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Sizing, Modeling, and Simulation of a Photovoltaic System for Powering a CubeSat-Type Nanosatellite

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ABSTRACT

With the rise of low-cost space technologies, CubeSat-type nanosatellites are becoming essential tools for scientific, educational, and remote sensing missions. This study presents a comprehensive approach to the sizing, modeling, and simulation of a photovoltaic system (PVS) for powering a 3U CubeSat. The project, conducted as part of a university collaboration in Djibouti (DJ-COTT) with the Montpellier Space Center, aims to design a reliable energy architecture adapted to the extreme constraints of the space environment. The study explores the choice of components (solar cells, MPPT controllers, batteries, DC-DC converters), their modeling in Matlab/Simulink, and the optimization of energy performance in sun-synchronous orbit. The results show that the use of triple-junction cells, combined with intelligent power management, ensures the CubeSat's energy autonomy throughout its mission.

KEYWORDS: *CubeSat, photovoltaic system, modeling, simulation, MPPT, MATLAB/Simulink, nanosatellite, space solar energy.*

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I. INTRODUCTION

CubeSats represent a revolution in access to space for universities and emerging countries. However, their small size poses major challenges in terms of energy management. The photovoltaic system, the main source of energy in orbit, must be designed with precision to ensure energy autonomy and mission reliability.

II. METHODOLOGY

The work is structured in several stages:

1. **Study of the CubeSat**: history, mission, technical constraints, and choice of sun-synchronous orbit (600 km, 97° inclination).
2. **Energy sizing**: calculation of power requirements (5.91 Wh/day), choice of triple-junction solar cells (type 3G30A), an SPV1040 MPPT controller, Nano Power P31U battery, and LTC3113 DC-DC converter.
3. **Modeling**: each component (PV cell, regulator, converter, battery) is modeled using functional blocks in Simulink according to representative physical and electrical equations.
4. **Simulation**: the complete system is simulated for different sunlight and temperature conditions in order to evaluate the performance of the solar generator by analyzing the panel's current-voltage (I-V) and power-voltage (P-V) curves.

III. RESULTS AND DISCUSSION

3.1. Electrical Design

The CubeSat is powered by **3G30A triple-junction solar cells** with an efficiency of 30%. The energy balance establishes an average consumption of **5.91 Wh/day**, requiring a peak power of **7.2 W to guarantee autonomy**. The energy architecture comprises:

- 6 solar cells connected in series-parallel;
- 3 SPV1040 MPPT controllers (97% efficiency);
- 1 NanoPower P31U battery (13.2 Wh capacity);
- One LTC3113 DC-DC converter.

3.2. Modeling and Simulation in Simulink

Each component (PV panel, controller, converter, battery) was modeled according to its electrical and thermal characteristic equations and implemented in Simulink.

The equations describing the model are:

$$Is = Iref \times \left(\frac{Tc}{Tref}\right)^3 \times e^{\left[\left(\frac{q \times Eg}{A \times K}\right) \times \left(\frac{1}{Tref} - \frac{1}{Tc}\right)\right]} \quad (1)$$

$$Isref = \frac{Iccref}{e^{\left(\frac{q \times Vocref}{n \times K \times Tref} - 1\right)}} \quad (2)$$

$$Ish = \frac{V + Ipv \times Rsh}{Rs} \quad (3)$$

$$Iph = \frac{G \times (Isc + Ki \times \theta T)}{Gn} \quad (4)$$

$$Ipv = Iph - \left[Is \times e^{\left(\frac{Vpv + Iph \times Rs}{Vt \times n} - 1\right)}\right] - \frac{Vpv + Iph \times Rs}{Rsh} \quad (5)$$

The study observed:

- The impact of **irradiance** on short-circuits current;
- The **negative** effect **of temperature** on output voltage;
- Stability of the maximum power point via the MPPT (Perturb & Observe) algorithm.

3.2.1. Influence of sunlight on panel characteristics

We chose the sun-synchronous orbit, where sunlight variation is relatively low. To see **the influence of irradiance** on panel characteristic variations, i.e., variations in current and power as a function of voltage, we set the temperature at **28°C** and varied the illuminance.

The following figures show the influence of irradiance on the characteristics of a PV panel:

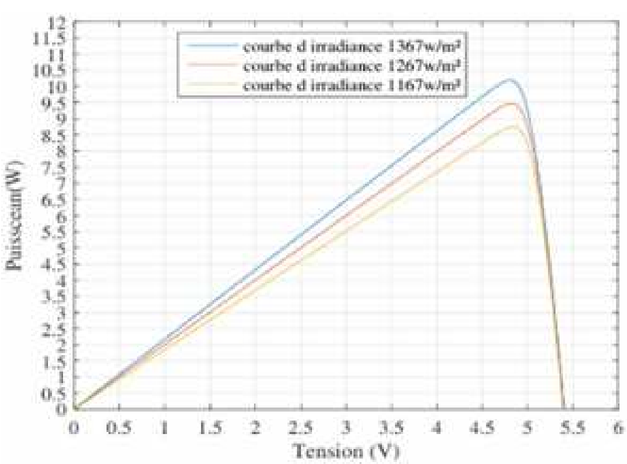

Figure 1: The influence of sunlight on power as a function of voltage

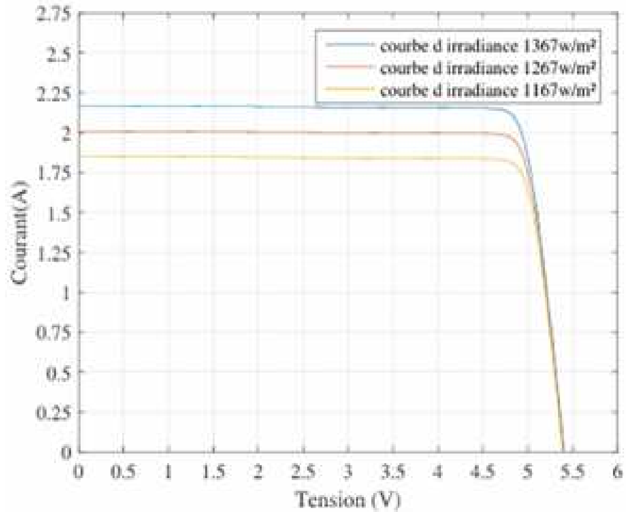

Figure 2: The influence of sunlight on current as a function of voltage

- **Analysis**

The blue curve corresponds to G=1367W/m², *the red curve to G = 1267 W/m², and the yellow curve to G = 1167 W/m².*

which represents the evolution of I as a function of V, and P as a function of V for G=1367 W/m² with T=28°C. The red curve represents the evolution of I as a function of V and P as a function of V for G=1267 W/m² with T=28°C, while the yellow curve represents the evolution of I as a function of V and P as a function of V for G=1167 W/m² with T=28°C. We *can see that the temperature is kept constant at 28°C,* and that as the irradiance increases, the currents (Impp, Icc) increase simultaneously. In addition, the maximum power (Pmax) increases as a function of irradiance (G). However, the voltages vary slightly as a function of irradiance (G).

- **Interpretation**

The I-V curves of a solar cell are highly dependent on solar irradiation values. Solar radiation resulting from changes in the environment continues to fluctuate, but there are control mechanisms in place to monitor these changes and modify the operation of the solar cell to meet the required load demands. The higher the solar irradiation, the higher the solar input into the solar cell, and consequently, the power increases for the same voltage value. As solar irradiation increases, the short-circuit current increases. This *is because* when more solar rays reach the solar cell, the electrons receive higher excitation energy, which increases electron mobility and thus generates more power.

3.2.2. Influence of temperature on panel characteristics

Now, for a given irradiance of **1367 W/m2**, for different temperature levels, we want to see **the**

influence of temperature on the characteristics of a solar panel, i.e., the current as a function of voltage and the power as a function of voltage.

The following figures show the influence of temperature on the characteristics of a PV panel:

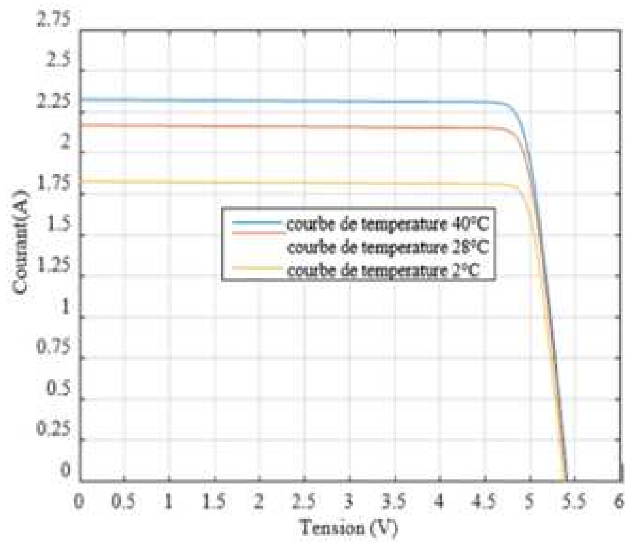

Figure 3: The influence of temperature on current as a function of voltage

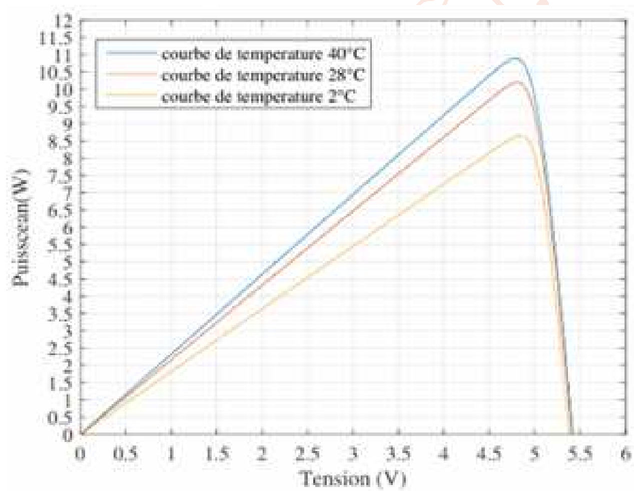

Figure 4: The influence of temperature on power as a function of voltage

Analysis and Interpretation

- **Current (A) versus Voltage (V) curve – Figure 3**

General trend: Current increases with voltage, but the relationship is not linear (non-ohmic). This could indicate the presence of a semiconductor component (e.g., diode) where the current increases exponentially after a voltage threshold.

- **Effect of temperature:**

✓ At 40°C, the current is higher for the same voltage, confirming that conductivity improves with temperature (typical behavior of semiconductors).

✓ At 2°C, the current is lowest, with a more pronounced voltage threshold, suggesting a greater energy barrier at low temperatures.

- **Power (W) versus Voltage (V) curve – Figure 4**

General trend: Power decreases as voltage increases, which is unusual for a typical component such as a resistor (where $P = V^2/R$). This suggests non-linear behavior, possibly due to a thermal effect or an active component such as a diode or transistor.

- **Effect of temperature:**

✓ At 40°C, power is generally higher than at 28°C or 2°C for the same voltage, indicating a possible increase in conductivity or a decrease in internal resistance with temperature.

✓ At 2°C, the power is lowest, reflecting higher internal resistance or reduced efficiency at low temperatures.

- **Summary**

The curves reveal semiconductor behavior, where temperature significantly influences conduction. Increasing temperature reduces internal resistance, facilitating current flow and increasing power dissipation. These results could correspond to a device such as a diode or transistor, where electrical properties are sensitive to temperature. In addition, to control the peak wattage (Pc), we must monitor our CubeSat regulator. Furthermore, significant solar radiation *is difficult to achieve in* the space where our CubeSat is located, as our nanosatellite can sometimes find itself in an orbit that is in shadow. Therefore, to *ensure sufficient power and guarantee the continuity of the mission,* we decided to *add an autonomous sun-tracking system* to help provide adequate power.

3.3. Energy Optimization

The electrical architecture was tested in a simulated orbital environment (sun-synchronous orbit at 600 km, inclination 97°). The simulations show that:

- The system remains stable over a 90-minute cycle;
- The battery is properly recharged between two eclipses;
- The consumption of critical loads (OBC, GPS, camera, radiometer) is ensured.

The following figure shows the complete synoptic diagram of the CubeSat's electrical architecture:

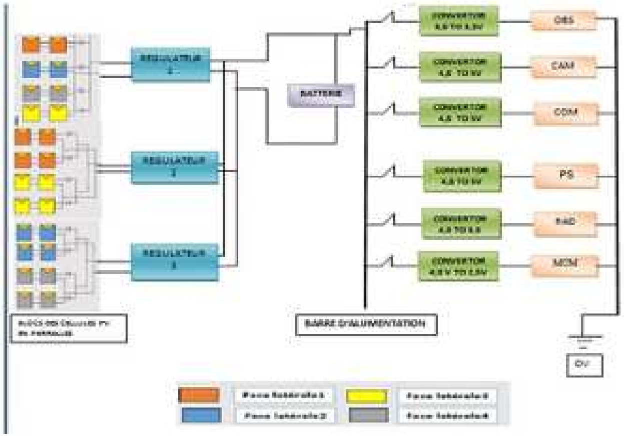

Figure 5: Complete electrical architecture diagram of the 3U CubeSat

This study shows that the combination of high-performance solar cells, an optimized battery, and regulated converters ensures the autonomy of a 3U CubeSat for Earth observation missions. The Matlab/Simulink modeling methodology makes it possible to *validate the system's performance before the prototyping or manufacturing phase,* which is essential for reducing risks during the orbital phase. This work lays the groundwork for the future development of low-cost CubeSats *for university science projects in Africa.*

IV. Conclusion

The study highlighted the importance of component selection (solar cells, MPPT controllers, batteries, converters) to ensure maximum energy efficiency in space conditions, while complying with mass and power constraints. Simulations validated the system's robustness in the face of variations in sunlight and temperature, confirming the project's feasibility. The electrical architecture selected, based on a regulated busbar, ensures optimal energy management and protection against deep discharges.

The results obtained demonstrate the viability of a CubeSat powered by an optimized photovoltaic system, capable of meeting the scientific and technical requirements of modern space missions.

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