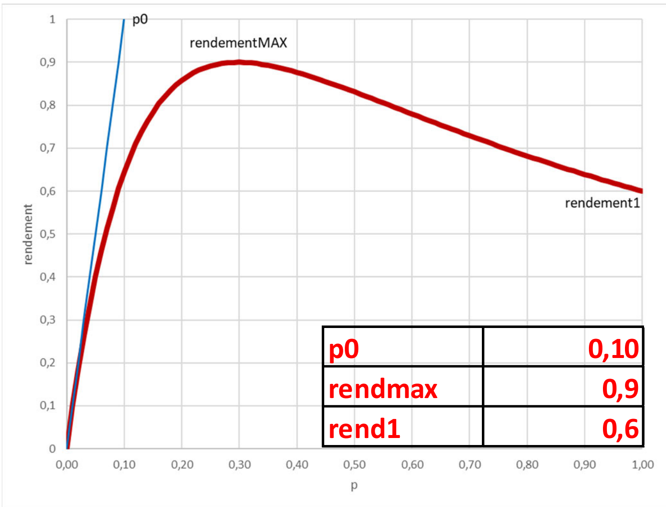


Figure 18: Efficiency curve 2

2.3 OPALIS ADVANCE SIMULATION ALGORITHM

The global algorithm of OPALIS simulation tool is represented on the figure 20.
It is composed by four main sections:
- Preliminary section,
- Slow loop,
- Fast loop,
- Final section.

2.3.1 PRELIMINARY SECTION

In this section, OPALIS takes into account all the parameters set in the "SIMULATION" tab.
Then OPALIS calculates the following variables:
- All the SAR polarization input voltage clipping values. These depend on the nature of the SAR topology chosen (see section 2.2.4).
- The coefficients of all efficiency models.
- All the state variables are initialized: energies at different points of the architecture, battery SOC, budget durations.

2.3.2 SLOW LOOP

In the slow calculation loop, OPALIS is clocked in a time step **Stepduration**. StepDuration is the same time step of the inputs profiles ephemeris defined by the input profiles. For example, if the input profiles are clocked at 10s, StepDuration is 10s. The StepDuration can be variable if the time step of the input profiles is variable. A value of 10s is a typical value and remains well adapted for energy budget or power sizing.
The slow loop starts with the date defined in the input profiles ephemeris (power profiles or flows profiles).
See 2.5.2 for input profiles formats.
The slow loop ends when the **simulation duration** is reached.

<u>Input date acquisitions:</u>
- OPALIS acquires the current date **Tdate** from the ephemeris flows or powers.
- StepDuration is the time between two consecutive input dates:
  Stepduration = $Tdate_n - Tdate_{n-1}$.

<u>Orbit budget:</u>
- If the OrbitDuration is reached, then OPALIS calculates energy budget elements: number of orbit, DOD, Energy minimum in the battery (Emin), battery charging stage durations (Til, Tvl), Cycled DOD (DODcycle), minimum battery voltage (Vmin).

<u>Input datas acquisition:</u>
- All input profiles are defined in the OPALIS "Inputs" tab.
- At each **Stepduration** step, OPALIS acquires the input data's:
  - powers profiles,
  - flow profiles: direct solar flux, albedo, Earth infrared,
  - battery voltage and current limits (if the option is selected),
  - battery temperature (if the option is selected),
  - SA temperatures (if the option is selected).

<u>Consumptions calculation:</u>

- OPALIS calculates PconsoS for all the distribution lines.
  - PconsoS = Pconstant (if there is not input power profile defined)
  - PconsoS = Pprofile + Pmargin (if input power profile is defined)
- For each distribution line, the distribution efficiency is computed thanks to the power transferred.
- Then PconsoP = PconsoS/efficiency
- The global power consumption is the summation of all PconsoP.

Fast Loop:
See Fast loop paragraph 2.3.3.

Powers, dissipations and energies calculation:

- For the energy budget, OPALIS calculates all the powers transferred trough the power architecture.
- The corresponding energies are incremented at each stepDuration:
  $enrergy_n = energy_{n-1} + power_n * stepduration$.
- The taper voltage duration **tvl** and current limitation duration **til** are computed.

End of slow loop:
- The slow loop is executed while **Tdate < simulationDuration**

2.3.3 FAST LOOP

A fast calculation loop for the functional operations of the power system, the regulations and the control is made every **timeStep**. Typically, timeStep is set at 0,1s and it is not recommended to change it.
- A calculation time **subStepTime** is set at 0 before starting the fast loop.
- At each timeStep subStepTime is increased by timeStep.

SA section calculation:
- From the flow profiles calculation of the thermal fluxes received on the SA sections.
- Temperature calculation of each SA section.
- Current delivered by each SA section.
- Voltage at MPP calculation for each SA section.

Current delivered by the SA sections:
- For each SA section, the output current **Ioreg** is calculated considering the SAR efficiencies, and the voltage ratio **Ver/vbnr**
- **IOregT** is the summation of all the **Ioreg**

Primary bus interface:
- Current to the battery **Ibattp = IOregT - Isl**

Battery calculations:
- In the Non Regulated Bus case, **IbattP = Ibatt**
- In the Regulated Bus case, **IbattP** and **Ibatt** are calculated considering BCD efficiencies and the voltage ratio **vbnr/ Vbatt**
- Calculation of the new **SOC**
- Calculation of the internal battery voltage **Ebat**
- Calculation of the battery internal resistances
- Calculation of **Vbattmodule** and **Vbatt**

Primary bus voltage:

- In the Non Regulated Bus case, **vbnr = Vbatt**
- In the Regulated Bus case, **vbnr= VBus**

<u>BCD calculation:</u>

- In the Regulated Bus case, the efficiencies of the BCD are calculated thanks to the power transferred trough the BCD.

<u>Error calculation:</u>

- The error calculation between Vbatt and Vl : vdif
  - If Reguldomain is Right then **vdif = vbatt - vl**
  - If Reguldomain is Left then **vdif = vl - vbatt**
- The error calculation between Ibatt and Ilim : idif
  - If Reguldomain is Right then **idif = ibatt - ilim**
  - If Reguldomain is Left then **vdif = ilim - ibatt**

<u>Regulation:</u>

- Proportional / integral corrector for the battery voltage regulation
- Control order for voltage regulation **vgsxV**
- Proportional / integral corrector for the battery current regulation
- Control order for current regulation **vgsxI**
- If the regulation of the SA section is on the right domain then control order **vgsx = max [vgsxV ; vgsxI]**
- If the regulation of the SA section is on the left domain then control order **vgsx = min [vgsxV ; vgsxI]**
- The set point **vgsx** is clipped.

<u>Control orders sharing:</u>

- If the regulator control is “parallel” then all the SAR receive the same control order vgsx.
- If the regulator control is “sequential” then the control order vgsx is shared sequentially from the first SAR to the last SAR. To increase power, sequential regulation connects to the bus the section 1 first, then section 2, and so on until the last section.

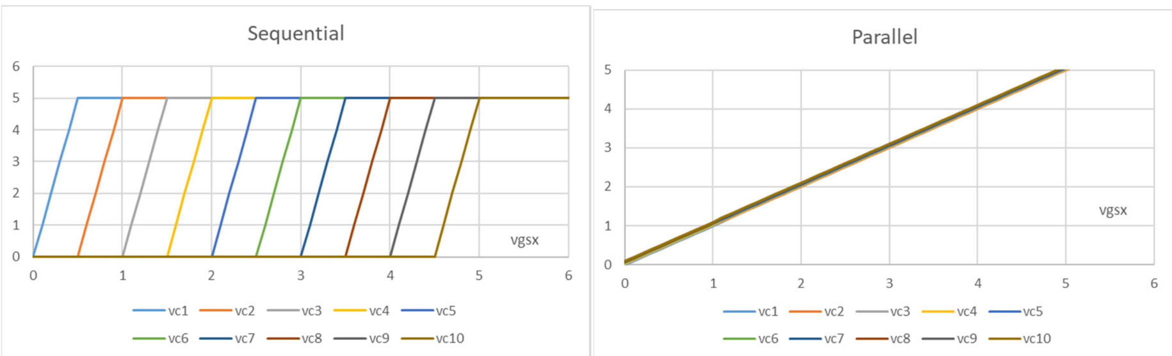


Figure 19: Control order sharing in sequential and parallel mode

<u>shuntDigitalDET:</u>

- If the regulation control is “shuntDigitalDET”, then OPALIS does not use the regulation function.
- The shuntDigitalDET control loop is activated only at each **DETstep** step defined in the “controller”. **DETstep** shall be higher than **timeStep** and higher than **Stepduration.**
- The shuntDigitalDET control loop uses a hysteresis comparator. The hysteresis voltage and current values: **DeltaVBus** and **DeltaIbatt** are defined in OPALIS controller tab.

- **If vdif > DeltaVBus And idif > Deltaibatt** then one additional SAR section is connected to the bus.
- **If vdif < -DeltaVBus Or idif < -Deltaibatt** then one SAR section is disconnected from the bus.

serialDigitalDET:
- If the regulation control is "serialDigitalDET", then OPALIS does not use the regulation function.
- The serialDigitalDET control loop is activated only at each **DETstep** step defined in the "controller". **DETstep** shall be higher than **timeStep** and higher than **Stepduration**.
- The serialDigitalDET control loop uses a hysteresis comparator. The hysteresis voltage and current values : **DeltaVBus** and **Deltaibatt** are defined in OPALIS controller tab.
- **If vdif > DeltaVBus Or idif > Deltaibatt** then one SAR section is disconnected from the bus.
- **If vdif < -DeltaVBus And idif < -Deltaibatt** then one additional SAR section is connected to the bus.

Input voltages of SAR:
- OPALIS generates, for each SAR and in function of all the control orders computed just before, all the input voltages **ver** that are the real voltages applied across all SAR inputs.
- These **ver** voltages are clipped depending on the classes of the regulator (see 2.2.4).
- If the SA is not illuminated (in eclipse, or bad pointing), OPALIS puts **ver** voltage arbitrarily at **ver = vbnr/20**. During eclipse or when the SA current is near zero, there is no influence on the energy budget.

SA voltage and power:
- From **ver,** the **vsa** voltage is calculated for each SA section taking into account the voltage drops **vdiode** and the harness resistance **rls**.
- If the SA is not illuminated (in eclipse, or bad pointing) OPALIS puts **vsa** voltage arbitrarily at **vsa = vbnr/30**.
- The power delivered from each SA is computed: **psa = isa x vsa**

SAR efficiency:
- The efficiency of each SAR is calculated taking into account the power transferred.

End of fast loop:
- The fast loop is executed while **subStepTime < stepDuration**.

2.3.4 FINAL SECTION

The final budget calculation where all the energy budgets of the simulation are finalized.
- The average powers are calculated:
  $P_{average}$ = energy / simulationDuration
- All the budget variables are put on the OPALIS "Synthesis" Tab
- Finally, OPALIS stores the state variables like the battery SOC, SA temperatures for the next simulation if OPALIS is running again.

2.4 SOFTWARE SYNOPTIC

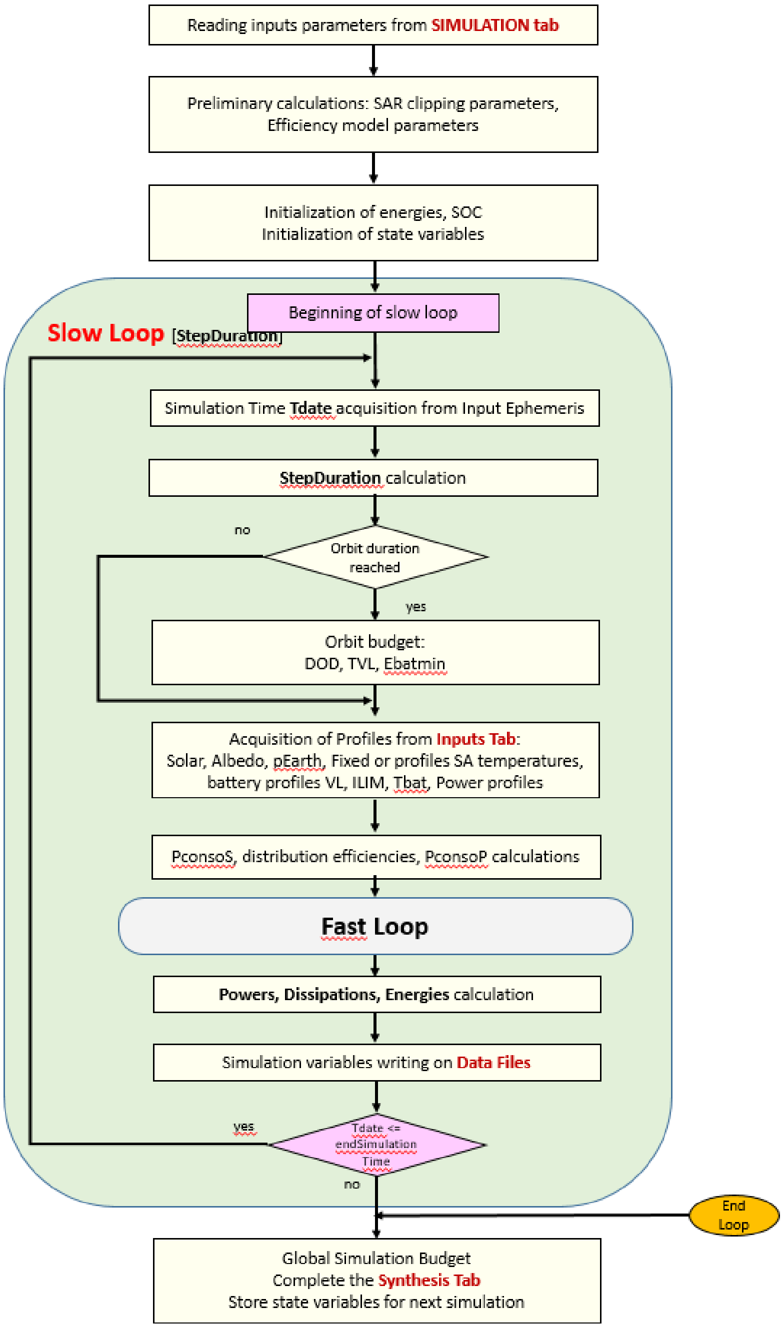


Figure 20: Global OPALIS simulation algorithm

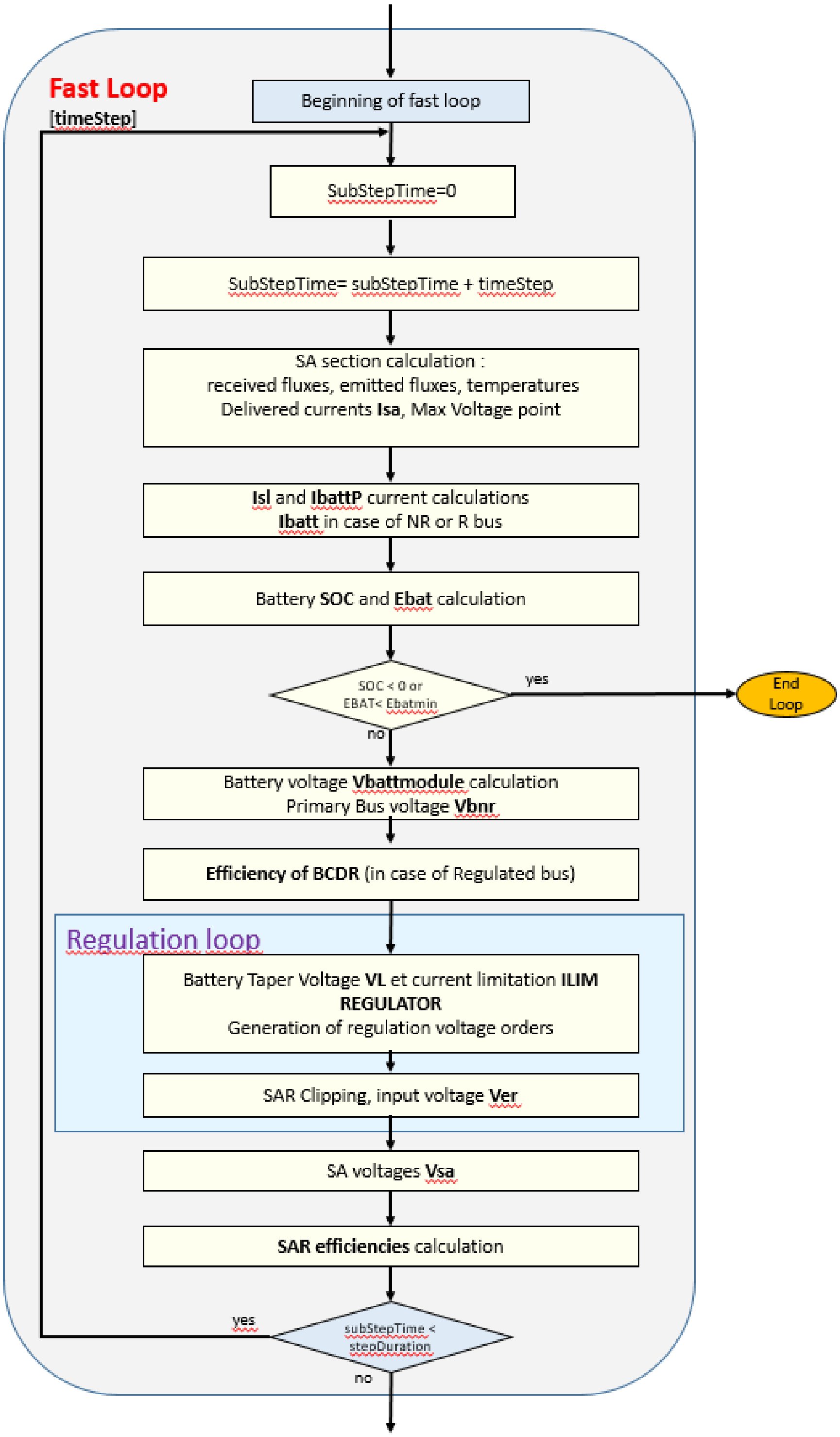


Figure 21: Fast Loop OPALIS simulation algorithm

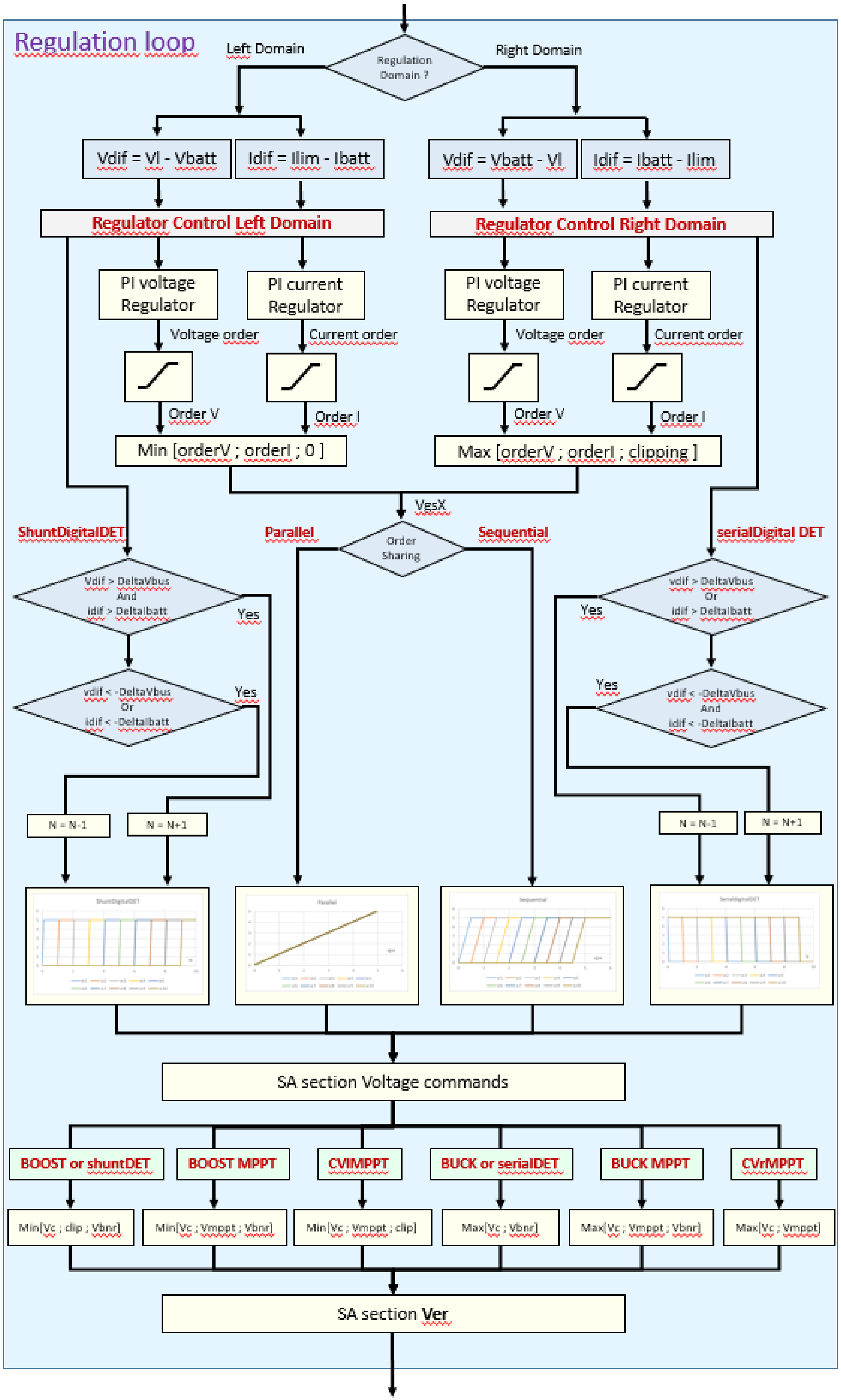


Figure 22: Regulation loop OPALIS simulation algorithm

2.5 OPALIS ADVANCE SIMILATION PREPARATION

2.5.1 STATIC INPUTS PARAMETERS

These parameters describe the system to be simulated and are displayed in the **Simulation tab**. In this tab, white cells are editable and grayed cells are not.

Some parameters are not used in the simulation, depending on the configuration of the system. Only useful parameters are displayed.

2.5.1.1 SIMULATION TIMING

Simulation timing

Simultation duration (s)	86550
Time step (s)	0.1
Orbit duration (s)	5770

Simulation Duration: It is the duration of the simulation in seconds. All the inputs (power profiles, fluxes profiles…) shall be defined for this Duration.

Time step: Simulation step in seconds
If this value is less than the step in the ephemeris data, the calculation loop will be subdivided.
If this value is greater than the step in the ephemeris data, it will have no effect in the calculation loop.
In order to have a good resolution and no problem of convergence by the simulation loops, the TimeStep is set at 0,1s by default.

Orbit Duration: If the simulation concerns a spacecraft in orbit, it is required to define this parameter.
OPALIS executes an energy budget at each orbit.
It is recommended to apply the following rule:

SimulationDuration = Norbits x OrbitDuration

Where Norbits is an integer (typically 14 to 16 in LEO, 3 to 5 in GEO).

2.5.1.2 POWER PROFILE

Power Profile

Satellite name	SAT-TEST-A
Satellite temperature (°C)	0
Regulated	Non regulated
Current limit mode	Constant
Voltage limit mode	Constant
Regul domain	Left domain
Thermal model	Albedo and pEarth profiles
Battery temperature mode	Constant

Satellite Name: This is to give a name to the satellite or the budget executed by OPALIS for your application.

Satellite temperature: Satellite temperature (°C). The satellite's wall temperature. It is used for a body mounted solar array.

Regul type: Indicates if the power system has a regulated or a non-regulated bus. The global architecture **vBus** parameter is shown only for regulated buses.

Current limit mode: Defines if the battery current limitation is constant (equal to **ilim1**) or varying in time (profile).

Voltage limit mode: Defines if the battery voltage limitation is constant (equal to **vl**) or varying in time (profile).

Regul domain: Determines if the solar array regulators will be all shunt (left domain) or all series (right domain). The regulators available in the solar array sections are filtered out depending of this parameter.

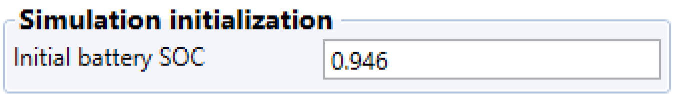
Thermal model: Defines the thermal model used (see 2.2.1.2).

- Reduced: Solar array reduced thermal model, albedo and earth IR are deduced from a ratio of the solar profile.
- Albedo and pEarth profiles: Model with two albedo and two earth IR profiles
- Fixed day and night temperatures: Model with fixed day/night temperatures
- Front and back temperature profiles: Model with front and back temperatures profiles

The following table shows what inputs OPALIS needs and how OPALIS computes the temperature and the delivered current of the SA in function of the selected thermal model.

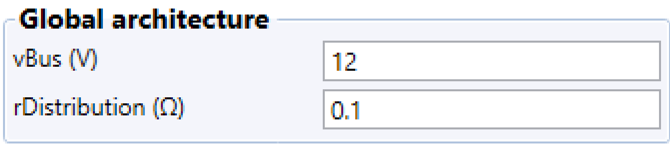
	Inputs in OPALIS Simulation							OPALIS SA computings		
Thermal Model	Solar Flux Front	Solar Flux Rear	Albedo Flux Front & Rear	pEarth Flux Front & Rear	Solar Constant	SA Temperature profiles Front & Rear	Constant SA Temperatures Day & Night	SA Temperature computed by OPALIS	SA current computed without Albedo	SA current computed with Albedo
Reduced	■				■			■	■	
Albedo & pEarth Profiles	■	■	■	■	■			■		■
SA Temp N & D fixed	■				■		■		■	
SA Temp Profiles	■				■	■			■	

2.5.1.3 SIMULATION INITIALIZATION



Battery SOC: OPALIS needs only the SOC of the battery to start the simulation. OPALIS initializes the SOC with the final SOC it got from the previous simulation. It is then possible to re-run simulations in order to converge to a stabilized SOC.
Others internal state variables are initialized from final results of a previous simulation to initialize the following run: battery voltage, temperatures of the SA sections.

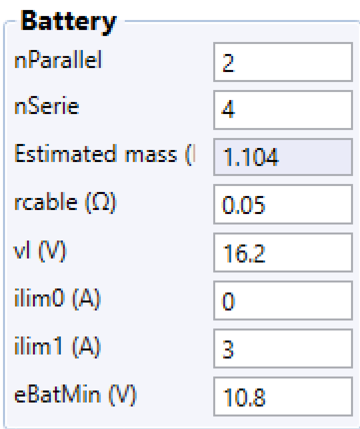
2.5.1.4 GLOBAL ARCHITECTURE



vBus: This is the voltage of the primary power bus in case of a regulated bus. OPALIS fixes this value on the VBNR node.

RDistribution: This is the resistance between the primary power bus node and the distribution units.

2.5.1.5 BATTERY PARAMETERS



nParallel: Number of accumulator strings put in parallel.

nSerie: Number of accumulators put in series (computed)

Estimated mass: The estimated mass of the battery is given here just for information and it is computed by OPALIS.

Rcable: Harness resistor between the battery and the bus.

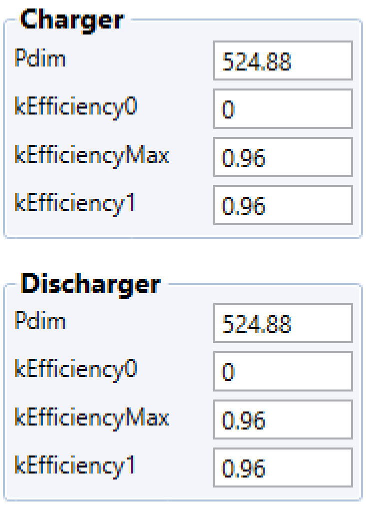
Vl: Limit voltage allowed for the battery (taper voltage). The voltage limitation is given by the battery technology (example 4,2V per Li-Ion cell). Vl shall be defined considering the number of accumulator cells in series (example for Li-Ion cells with nSerie=6: Vl=25,2V).

ilim0: If accumulators need current even though they are fully charged, this parameter defines this current value. Typically, Ilim0 is set to 0, for LiIon battery.

ilim1: Maximal current value allowed for charging the battery (battery charging current until vl is reach).

eBatMin: Minimal acceptable value of the battery electromotive force. If the simulation goes under this value, the software detects an issue and stops the simulation. This is another way to detect the full discharge of the battery during simulation. eBatMin shall be defined considering the open circuit voltage of the battery in the region where the SOC is near zero.

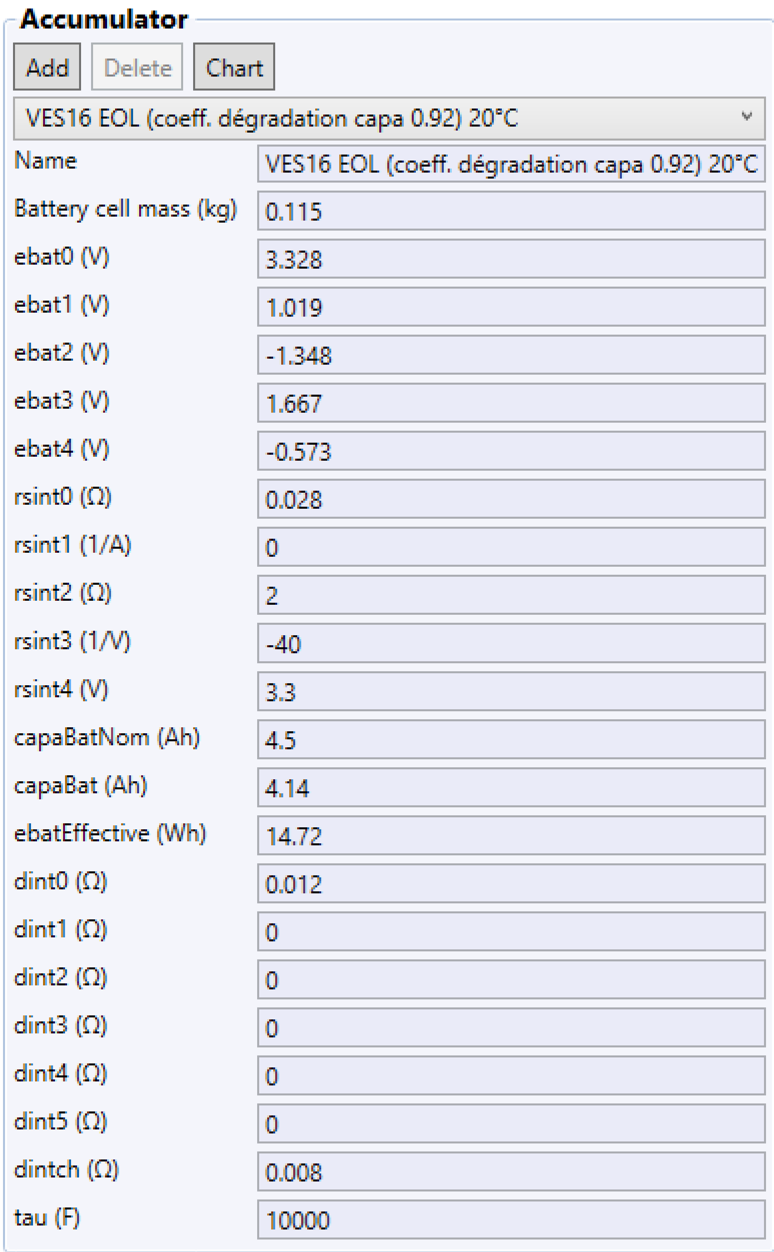
2.5.1.6 CHARGER/DISCHARGER



The charger and discharger sections are used only when Regulated is selected in the Power profile section.

Pdim, kEfficiency0, kEfficiencyMax, kEfficiency1 shall be set for the charger and for the discharger to define the efficiency curves. (See 2.2.12).

2.5.1.7 ACCUMULATOR



In this section all the accumulator parameters are defined.
It is possible to choose a proposed model of an accumulator or add a set of parameters coming from an imported model. Alternatively, it is possible directly to change or define all the parameters for a new model and then to export it.
Chart allows users to visualize the characteristics of the accumulators available.
The model of accumulator with its parameters are described in 2.2.7.

Name: Name of the accumulator

Battery cell mass: Mass of a battery cell.

ebat0 to ebat4: Parameters used for the computation of the internal voltage of the accumulator model.

rsint0 to rsint4: Parameters used for the computation of the internal resistor rint of the accumulator model. Used for constant battery temperature mode.

rsint_t1 to rsint_t7: Parameters used for the computation of the internal resistor rint of the accumulator model. Used for profile battery temperature mode.

capaBatNom: Nominal capacity of the accumulator (nameplate).

capaBat: Effective value of the accumulator capacity (here the accumulator ageing is considered).

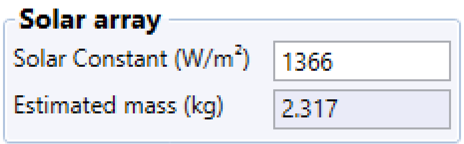
ebatEffective: Effective value of energy in the accumulator (here the accumulator ageing is considered).

dint0 to dint5: Parameter used for the computation of the internal resistor rint of the accumulator model.

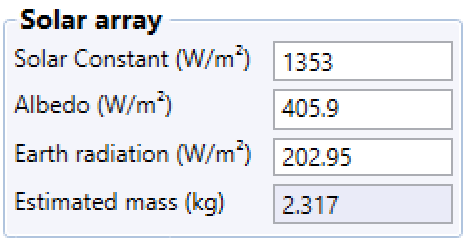
Dintch: Parameter used for the computation of the internal resistor rint of the accumulator model.

Tau: Parameter used for the computation of the internal resistor rint of the accumulator model

2.5.1.8 SOLAR ARRAY



Solar Constant: Value of the solar constant in W/m². AM0 = 1366W/m².

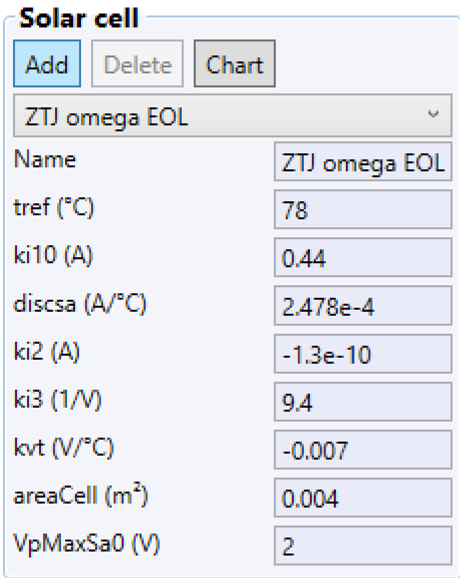


Albedo: Value of albedo in W/m², used only in case of a “Reduced” thermal model.

Earth radiation: Value of Earth’s infrared flux in W/m², used only in case of a “Reduced” thermal model.

Estimated mass: The estimated mass of the solar array (computed)

2.5.1.9 SOLAR CELL



In this section, all the solar cell parameters are defined.
It is possible to choose a proposed model of a solar cell or add a set of parameters coming from an imported model. Alternatively, it is possible directly to change or define all the parameters for a new model and then to export it.
Chart allows users to visualize the characteristics of the solar cells available.
The model of solar cell with its parameters are described on2.2.1.1.

Name: The name of the cell.

Tref: Reference temperature used for the solar cell model.

ki10: Parameter used to describe the solar cell.

Discsa: Parameter used to describe the solar cell.

ki2: Parameter used to describe the solar cell.

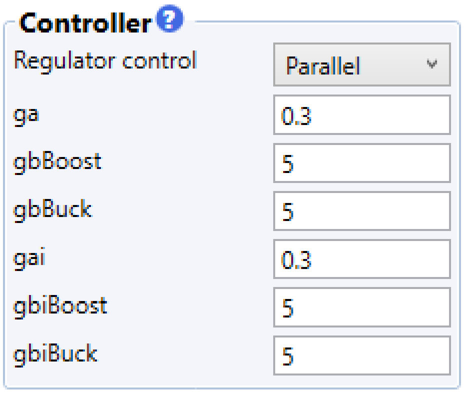
ki3: Parameter used to describe the solar cell.

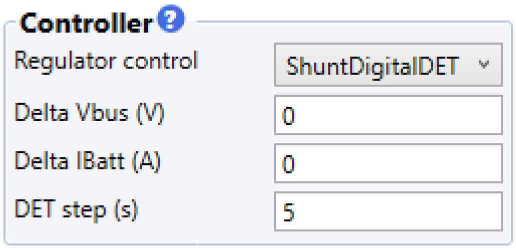
Kvt: Parameter used to describe the solar cell.

areaCell: Area of the cell.

VpMaxSa0: Voltage value at maximum power point and at the reference temperature. Parameter used to describe the solar cell.

2.5.1.10 CONTROLLER





In the controller section, it is possible to select analog type regulations (Parallel or Sequential) in accordance with the Regul Domain selected in Power Profile section (Left or Right Domain). This type of regulation allows to ajust the controller gains if needed (see 2.2.11).

A DET controller can also be selected, with its parameters DeltaVBus, DeltaIBatt and DET Step.

2.5.1.11 SOLAR ARRAY SECTIONS

Solar array sections

Add Section

	Section 1	Section 2	Section 3	Section 4	Section 5
Activation	On	On	On	On	On
Type	Rigid panel	Rigid panel	Rigid panel	Rigid panel	Rigid panel
Anchor type	Deployed	Deployed	Deployed	Deployed	Deployed
Section area (m^2)	0.089	0.089	0.089	0.089	0.044
Filling factor	0.85	0.85	0.85	0.85	0.85
Estimated mass (kg)	0.515	0.515	0.515	0.515	0.257
nSsection	10	10	10	10	10
nPsection	2	2	2	2	1
Alpha front	0.92	0.92	0.92	0.92	0.92
Alpha rear	0.97	0.97	0.97	0.97	0
Epsilon front	0.82	0.82	0.82	0.82	0.82
Epsilon rear	0.55	0.55	0.55	0.55	0
Heat capacity ($J/K/m^2$)	4250	4250	4250	4250	4250
Conductivity ($W/K/m^2$)	1000	1000	1000	1000	1000
vdiode (V)	0.55	0.55	0.55	0.55	0.55
rls (Ω)	0.4	0.4	0.4	0.4	0.4
pdim	524.88	524.88	524.88	524.88	524.88
kEfficiency0	0	0	0	0	0
kEfficiencyMax	0.95	0.95	0.95	0.95	0.95
kEfficiency1	0.95	0.95	0.95	0.95	0.95
Regulator	Boost	Boost	Boost	Boost	Boost
Cell	ZTJ omega EOL	ZTJ omega EOL	ZTJ omega EOL	ZTJ omega EOL	ZTJ omega EOL

SA sections can be added or removed.

Each SA section is defined by the following parameters:

Activation: This button allows to simulate a failure of one SA section without removing it.

Type: Rigid or Deployed type, this influences the thermal behavior of the SA section.

Section area: Is computed by OPALIS with nPsection, nSsection, filling factor, and areaCell. It is the mechanical surface the SA section.

Filling factor: it is the ration between the effective area of all the solar cells in the section and the geometric area.

Estimated mass: is given only for information.

nPsection: number of solar cells in parallel for the considered section.

nSsection: number of solar cells in series for the considered section.

Alpha and Epsilon: Thermo-optic coefficients of the SA section.

Heat capacity and Conductivity: see 2.2.1.2.

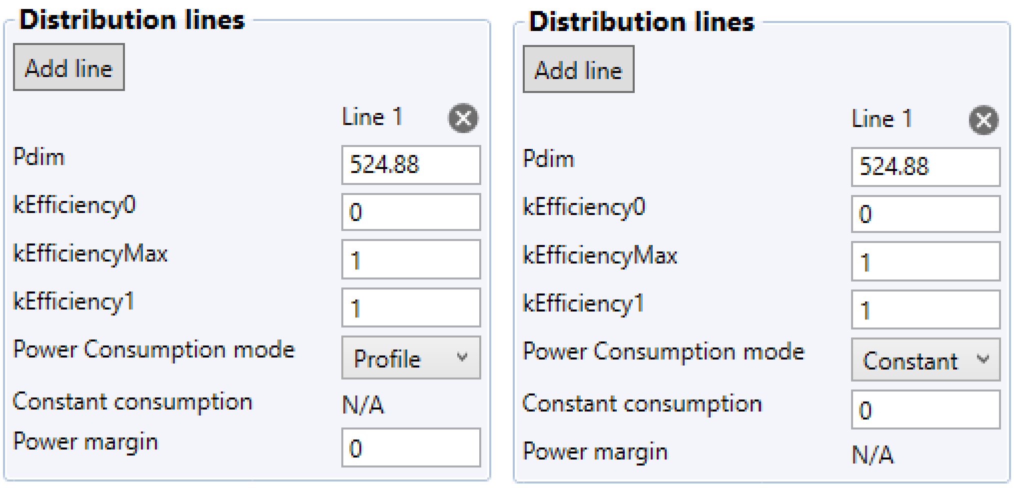
Vdiode and rls: Voltage drop in the diode and SAsection harness resistance.

Efficiency parameters of the SAR: **pdim, kEfficiencyO, kEfficiencyMax, kEfficiency1**.

Regulator: **Boost, BoostMppt, CvlMppt** if Left Domain or **Buck, BuckMppt, CvrMppt** if Right Domain, BOOST if ShuntDigitalDET or Buck if SerialDigitalDET.

Cell: selection of a solar cell.

2.5.1.12 DISTRIBUTION LINES



Efficiency parameters of the distribution line: **pdim, kEfficiencyO; kEfficiencyMax, kEfficiency1**.

Power consumption mode: Profile with an input profile file or Constant.

Power margin: If Profile selected.

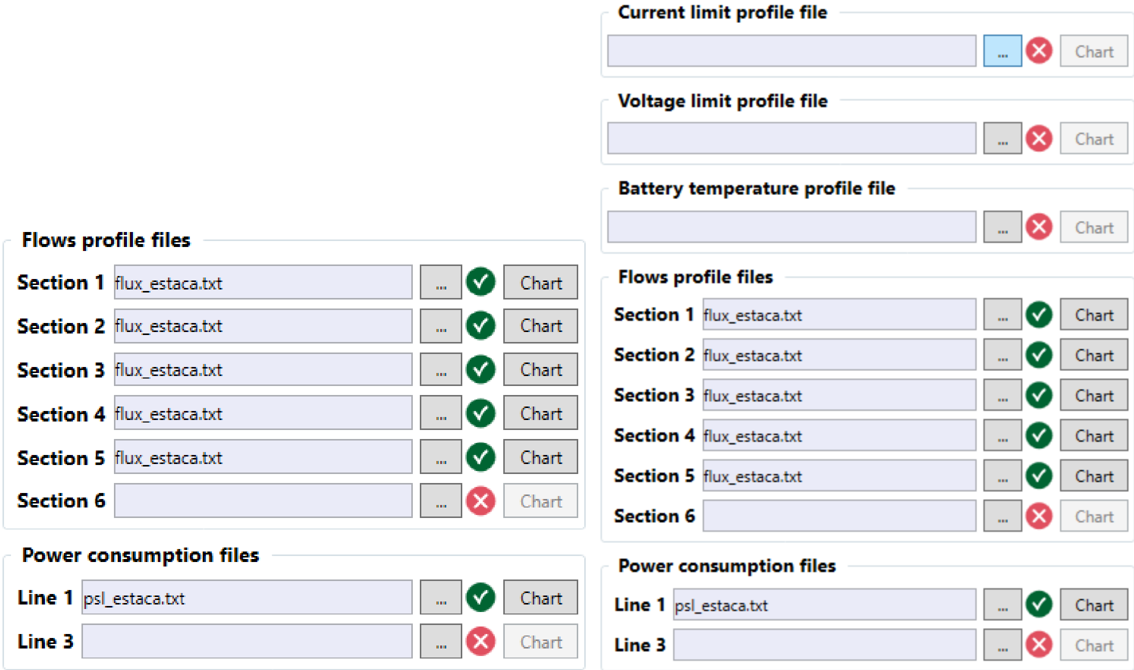
Constant consumption: if constant selected.

2.5.2 INPUTS PROFILES

The **inputs tab** is used to collect time-dependent data. This data is expected to be in the form of files in the CIC-CCSDS format. It is possible to generate those with a variety of tools from ephemeris data files, but the .txt file shall respect a defined format with a specific header. See MEM files in [RD01].

Only the files required for the simulation configuration are displayed.

The files can be dropped from the Windows file explorer or selected using the Browse button.



The marker to the right of each file indicates whether the file is suitable. The red-cross indicates that no file is selected or the file is not valid. The green-check indicates that the selected file is valid.

Flows profile files
This file describes the irradiance flows received on the solar array. There is one file for each section. These files are always required.

This file is expected to be a CIC FLUXES_SA standard file but every MEM file with exactly 6 REAL columns can be used: solar front, solar rear, albedo front, albedo rear, earth front, earth rear.

```
CIC_MEM_VERS = 1.0
COMMENT Generated by Spacebel CCSDS library
CREATION_DATE = 2019-04-22T14:33:58.254138
ORIGINATOR = CNES

META_START

COMMENT labels SOLAR_FRONT. SOLAR_REAR. ALBEDO_FRONT. ALBEDO_REAR. EARTH_FRONT. EARTH_REAR
USER_DEFINED_PROTOCOL = NONE
USER_DEFINED_CONTENT = FLOWS
USER_DEFINED_SIZE = 6
USER_DEFINED_TYPE = REAL
USER_DEFINED_UNIT = [W/m**2]
TIME_SYSTEM = UTC

META_STOP

0       10      0       0       0       0       50.65300477     50.65300477
0       20      0       0       0       0       50.65300477     50.65300477
0       30      0       0       0       0       50.65300477     50.65300477
0       40      0       0       0       0       50.65300477     50.65300477
0       50      0       0       0       0       50.65300477     50.65300477
0       60      0       0       0       0       50.65300477     50.65300477
0       70      0       0       0       0       50.65300477     50.65300477
0       80      0       0       0       0       50.65300477     50.65300477
0       90      0       0       0       0       50.65300477     50.65300477
0       100     0       0       0       0       50.65300477     50.65300477
0       110     0       0       0       0       50.65300477     50.65300477
0       120     0       0       0       0       50.65300477     50.65300477
0       130     0       0       0       0       50.65300477     50.65300477
0       140     0       0       0       0       50.65300477     50.65300477
0       150     0       0       0       0       50.65300477     50.65300477
0       160     0       0       0       0       50.65300477     50.65300477
0       170     0       0       0       0       50.65300477     50.65300477
0       180     0       0       0       0       50.65300477     50.65300477
0       190     0       0       0       0       50.65300477     50.65300477
0       200     0       0       0       0       50.65300477     50.65300477
0       210     0       0       0       0       50.65300477     50.65300477
```

Temperature profile files

This file describes the temperature of the solar array. There is one file for each section. This file is required when Thermal model is set to Front and back temperature profiles.

There is no CIC standard file, every MEM file with exactly 2 REAL columns can be used : front temperature, rear temperature.

Power consumption files

This file describes the power consumption of a distribution line in watts. This file is required when Power consumption mode is set to Profile.

This file is expected to be a CIC SATELLITE_CONSUMED_POWER standard file, but any MEM file with exactly one REAL column can be used.

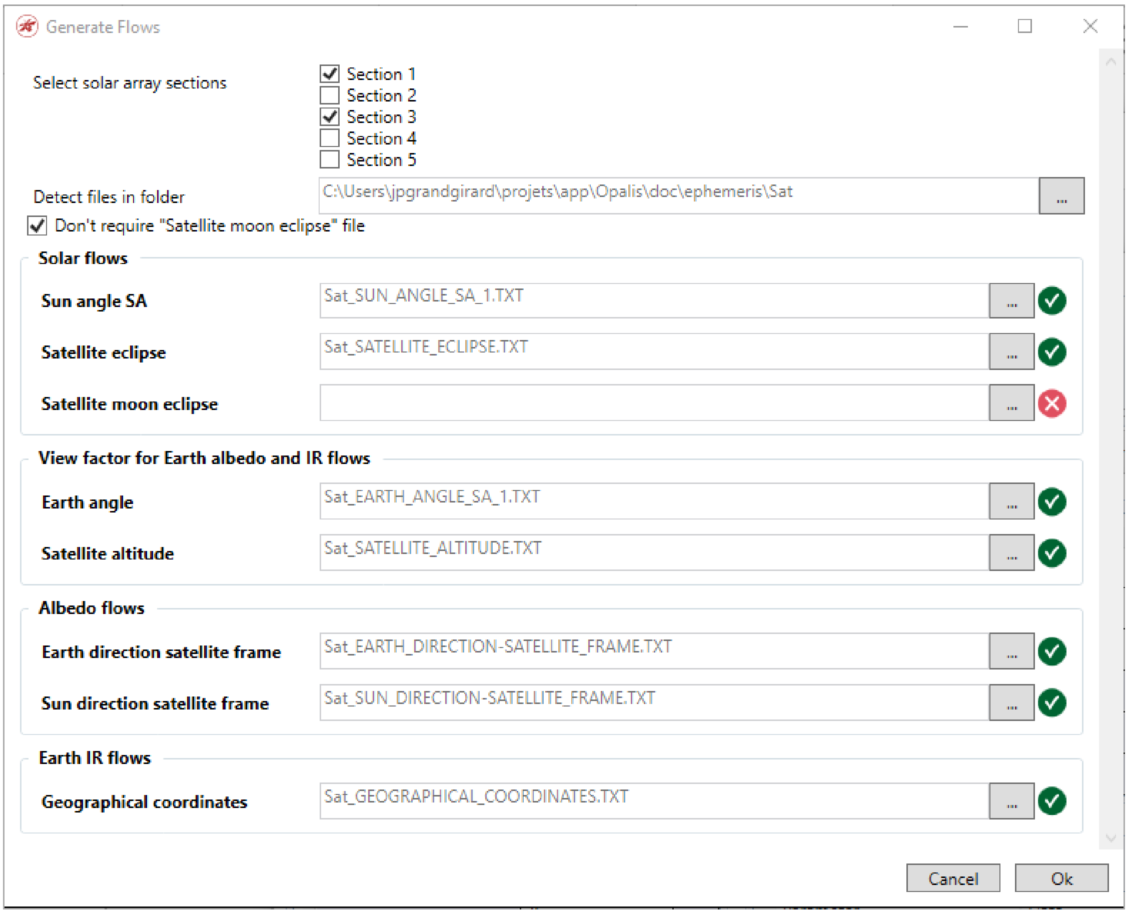
```
CIC_MEM_VERS = 3.0
COMMENT Generated by Spacebel CCSDS library
CREATION_DATE = 2023-11-03T10:08:55.778023
ORIGINATOR = IDM-Plot 1.3.0.10

META_START

OBJECT_NAME = Psl
OBJECT_ID = UNKNOWN
USER_DEFINED_PROTOCOL = NONE
USER_DEFINED_CONTENT = Psl
USER_DEFINED_SIZE = 1
USER_DEFINED_TYPE = REAL
USER_DEFINED_UNIT = W
TIME_SYSTEM = UTC

META_STOP

    0         10                                        31.7
    0         20                                        31.7
    0         30                                        31.7
    0         40                                        31.7
    0         50                                        31.7
    0         60                                        31.7
    0         70                                        31.7
    0         80                                        31.7
    0         90                                        31.7
    0        100                                        31.7
    0        110                                        31.7
    0        120                                        31.7
    0        130                                        31.7
    0        140                                        31.7
    0        150                                        31.7
    0        160                                        31.7
    0        170                                        31.7
    0        180                                        31.7
```

```
CIC_MEM_VERS = 3.0
COMMENT Generated by Spacebel CCSDS library
CREATION_DATE = 2023-11-03T10:08:55.778023
ORIGINATOR = IDM-Plot 1.3.0.10

META_START

OBJECT_NAME = Psl
OBJECT_ID = UNKNOWN
USER_DEFINED_PROTOCOL = NONE
USER_DEFINED_CONTENT = Psl
USER_DEFINED_SIZE = 1
USER_DEFINED_TYPE = REAL
USER_DEFINED_UNIT = W
TIME_SYSTEM = UTC

META_STOP

57578   0       175
57578   10      175
57578   20      175
57578   30      175
57578   40      175
57578   50      175
57578   60      175
57578   70      175
57578   80      175
57578   90      175
57578   100     175
57578   110     175
57578   120     175
57578   130     175
57578   140     175
57578   150     175
57578   160     175
57578   170     175
57578   180     175
57578   190     175
57578   200     175
57578   210     175
57578   220     175
57578   230     175
57578   240     175
```

Current limit profile file / Voltage limit profile file / Battery temperature profile file
These files describe the battery current limitation over time / the battery voltage limitation over time / the battery temperature over time. These files are required when Current limit mode / Voltage limit mode / Battery temperature mode are set to Profile.

Each one of these files is expected to be a CIC SATELLITE_CONSUMED_POWER standard file, but any MEM file with exactly one REAL column can be used.

Fluxes profile generation
The Generate Fluxes button in the Data ribbon allows to generate Fluxes profile files from geometric data. Inputs and outputs are expected to be in CIC-CCSDS format.



There are four different sections for loading files. Loading a specific file can be done by dropping a file into the appropriate text box or by clicking the Browse button.

The first section refers to the inputs used to calculate solar fluxes. The second is used for the Earth view factor. The last two sections depend on the Earth view factor and are used to calculate the Earth's albedo and the Earth's infrared fluxes if a file fulfills the requirements (see Files specification), a green checkmark appears on the left, otherwise a red cross is displayed.

In order to automatically detect the input files from a folder, drop a folder in the first text box or click the button.

If 'Don't require "Satellite moon eclipse" file' is checked, the calculation will not require this file.

Files specification

Sun angle SA (required)

Standard CIC-CCSDS MEM file with one real data column. The data represents the angle in degrees between the direction of the sun and the normal of the solar panel section. The default auto-detection file is the first one with the USER_DEFINED_CONTENT defined by SUN_ANGLE_SA_1.

Satellite eclipse (required)

Standard CIC-CCSDS MEM file with one real data column. The data represents the eclipse ratio of the satellite (0.0 : 0% eclipsed, 1.0: 100% eclipsed (umbra)). This ratio only considers the Earth. The default auto-detection file is the first one with the USER_DEFINED_CONTENT defined by SATELLITE_ECLIPSE.

Satellite moon eclipse (optional)

Standard CIC-CCSDS MEM file with one real data column. The data represents the eclipse ratio of the satellite (0.0 : 0% eclipsed, 1.0: 100% eclipsed (umbra)). This ratio only considers the Moon. The default auto-detection file is the first one with the USER_DEFINED_CONTENT defined by SATELLITE_ECLIPSE_MOON. This file is not required if the ‘Don’t require “Satellite moon eclipse” file’ control is checked.

Earth angle (required)
Standard CIC-CCSDS MEM file with one real data column. The data represents the angle in degrees between the Earth direction and the normal of the solar panel section. The default auto-detection file is the first one with the USER_DEFINED_CONTENT defined by EARTH_ANGLE_SA_1.

Satellite altitude (required)
Standard CIC-CCSDS MEM file with one real data column. The data represents the altitude of the satellite in kilometers. The default auto-detection file is the first one with the USER_DEFINED_CONTENT defined by SATELLITE_ALTITUDE.

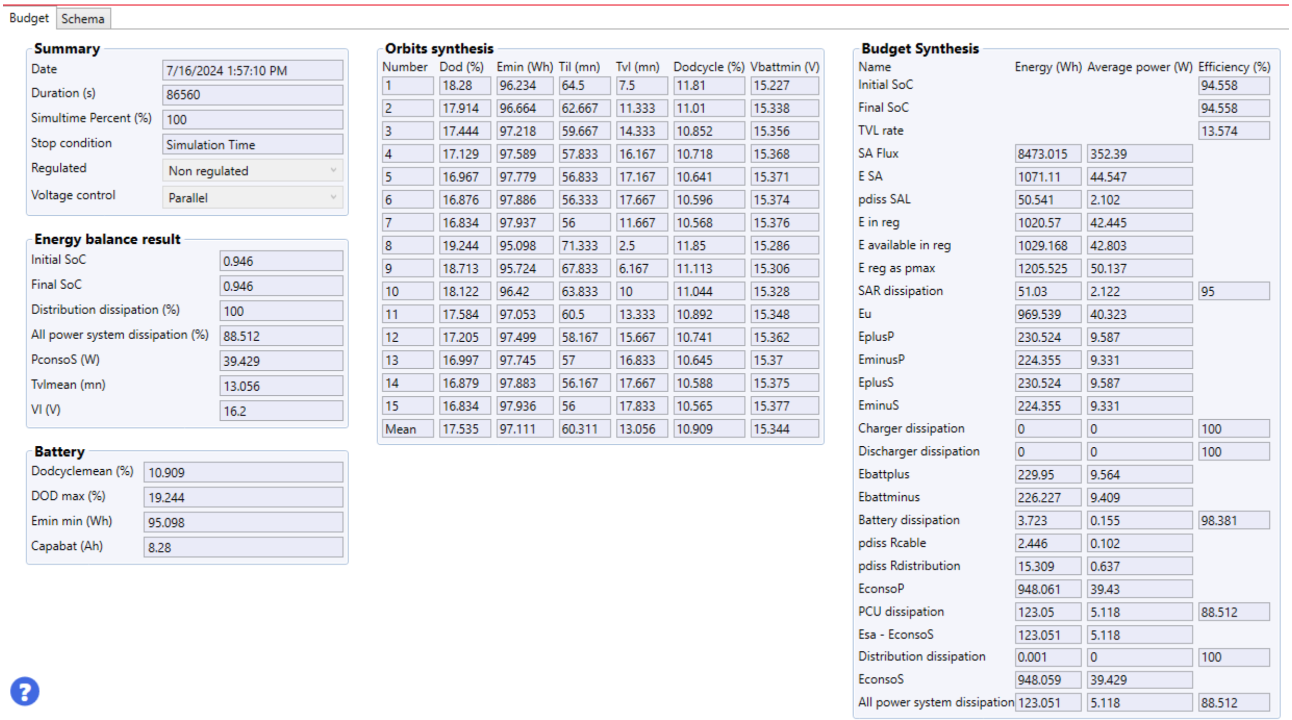
Earth direction satellite frame (required)
Standard CIC-CCSDS MEM file with 3 real data columns. The data represents the Earth direction (cosine director) in the satellite reference frame. The default auto-detection file is the first one with the USER_DEFINED_CONTENT defined by EARTH_DIRECTION-SATELLITE_FRAME.

Sun direction satellite frame (required)
Standard CIC-CCSDS MEM file with 3 real data columns. The data represents the Sun direction (cosine director) in the satellite reference frame. The default auto-detection file is the first one with the USER_DEFINED_CONTENT defined by SUN_DIRECTION-SATELLITE_FRAME.

Geographical coordinates (required)
Standard CIC-CCSDS MEM file with 2 real data columns. The data represents the longitude and latitude of the satellite in degrees. The default auto-detection file is the first one with the USER_DEFINED_CONTENT defined by GEOGRAPHICAL_COORDINATES.

2.6 OPALIS ADVANCE SIMULATION OUTPUTS

2.6.1 SYNTHESIS TABLE



Budget | Schema

Summary

Date	7/16/2024 1:57:10 PM
Duration (s)	86560
Simultime Percent (%)	100
Stop condition	Simulation Time
Regulated	Non regulated
Voltage control	Parallel

Energy balance result

Initial SoC	0.946
Final SoC	0.946
Distribution dissipation (%)	100
All power system dissipation (%)	88.512
PconsoS (W)	39.429
Tvlmean (mn)	13.056
Vl (V)	16.2

Battery

Dodcyclemean (%)	10.909
DOD max (%)	19.244
Emin min (Wh)	95.098
Capabat (Ah)	8.28

Orbits synthesis

Number	Dod (%)	Emin (Wh)	Til (mn)	Tvl (mn)	Dodcycle (%)	Vbattmin (V)
1	18.28	96.234	64.5	7.5	11.81	15.227
2	17.914	96.664	62.667	11.333	11.01	15.338
3	17.444	97.218	59.667	14.333	10.852	15.356
4	17.129	97.589	57.833	16.167	10.718	15.368
5	16.967	97.779	56.833	17.167	10.641	15.371
6	16.876	97.886	56.333	17.667	10.596	15.374
7	16.834	97.937	56	11.667	10.568	15.376
8	19.244	95.098	71.333	2.5	11.85	15.286
9	18.713	95.724	67.833	6.167	11.113	15.306
10	18.122	96.42	63.833	10	11.044	15.328
11	17.584	97.053	60.5	13.333	10.892	15.348
12	17.205	97.499	58.167	15.667	10.741	15.362
13	16.997	97.745	57	16.833	10.645	15.37
14	16.879	97.883	56.167	17.667	10.588	15.375
15	16.834	97.936	56	17.833	10.565	15.377
Mean	17.535	97.111	60.311	13.056	10.909	15.344

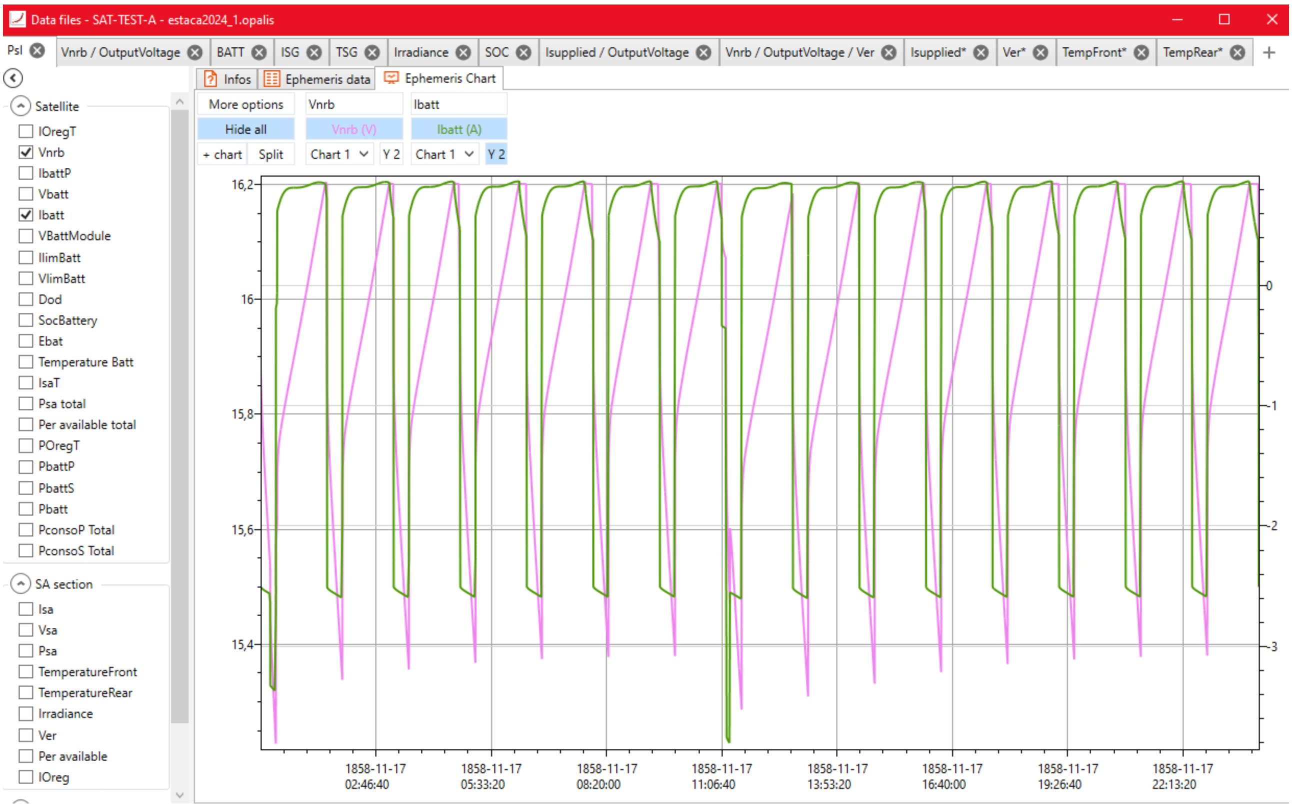
Budget Synthesis

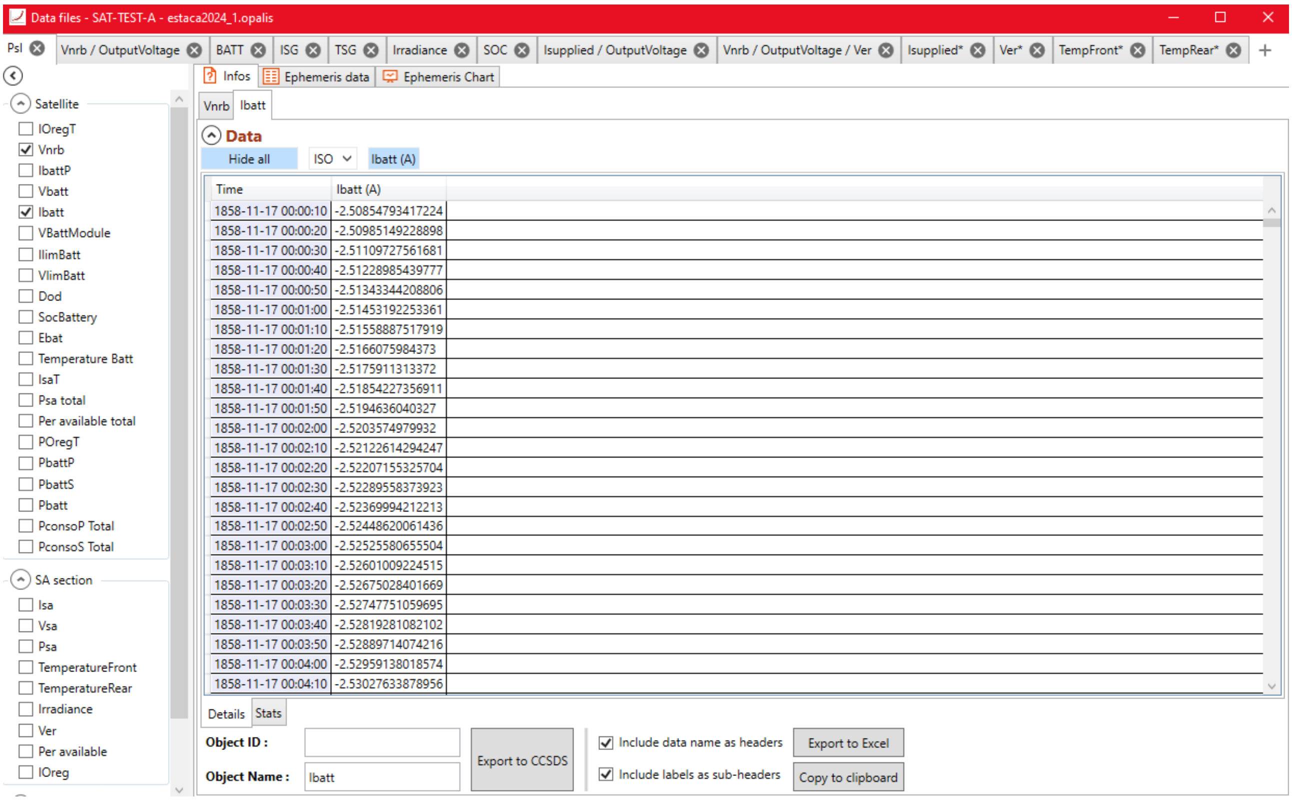
Name	Energy (Wh)	Average power (W)	Efficiency (%)
Initial SoC			94.558
Final SoC			94.558
TVL rate			13.574
SA Flux	8473.015	352.39	
E SA	1071.11	44.547	
pdiss SAL	50.541	2.102	
E in reg	1020.57	42.445	
E available in reg	1029.168	42.803	
E reg as pmax	1205.525	50.137	
SAR dissipation	51.03	2.122	95
Eu	969.539	40.323	
EplusP	230.524	9.587	
EminusP	224.355	9.331	
EplusS	230.524	9.587	
EminuS	224.355	9.331	
Charger dissipation	0	0	100
Discharger dissipation	0	0	100
Ebattplus	229.95	9.564	
Ebattminus	226.227	9.409	
Battery dissipation	3.723	0.155	98.381
pdiss Rcable	2.446	0.102	
pdiss Rdistribution	15.309	0.637	
EconsoP	948.061	39.43	
PCU dissipation	123.05	5.118	88.512
Esa - EconsoS	123.051	5.118	
Distribution dissipation	0.001	0	100
EconsoS	948.059	39.429	
All power system dissipation	123.051	5.118	88.512

For budget synthesis: See 2.7.2.

2.6.2 TIME DOMAIN OUTPUTS

The raw results of the simulation over time can be analyzed in the Data files window. It is accessible via the Data files ribbon button.
It is possible to add as many groups as you need. Each group allows you to manage the data that you want to display.
Each group is divided into three distinct tabs: **Infos**, **Ephemeris data** and **Ephemeris chart**. You can select the parameters to instantiate in the left panel.


Data files - SAT-TEST-A - estaca2024_1.opalis
Psl
Vnrb / OutputVoltage
BATT
ISG
TSG
Irradiance
SOC
Isupplied / OutputVoltage
Vnrb / OutputVoltage / Ver
Isupplied*
Ver*
TempFront*
TempRear*
Infos
Ephemeris data
Ephemeris Chart
Satellite
IOregT
Vnrb
IbattP
Vbatt
Ibatt
VBattModule
IlimBatt
VlimBatt
Dod
SocBattery
Ebat
Temperature Batt
IsaT
Psa total
Per available total
POregT
PbattP
PbattS
Pbatt
PconsoP Total
PconsoS Total
SA section
Isa
Vsa
Psa
TemperatureFront
TemperatureRear
Irradiance
Ver
Per available
IOreg
More options
Vnrb
Ibatt
Hide all
Vnrb (V)
Ibatt (A)
+ chart
Split
Chart 1
Y 2
Chart 1
Y 2
16,2
16
15,8
15,6
15,4
0
1
2
3
1858-11-17 02:46:40
1858-11-17 05:33:20
1858-11-17 08:20:00
1858-11-17 11:06:40
1858-11-17 13:53:20
1858-11-17 16:40:00
1858-11-17 19:26:40
1858-11-17 22:13:20


Data files - SAT-TEST-A - estaca2024_1.opalis
Psl
Vnrb / OutputVoltage
BATT
ISG
TSG
Irradiance
SOC
Isupplied / OutputVoltage
Vnrb / OutputVoltage / Ver
Isupplied*
Ver*
TempFront*
TempRear*
Infos
Ephemeris data
Ephemeris Chart
Vnrb
Ibatt
Data
Hide all
ISO
Ibatt (A)
Time
Ibatt (A)
1858-11-17 00:00:10 -2.50854793417224
1858-11-17 00:00:20 -2.50985149228898
1858-11-17 00:00:30 -2.51109727561681
1858-11-17 00:00:40 -2.51228985439777
1858-11-17 00:00:50 -2.51343344208806
1858-11-17 00:01:00 -2.51453192253361
1858-11-17 00:01:10 -2.51558887517919
1858-11-17 00:01:20 -2.5166075984373
1858-11-17 00:01:30 -2.5175911313372
1858-11-17 00:01:40 -2.51854227356911
1858-11-17 00:01:50 -2.5194636040327
1858-11-17 00:02:00 -2.5203574979932
1858-11-17 00:02:10 -2.52122614294247
1858-11-17 00:02:20 -2.52207155325704
1858-11-17 00:02:30 -2.52289558373923
1858-11-17 00:02:40 -2.52369994212213
1858-11-17 00:02:50 -2.52448620061436
1858-11-17 00:03:00 -2.52525580655504
1858-11-17 00:03:10 -2.52601009224515
1858-11-17 00:03:20 -2.52675028401669
1858-11-17 00:03:30 -2.52747751059695
1858-11-17 00:03:40 -2.52819281082102
1858-11-17 00:03:50 -2.52889714074216
1858-11-17 00:04:00 -2.52959138018574
1858-11-17 00:04:10 -2.53027633878956
Details
Stats
Object ID :
Object Name :
Ibatt
Export to CCSDS
Include data name as headers
Include labels as sub-headers
Export to Excel
Copy to clipboard
Satellite
IOregT
Vnrb
IbattP
Vbatt
Ibatt
VBattModule
IlimBatt
VlimBatt
Dod
SocBattery
Ebat
Temperature Batt
IsaT
Psa total
Per available total
POregT
PbattP
PbattS
Pbatt
PconsoP Total
PconsoS Total
SA section
Isa
Vsa
Psa
TemperatureFront
TemperatureRear
Irradiance
Ver
Per available
IOreg

2.6.3 NEXT SIMULATION RUN

When a simulation is finished, it is possible to click again on "Run Simulation" button. Than OPALIS executes a new simulation taking into account all the results of the previous simulation.

2.7 OPALIS ADVANCE ENERGY BUDGET

2.7.1 ENERGY BALANCE AND SIZING CONDITIONS

To have a good sizing of the power supply, OPALIS simulation gives a global energy budget with all the energies, power transferred, power dissipations, and efficiencies from the SA to the satellite power consumption.

The budget is considered to be balanced if the final SOC of the battery is equal (or higher) than the initial one.
To be in a good condition of balance, it is recommended to take the following arrangements:

Simulation Duration: In general, a simulation duration equal to an integer number of orbital period, typically 10 to 15 orbits in LEO, or 3 to 4 orbits in GEO

Time Step: 0,1s

StepDuration: 10s is a good value for input ephemeris profiles. If it is needed to have more precision in time, a shorter stepDuration can be useful.

Orbite Duration: In accordance with the simulation duration. This parameter is also usable to have intermediate budget at each orbit.

Dodcyclemean: This parameter shall be lower than the value that is taken into account for the battery degradation. For example, a typical cycled DOD of 15% for LEO and 60 000 cycles are requested to have a contained degradation, or a cycled DOD of 80% for GEO and 4000 cycles. In OPALIS, the real capacity (EOL) CapaBat, and all the battery parameters are defined with a given degradation that is reached with a maximum cycled DOD. The Dodcyclemean resulting shall be lower than this maximum cycled DOD.

Tvlmean: The average taper voltage of all the orbits shall be higher than a few minutes. This arrangement allows to maintain the battery SOC near full charge.

TVL rate: It is the same criteria as Tvlmean, but here TVL rate is the ratio of total taper voltage duration with respect to the simulation duration. A few percent is recommended.

FinalSoC = InitialSoC: In this condition, the energy budget is well balanced. It is recommended to relaunch the simulation in order to have convergence.

Emi min: This is the minimum remaining energy in the battery that occurs during the simulation. This parameter is important as it allows to check is there is sufficient energy to pass through a critical satellite mode like survival mode where the SA pointing is not stabilized.

2.7.2 BUDGET SYNTHESIS

The following table and figures give all the energies and power transferred through the power system architecture.
It possible to know the dissipations or efficiencies in different points.

Name	Definition	Energy (Wh)	Power (W)	Efficiency or rate
Initial SOC	Battery SOC at the Beginning of simulation			
Final SOC	Battery SOC at the End of simulation			
TVLrate	Taper voltage duration versus simulation duration			TVLcumul / Duréesimul *100
SA Flux	Total Solar Flux Energy or average power received on the SA	SAFlux	SAFlux / Duration	
Esa	Energy or average power delivered by the SA	Esa	Esa / Duration	
Pdiss SAL	Average Dissipation in blocking diode and SA harness	EdissSAL	EdissSAL/Duration	
EinReg	Energy transferred at SA regulator Inputs	EinReg	EinReg / Duration	
E available Reg	Available Energy if full connected to the Power Bus	EavailableReg	EavailableReg / Duration	
EReg as Pmax	Available Energy if at SA Power Max conditions	EpmaxReg	EpmaxReg / Duration	
Eu / EinReg	Dissipation at the solar array regulators	EinReg-Eu	PdissSAR = EinReg-Eu / Duration	Regefficiency = Eu/EinReg*100
Eu	Energy delivered at SA Regulators Outputs	Eu	Eu / Duration	
EplusP	Recharge Energy transferred at Charger/Discharger primary	EplusP	EplusP / Duration	
EminusP	Discharge Energy transferred at Charger/Discharger primary	EminusP	EminusP / Duration	
EplusS	Recharge Energy transferred at Charger/Discharger secondary	EplusS	EplusS / Duration	
EminusS	Discharge Energy transferred at Charger/Discharger secondary	EminusS	EminusS / Duration	
EplusS / EplusP	Charger losses and efficiency	EplusP-EplusS	(EplusP-EplusS) / Duration	EplusS/EplusP*100
EminusP /EminusS	Discharger losses and efficiency	EminusS-EminusP	(EminusS-EminusP) / Duration	EminusP/EminusS*100
Ebattplus	Recharge Energy transferred at Battery	Ebattplus	Ebattplus / Duration	
Ebattmoins	Discharge Energy transferred at Battery	Ebattminus	Ebattminus / Duration	
Edissbat	Battery losses and Efficiency	Ebattplus - Ebattminus	(Ebattplus – Ebattminus) / Duration	Ebattminus/Ebattplus*100
Pdiss Rcable	Average Dissipation of battery Harness	EdissRcable	PdissRcable = EdissRcable / Duration	
Pdiss Rdistribution	Average Dissipation in the Distribution	EdissRditr	PdissRdistr = EdissRdistr / Duration	
EconsoP	Energy at the primary of distribution lines	EconsoP	EconsoP / Duration	
EconsoP / Esa	Global Efficiency of Power Conditioning	Esa - EconsoP	(Esa – EconsoP) / Duration	EconsoP/Esa*100
EconsoS / EconsoP	Distribution lines losses and efficiency	EconsoP-EconsoS	(EconsoP-EconsoS) / Duration	EconsoS/EconsoP*100
EconsoS	Energy at the secondary of distribution lines	EconsoS	EconsoS / Duration	
EconsoS / Esa	Global efficiency of the power architecture	Esa - EconsoS	(Esa – EconsoS) / Duration	EconsoS/Esa*100

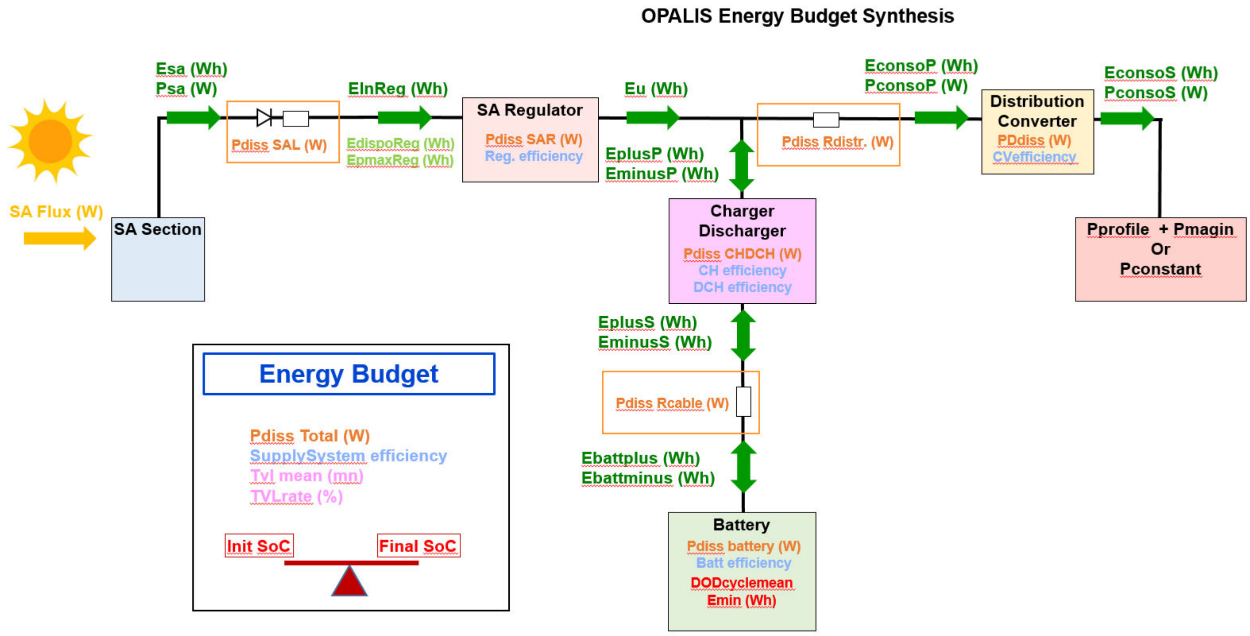


Figure 23: OPALIS Energy Budget Synthesis

2.8 OPALIS ADVANCE GUIDELINES TO START

Some indications are proposed to start the sizing of the power system.

For the SA, the ration $\mathbf{k_{SA}}$ in (m²/kW) between the SA surface and the Satellite power consumption is between 6 to 10 for LEO and can reach 14 for a LEO with low inclination and without SADM. In GEO the SA sizing is more advantageous with $\mathbf{k_{SA}}$ = 6 (See figure 24).

The ration $\mathbf{k_{BAT}}$ in (Wh/W) between the battery energy and the satellite consumption is around 3 for GEO and 5 for LEO (See figure 24).

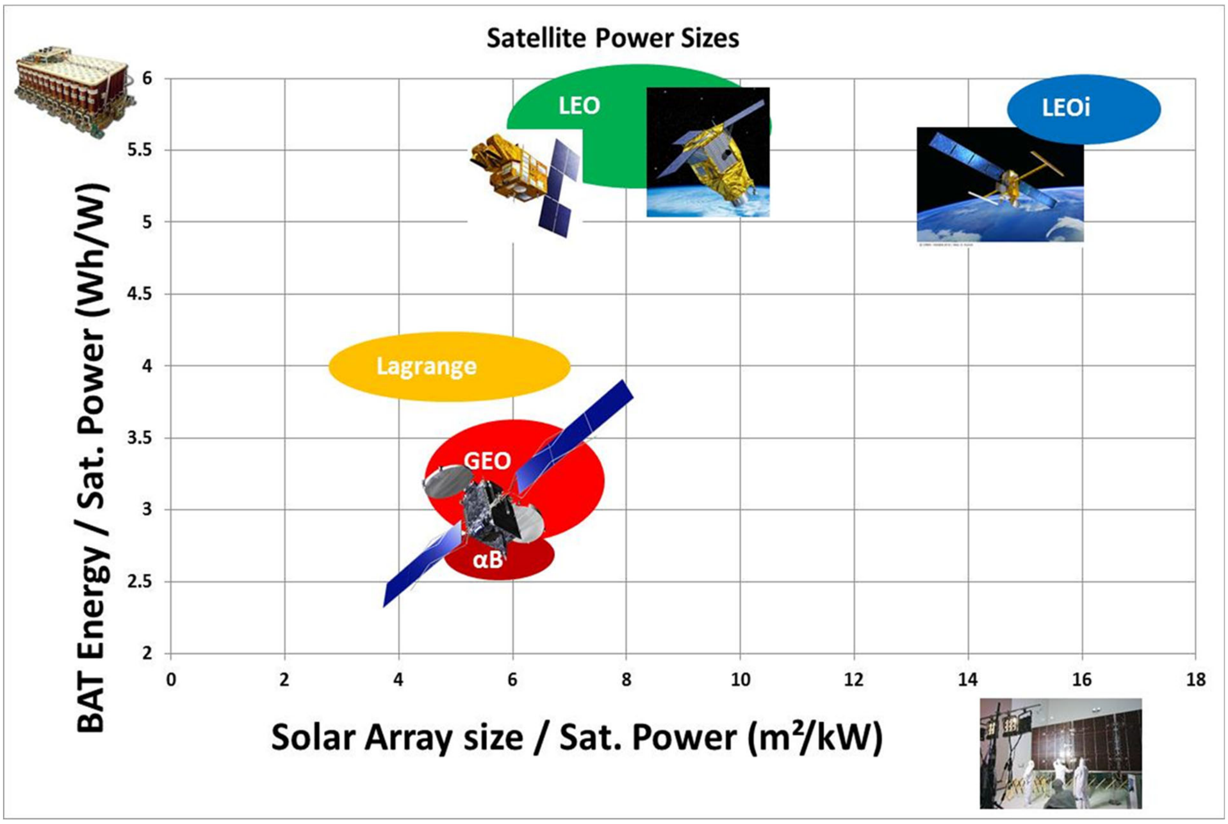


Figure 24: Power system sizing indications

In order not to degrade the battery too much during cycling, it is recommended to use it in the following way:

- In GEO a high cycled DOD is possible for 3000 cycles and 15 years of lifespan.
- In LEO a low cycled DOD is essential if we want to carry out 60,000 cycles and 10 years.

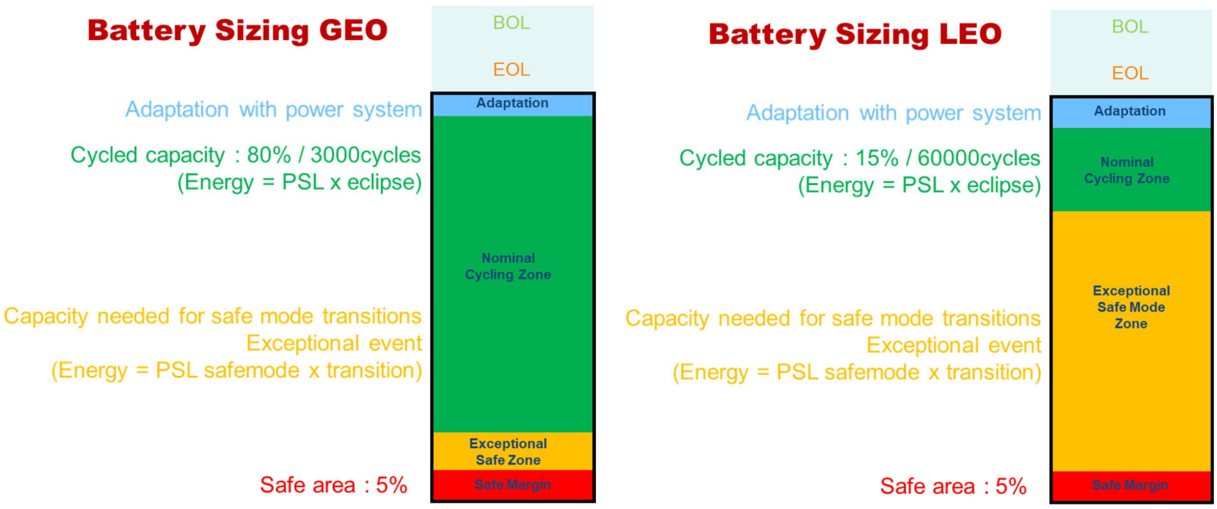


Figure 25: Battery sizing

Efficiencies on the power system are not well known at the beginning of a project. It is recommended to use constant efficiency curves with typical values:

Efficiency parameter	SAR DET	SAR (BOOST, BUCK, CV, CVMPPT)	BCD	Distribution
Pdim	2 * PconsoS	2 * PconsoS	2 * PconsoS	2 * PconsoS
kEfficiency0	0	0	0	0
kEfficiencyMax	0,95	0,92	0,94	0,98
kEfficiency1	0,95	0,92	0,94	0,98

pConsoS: Average power consumption of the satellite.

Proposed power architecture configuration:

If the power architecture is not defined at the beginning of a project, it is proposed to start with this configuration:

- Choose one of the proposed solar cells in OPALIS
- Choose one of the proposed accumulator in OPALIS
- Then **nSsecion**, **nPsection**, **nParallel**, **nSerie**, **VSUPPLY, vl, ilim0, ilim1, rcable, eBatMin** parameters can be calculated as it is proposed in 3.2.1.
- Choose Non Regulated Bus, Left Domain, BOOST regulator.

3 OPALIS SIMPLE

3.1 OPALIS SIMPLE ARCHITECTURE

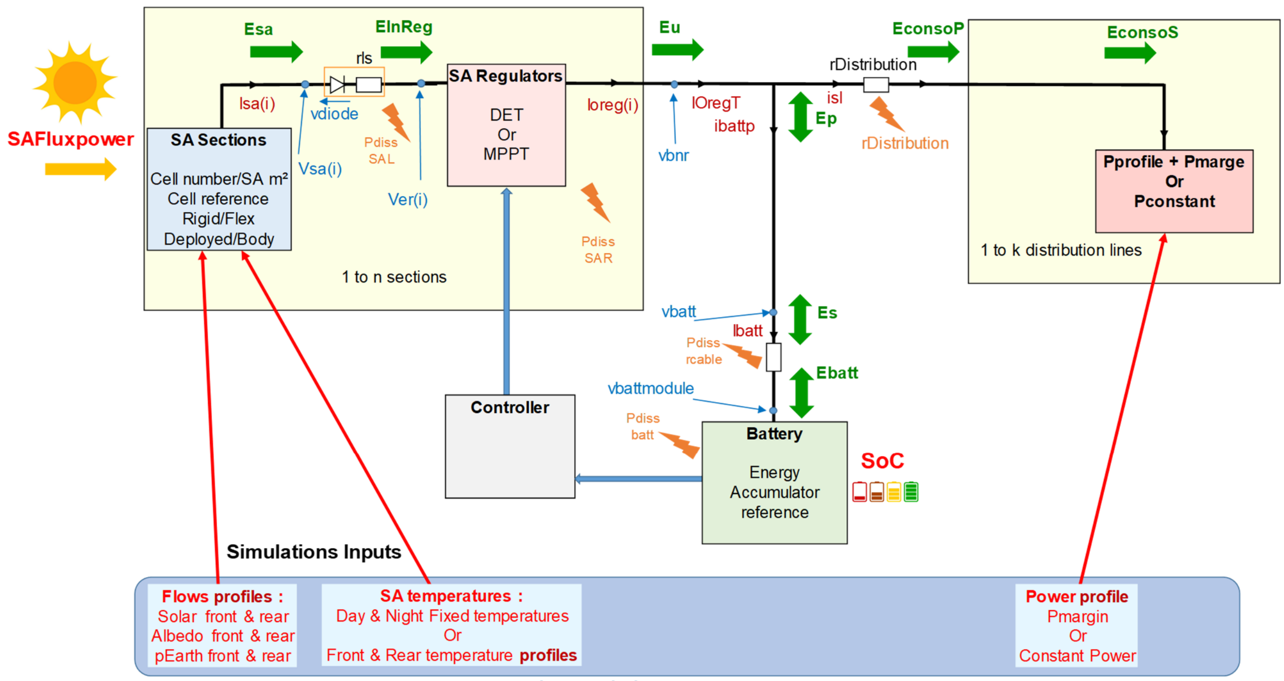


Figure 26: OPALIS SIMPLE Architecture

The objective is to have an idea of the solar array surface and the size of the battery. It is a very preliminary sizing of the power supply.

OPALIS SIMPLE uses exactly the same simulation tool as OPALIS ADVANCE.

With OPALIS SIMPLE, the HMI is drastically reduced and all the parameters needed for the simulation are automatically calculated.

3.2 OPALIS SIMPLE OPERATION

OPALIS SIMPLE does not require to define a calculation step.
timeStep = 0,1s

OPALIS SIMPLE gives access to only a limited type of configuration:
- Choice of a DET or MPPT type solar regulator without having to choose the type of regulator or the operating range to the right or left of the SA MPP.
- OPALIS SIMPLE works with Non regulated Bus Only.

- The voltage adaptation between solar array and battery is done automatically. The user only has to choose a standard supply voltage VSUPPLY which is offered according to the class of satellite studied.
- For the battery, the user only defines the desired energy at the end of life and the accumulator reference (several references offered in OPALIS).
- The battery voltage and current limitations are automatically set by OPALIS.
- For the solar generator, the user chooses the surface area of each section, the filling factor. OPALIS calculates nParallel, nSerie, nPsection and NSsection for each section on its own.
- It is possible to choose the number of solar cells proposed by OPALIS (instead of the surface of the panels).
- All parameters of the accumulator, solar cell and thermal solar panel models disappear from the HMI, the user only chooses references.
- The gains of the SAR and the efficiency parameters of the regulator disappear from the HMI.

3.2.1 OPALIS SIMPLE COMPUTING BEFORE SIMULATION

Before simulation, OPALIS SIMPLE executes some calculations of static parameters.

Battery parameters

The number of battery cells in series nSerie:

nSerie : ROUNDED.SUP (VSUPPLY) / vcellMax

Where vcellMax = ebat0 + ebat1 + ebat2 + ebat3 + ebat4

VSUPPLY is proposed in a table after.

The voltage regulation VL:

vl = nSerie * vcellMax * 0.98

The number of battery strings in parallel nParallel

nParallel = ROUNDED.SUP (ENERGY / ebatrelle / nSerie)

rcable = 50 mOhm

eBatMin = 1.1 * ebat0 * nSerie

The current limitations are set as:

ilim0 = 0
ilim1 = nParallel * capabatNom / 4

SA parameters

The number of solar cells in series nSsection:

nSsection = INT((VL +1,5) / Vpmaxgs0)

The number of solar strings in parallel nPsection:

nPsection = INT(Section area / areaCell / nSsection * Filling Factor)

Or if the total number of solar cells nTsection is chosen by the user:

nPsection = INT(nTsection / nSsection)

Vdiode = 0,5 V

Rls = 0,05 Ohm

Regulator parameters

ga	0,3
gbBoost	5
gbBuck	5
gai	0,3
gbiBoost	5
gbiBuck	5
timesptep	0,1

The bus voltage is fixed as defined in the following table.

Type de satellite	Pmoy satellite	VSUPPLY	Rdistribution	PdimGS et PdimL
CubeSat 1U à 2U	10W	4V	0,1 Ohm	20
CubeSat 3U à 6U	25W	8V	0,17 Ohm	50
CubeSat 8U à 27U	50W	16V	0,35 Ohm	100
MICROSAT	50W à 150W	30V	0,4 Ohm	300
MINISAT	150W à 2500W	36V	0,035 Ohm	5000
MEDIUMSAT	2500W à 5000W	50V	0,035 Ohm	10000
LARGESAT	5000W à 25000W	100V	0,03 Ohm	50000
VERYLARGESAT	25kW à 100kW	300V	0,06 Ohm	200000

Efficiency parameters:

parameter	DET SAR	SAR MPPT	Distribution
Pdim	See table before	See table before	See table before
kEfficiency0	0	0	0
kEfficiencyMax	0,96	0,91	1

kEfficiency1	0,95	0,9	1

3.2.2 OPALIS SIMPLE SIMULATION

The simulation algorithms are the same as in the advanced version of OPALIS.

The simulation synthesis in OPALIS SIMPLE is simplified with only a global energy balance.

- END OF DOCUMENT -