Multi-Variable Optimization Applied to Power Subsystem

MTS-UFS-CONAE

Adrian David Mentesana, Roberto Alonso and Gustavo Bisaccio

1st IAA Latin American Symposium on Small Satellites
Advances Technologies and Distributed Systems
March 7-10, Buenos Aires, Argentina

Agenda

Introduction

Multi-Objective Optimization

Optimization framework

Case Study

Conclusions

- Competition in the spacecraft industry has forced system designers to choose the design for spacecraft systems in a way that results in the most cost-effective product.

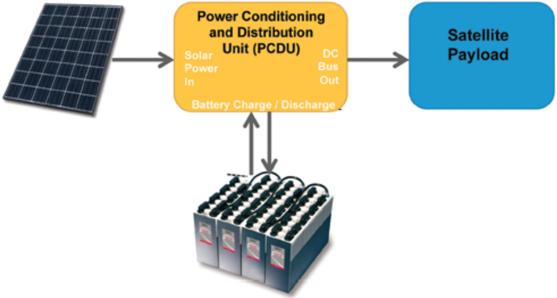
- Trade-off among different design parameters to achieve the desired goals is a lengthy and iterative process.

- This work aims to obtain a methodology for a whole design and optimization of the LEO satellite power system instead of search for optimal at component level.
- This approach seeks to harmonize the different efforts of each of the system engineers of each component, trying to optimize the whole.

Introduction
System Scope

PV-battery power systems based on DET architecture is a deal of this work. In many cases, it is provide:

- Lowest part count
- High efficiency
- Lower cost



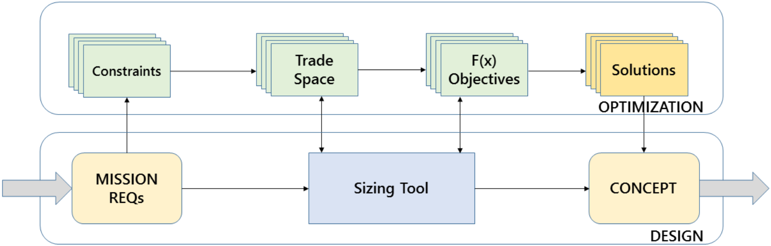
Multi-Objective Optimization
Definitions

Optimization: A procedure for find one or more solutions, which minimize (or maximize) one or more specified objectives and which satisfy all constraints.

Multi-Objective Optimization (MOO): A MOO considers several conflicting objectives simultaneously.
A multi-objective problem can be written as:

$$\text{Minimize}_{\mathbf{x}}\ \mathbf{F}(\mathbf{x}) = [f_1(\mathbf{x}), f_2(\mathbf{x})\ \ldots\ f_k(\mathbf{x})]^T$$
$$\text{subject to } g_i(\mathbf{x}) \leq 0\,,\ j = 1 = 1,\, 2,\, \ldots\, m$$
$$\text{subject to } h_j(\mathbf{x}) = 0,\ j = 1 = 1,\, 2,\, \ldots\, n$$
$$\mathbf{x}_{\text{lower}} \leq \mathbf{x}_{\text{upper}}\ .$$

Optimization Framework
Description



Optimization Framework
Trade Space

Variable	Description	Values
SCELL	Solar cell type	Si High-η Si GaAs/Ge SJ GaInP2/GaAs/Ge DJ GaInP2/GaAs/Ge TJ
ATYPE	Solar array type	Rigid planar Flexible planar
BATT	Battery cell type	NiCd NiH_2 Li-ion
VBUS	Bus voltage	28 V 50 V 100 V
NBATT	No. of batteries	1 to 6
NCELL	No. of cells per battery	According to V_{BUS}
MDOD	Maximum discharge rate	0.2C to 0.5C

Optimization Framework

Objective functions & Constraints

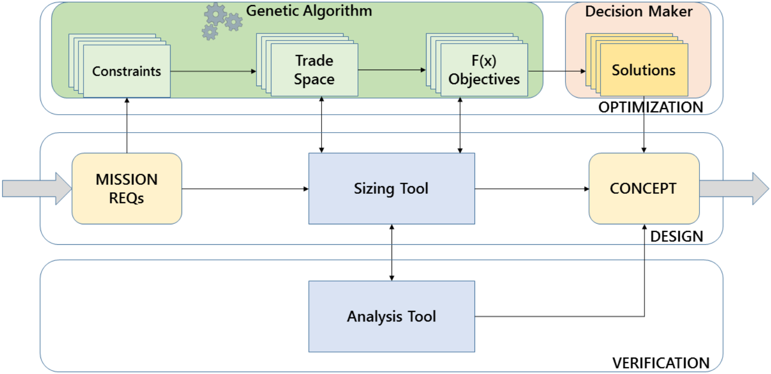
Three objectives for MOO are set: J_1 for system mass, J_2 for system cost and J_3 for performance (inverse index is used) functions are used.

$$
\begin{aligned}
J_1 &= \min\left(M_{eps}\right) \\
J_2 &= \min\left(C_{eps} + C_{eff-launch}\right) \\
J_3 &= \min\left(\frac{1}{F_o M_{SA}} + \frac{1}{R_{\text{eps}}}\right)
\end{aligned}
$$

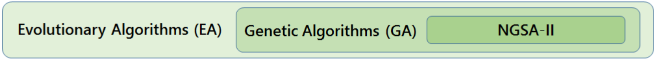
A first constraint applied to the problem ensure that battery design is within allowable operation limits.

$$h_1(x) = \frac{DOD}{DOD_{max}} - 1 = 0$$

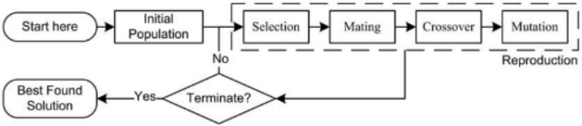
Optimization Framework
Description



Optimization Framework
GA Approach



Non-dominated Sorting Genetic Algorithm II (NSGA-II) method to tackle MOO problem is selected. It was developed by Deb in 2002.



Why NSGA-II?

- Most popular multi-objective genetic algorithm
- Very-well accepted in engineering area

Decision maker (DM): It is "human factor" of the problem. From the DM's perspective, it is desired that only a "few" solutions are available for ease of decision.

- "Optimize" means finding such a solution which would give the values of all the objective functions acceptable to the decision maker.
- In this point, the DM must be able to select a trade-off solution according to:
  - Strategy decisions
  - Programatic conflicts
  - etc.

  i.e.: A long lead item can potentially discarded from trade-off solutions

Optimization Framework

Analysis tool

A power system analysis model is developed. This approach allows verifying the dynamic behavior of the solution found.

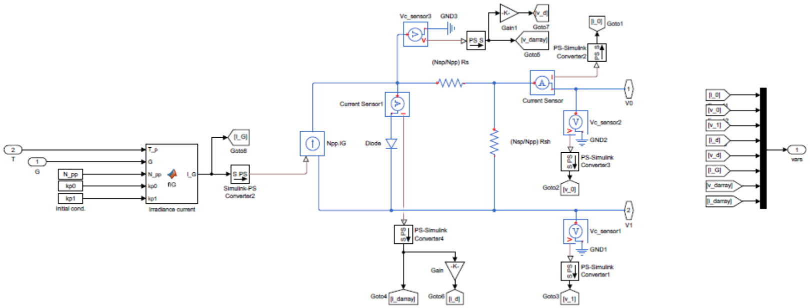


Figure 1: Exponential diode solar array model

NSGA-II: A population size of 50 and 70 generations.

Mission requirements:

- Orbit altitude: 798 [km]
- Inclination angle: 68 [deg]
- Mission life: 3 [years]
- Sunlight power requirements: 2 [kW]
- Eclipse power requirements: 2 [kW]

Two cases are raised:

- Case 1: Max. DOD constraint included
- Case 2: No constraints

Case Study
Results

	Baseline	Case 1	Case 2
Solar cell technology	Si	Triple Junction	Triple Junction
Array type	Rigid planar	Flexible planar	Flexible planar
Battery technology	NiCd	NiH_2	Li-ion
Bus voltage	28 [V]	50 [V]	50 [V]
No. of battery cells	21	33	15
No. of batteries	6	4	5
Max. discharge rate	0.5	0.5	0.35
Battery capacity	27 [Ah]	13 [Ah]	16 [Ah]
Array area	32 [m^2]	17 [m^2]	17 [m^2]
System mass	305.61 [kg]	169.94 [kg]	166.09 [kg]
System cost	5315.14 [k$]	2923 [k$]	3282.73 [k$]
Inverse perf. index	39.47	30.55	30.26

Conclusions

- The design and development of an optimization framework for computed-automated design of spacecraft power subsystems have been presented here.
- The framework takes subsystem level trade-offs into account the main issues of concern for design engineer and provide a mean for evaluating the performance along with mass and cost factors.
- The methodology used in this work can be applied to other complex scenarios.

Thank you for attend this research