STUDY OF THE IMPACT OF THE NANOSATELLITE ATTITUDES ON THE POWER GENERATION ISSUE

Abderrahmane SEDDJAR,
Engineering Department, Satellite Development Centre, Algerian Space Agency, Oran, Algeria, aseddjar@cds.asal.dz

***Abstract*—**The presented study within this paper considers the areas relating to the satellite EPS with the main focus on the nanosatellite platform. To fulfill a continuous operation throughout the nanosatellite life mission, the energy requirements of all on-board subsystems are considered to support payloads and platform using solar panels as primary energy source and batteries as a secondary source for the eclipse time. The power generation depends on many factors such as the mission parameters, the solar panels' performances, and the attitude of the nanosatellite. Therefore, in this paper, the impact of the nanosatellite attitude on the power generation issue is studied. We deal here with an Earth observation mission at an altitude of 680km sun-synchronous orbit with an LTDN of 10:30 AM. An eclipse period of 33% is expected. The simulations of the instantaneous generated power using STK software during: Tumbling, Y-Thomson, and Nadir nanosatellite modes at: Worst case beta angle, Aphelion, and Perihelion periods are done. Then the power profile is estimated for the worst period in the year in term of energy for the nadir mode. The obtained results are discussed and analyzed.

1 INTRODUCTION

Since the 1990s, Nanosatellites increasingly become an effective tool for technologies demonstration and validation. According to the statistics presented in [1], about 438 Nanosatellites were launched in 2019. The most important advantages of these systems are their reduced cost of realization and launch. Moreover, in the last few years, they evolved a sufficient capability to provide services as Microsatellites do. Consequently, their missions are extended which means more power is required to fulfill this evolution. However, the size and the weight of the power sources (solar panels and battery) are limited by the structural and mass constraints of the nanosatellites. These deals make the efficiency of the Electrical Power System (EPS) a relevant feature in the nanosatellites design [2-4].

The orbit and the mission constraints should be considered to select one of the EPS configurations (DET (Direct Energy transfer) or PPT (Peak power Tracking)). EPS based on DET are generally designed for high power satellites with large solar panels suitable for Geostationary Earth Orbit applications, where the environmental conditions do not change significantly. However, EPS based on PPT technique are mostly designed for Low Earth Orbit applications, to be capable to extract the maximum power from the solar panels with less power dissipation considering the variations of the environmental conditions.

The Power generation is one of the critical processes that deals with different constraints, environmental, efficiency, Orbital parameters and satellite architecture (e.g. deployed panel configurations). Furthermore, the power generation is limited due to the small surface allocated to the solar panels. Thus, the attitude determination and control system components (e.g. Reaction wheels, magneto- torquers…) cannot be powered throughout the whole mission to ensuring three axes stabilizations. Instead of that, the nanosatellite is expecting to spinning and tumbling during the mission lifetime. Therefore, the principal objective of this paper, is to study the impact of the Nanosatellite attitude on the power generation issue.

The remaining part of this paper is organized as follows: in the section II, the mission parameters have been presented, then the power consumption of all subsystems, where the duty cycle of each equipment has been defined. The nanosatellite power system is then presented. In the section III, the nanosatellite's systems are presented. The section IV is dedicated to the simulations of the instantaneous generated power using STK software during one orbit for, tumbling, Y-Thomson, and Nadir modes at: Worst case beta angle, Aphelion, and Perihelion periods. Finely, in the last section, the power profile was estimated for the worst-case mode using Excel software, the obtained results are discussed and analyzed.

2 MISSION PARAMETERS AND POWER CONSUMPTION ESTIMATION

The mission orbit is a Sun Synchronous Orbit (SSO) with an altitude of 680 km. The orbit parameters are presented in the

Table I. In which they are calculated based on SMAD document (Space Mission Analysis and Design) [5].

TABLE I. MISSION PARAMETERS

Mission	Payload	Imaging Camera
	Mission Duration	One-year
Orbit	LEO/SSO	LTDN 10:30 AM
	Altitude (Km)	680
	Semi-major axis (Km)	7051
	Eccentricity (e)	0
	Elevation ξ	17°
	Revolution Period T (mn)	98,20
	Eclipse Period (mn)	35,26
Phase	Number of Orbits per day	14,62
Ground Station	Satellite Visibility Time (mn)	7,12

In this study, four different operations in Nadir mode which can be performed in one day (14 Orbits) are considered:

- *Imaging mode:* the nanosatellite performs its main mission by operating its camera.
- *Images downloading mode:* the images are downloaded to the ground station.
- *TM/TC mode:* the nanosatellite sends the telemetry data as well as the commands, that will be received from the ground station.
- *Standby mode:* the nanosatellite is orbiting with no mission plan on board, i.e low power consumption of all subsystems.

TABLE II. DIFFERENT MISSION MODES.

Orbits	Modes	Periods (mn)
Orbit 1	TM/TC	7
	Imaging	7
Orbit 2	Images downloading	14
	Imaging	21
Orbit 3	Imaging	7
Orbit 4-8	Standby	-
Orbit 9	Images downloading	14
	TM/TC	7
Orbit 10	Images downloading	10
	TM/TC	7
Orbit 11-14	Standby	-

3 NANOSATELLITE'S SYSTEMS

The Nanosatellite studied in this paper has one payload. The camera C3D2, based on the C3D imager that has already been demonstrated on Alsat-1N and UKube-1. To support this camera, the nanosatellite platform is composed of:

- ADCS components:
    - iMTQ board, for the nanosatellite detumbling and magnetic attitude control.
    - StarTracker, CubeStar outputs inertially-referenced attitude quaternions.
    - Cubesense, a CMOS-based Sun and Earth sensor with a wide field of view.
- ISIS OBC, onboard computer high-performance processing unit based on ARM9 processor.
- ISIS VHF/UHF, transceiver.
- ISIS AntS, antenna system.
- NanoPower P31U, power system with a BP4 Battery.
- Solar panels, based on AzurSpaceTJ Solar Cell 3G30C.

The estimated power consumption is based on the maximum power consumption of its onboard equipment under worst-case conditions; a 30% margin is added to the total power consumption to consider any unexpected consumption excess as suggested by SMAD and ECSS standards [5, 6]. Moreover, it is necessary to consider the worst-case power consumption orbits. Therefore, as illustrated in Table III, the maximum power consumption during Nadir mode is estimated during the sunlight time of orbit n° 02 (longest imaging duration and TM/TC period), and during the eclipse time of orbit n°09 (longest images downloading period).

TABLE III. POWER CONSUMPTION ESTIMATION FOR NADIR MODE

Sub-systems		**Power consumption (mW)**	**Nadir Mode**			
			Eclipse (35,26mn) Orbite n°9		**Sunlight (62,81mn) Orbite n°2**	
			Duty cycle (%)	Power (mW)	Duty cycle (%)	Power (mW)
ISIS VHF/UHF Transceiver	(receiver only)	480	100	480	100	480
	(transmitter on)	2000	19.85	397	-	-
	Images downloading	4000	-	-	22,29	891.6
iMTQ Board	No actuation	175	100	175	100	175
	Full actuation (3-Axis)	1200	0	0	33,43	401,16
ISIS OBC		400	100	400	100	400
CubeSense		360	100	360	100	360
NanoPower P31U		260	100	260	100	260
ISIS AntS Electrical model	antennas stowed	27,7	0	0	0	0
	during deployment	1848	0	0	0	0
	antennas deployed	52,8	100	52,8	100	52,8
Payload: C3D2		850	0	0	33,43	284,155
StarTracker		246	100	246	0	0
Total power consumption (mW)			2370,8		3304,715	
Margin 30 %			711,24		991,4145	
Total Power consumption (mW)			3082,04		4296,1295	

The nanosatellite's battery is provided by GomSPACE BP4 [6]; this battery, provides a capacity of 38.5 Wh with a nominal voltage bus varies between 6.0 and 8.4V. To confirm that it fulfills the nanosatellite power requirement, the battery capacity for the nanosatellite mission is calculated as follows:

$$Battery\ capacity = \frac{(eclips\ load\ power)\ \text{x}\ (\ eclipse\ time\ in\ hours)}{(average\ battery\ discharge\ voltage)\ \text{x}\ (\ DoD)} \quad (1)$$

$$Battery\ capacity = \frac{3082.04\ x\ (35.26/60)}{6\ \text{x}\ 0.10}$$

$$Battery\ capacity = 3018{,}68\ m\text{Ah}$$

This study assumed that the solar panels of the nanosatellite are based on two strings of three solar cells 3G30C, provided by AzurSpaceTJ Solar Cell 3G30C [7]. The solar panels power requirement is calculated by the following equation:

$$P_{sa} = \frac{P_l}{n_{ppt} n_{tr}} \left[1 + \frac{T_{dis} V_{ch}}{T_{ch} V_{dis}} RF\right] \quad (2)$$

Where,
P_{sa} : Solar array power at regulated bus voltage value, W.
P_l : The load power (considered constant throughout the orbit), 4.296 W.
n_{tr} : Peak power tracker accuracy, 0.99.
n_{ppt} : Peak power tracker efficiency, 0.99.
T_{dis} : Battery discharge time, 35.26 min.
V_{ch} : Average battery charge voltage, 5.0 V.
T_{ch} : Battery charge time, 62.81min.
V_{dis} : Average discharge voltage, 7.4 V.
RF : Battery ampere hour recharge fraction, 1.1.

As a result, a 6.18 W has to be generated by the solar panels of the nanosatellite. Which can sufficiently be provided by two strings of three 3G30C solar cells.

In order to perform the analysis, the 3D model of the nanosatellite is made carefully according to the Cubesat standard. The Nanosatellite is equipped by 6 cells (3 cells in series and 2 strings) for solar panels 1 and 3, and 4 cells in series for the remaining panels, as shown in Figure 1. To achieve a correct configuration of the solar cells, the Star-tracker, CubeSense and the Camera C3D2 are mounted on the structure. This was done using two softwares: Modeler and Solidworks. Then, the Blender software was used to convert the CAD file into a script, in order to define the solar panel area. After that, it was saved in *.anc format to set the efficiency of the solar panel. The orbit is propagated using the Simplified General Perturbations Model SGP4 and analysis conducted using Analytical Graphics (AGI) System Tool Kit (STK) (Figure 2). Figure. 1 shows solar panels mounted on the four sides of the nanosatellites.

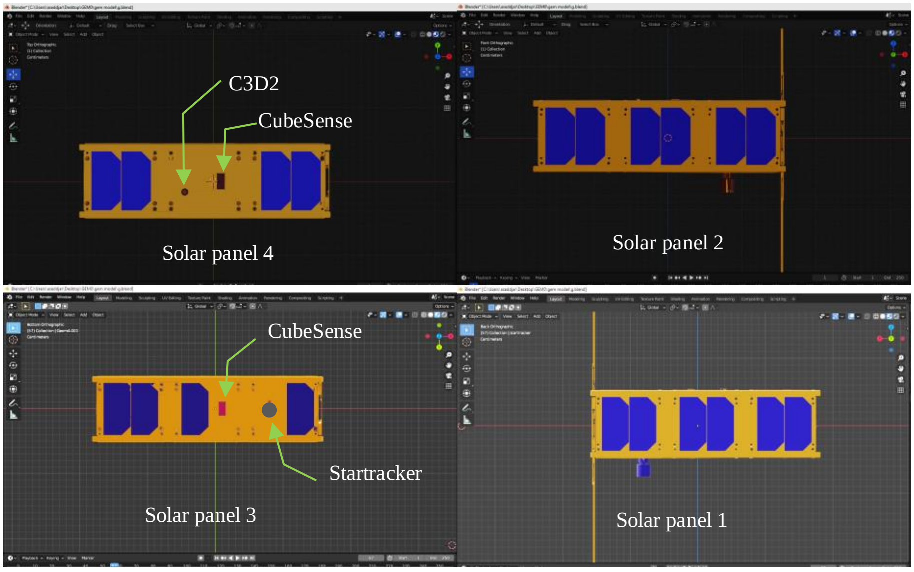

Figure 1. Nanosatellite's faces under blender software

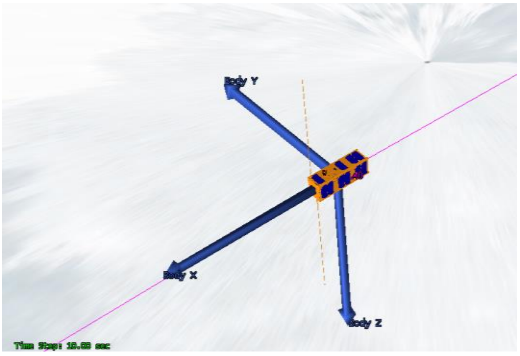

Figure 2. Nanosatellite axes with STK software.

4 SIMULATION RESULTS

4.1 Simulations of the solar panels power generation

The simulations of the solar panels power generation are carried out during the three most critical periods for power production, namely:

- Worst Beta angle value: the angle between the solar rays and the orbital plane
- Perihelion: the shortest distance between the earth and the sun.
- Aphelion: the longest distance between the earth and the sun.

For each of these three worst-case dates, simulations are provided for three modes:

- Tumbling mode: based on previous in-orbit nanosatellite data.
- Y-Thomson mode: Speed of rotation around the y-axis: 1 deg/s
- Nadir mode: ECI (Earth Centred Inertial) speed constraint.

4.1.1 Worst Beta angle value

Beta angle is one of the most important parameters impacting the solar panels power generation, it is the angle between the solar irradiance and the orbital plane of the nanosatellite (Figure 3. Where, the more the angle value is closer to 90 ° the more energy is produced. To consider this constraint, the simulation of the beta angle value during one year is accomplished. From the obtained result (Figure 4), the greatest value of this angle (for LTDN: 10:30 AM) is

34.397 ° and this occurs on Feb 10, 2023 22:00 (best case). And, the smaller value is estimated at 23.44 ° obtained on 3 Jun 2022 at 05:00 AM (worst case). Therefore, simulations of the power generated by the solar panels of the nanosatellite are performed during this worst-case date for the three modes.

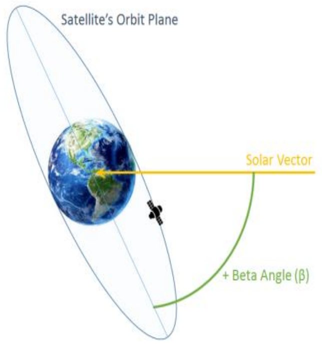

Figure 3. Beta angle (β).

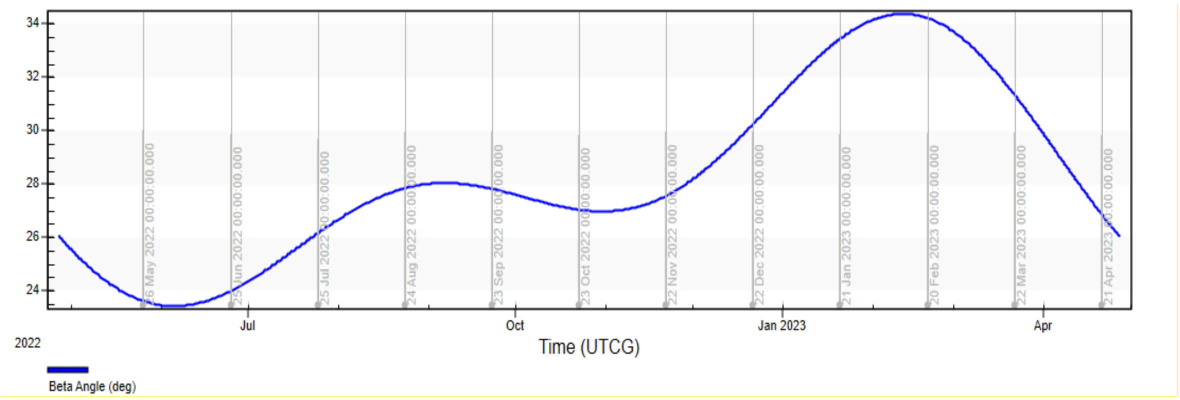

Figure 4. β angle values at LTDN of 10:30 AM.

The solar panels power generation for, Tumbling, Y-Thomson and nadir modes during the worst Beta angle value are presented in the figures 5, 6 and 7 respectively.

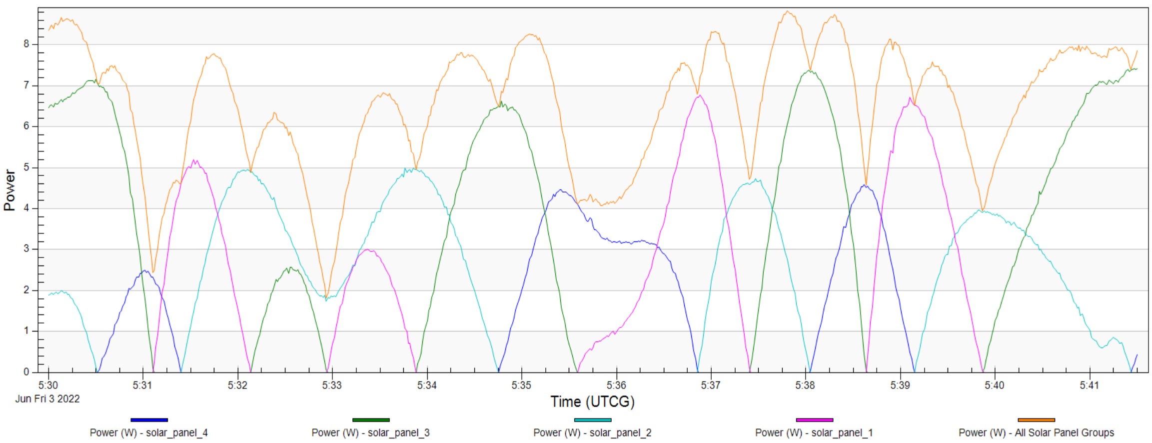

Figure 5. Solar panels power generation for Tumbling mode during « Worst Beta angle value ».

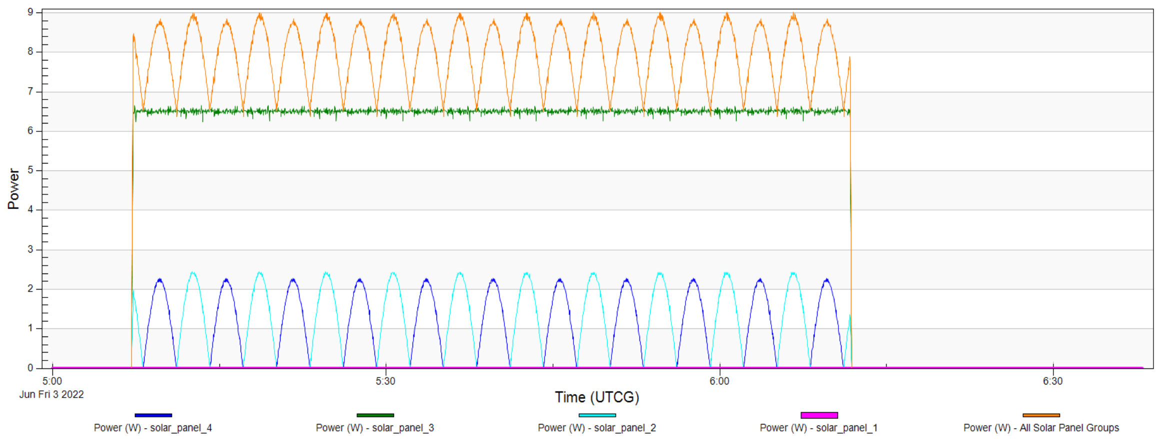

Figure 6. Solar panels power generation for Y-Thomson mode during « Worst Beta angle value ».

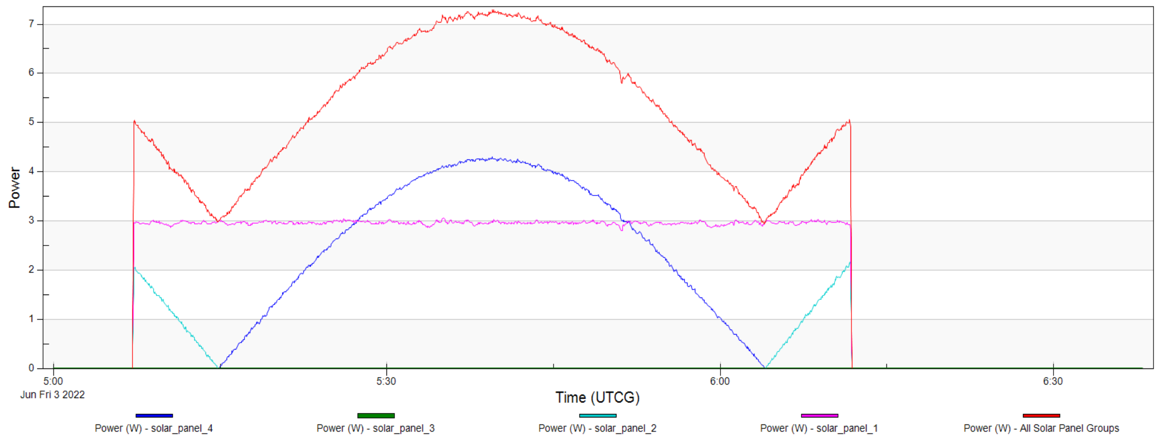

Figure 7. Solar panels power generation for Nadir mode during « Worst Beta angle value ».

The simulations results show that the average generated power during the Worst Beta angle value is sufficient for the three modes, Tumbling, Y-Thomson and Nadir. Also, it is noted that Nadir mode results in lower generated power, therefore, operations in this mode should deals with this constraint.

TABLE IV
AVERAGE GENERATED POWER DURING WORST BETA ANGLE VALUE.

Periods	Modes	Average power (W)
Worst Beta angle value	Tumbling	6.57
	Y-Thomson	7.95
	Nadir	5.25

4.1.2 Perihelion

Perihelion is a point in Earth's orbit where the distance between the Earth and the Sun is minimal. The perihelion date is not fixed and differs from year to another, for the year 2023, it will be on January 4th. The simulations of the power generated by the solar panels for one day in this date for the three modes of the Nanosatellite are illustrated in Figures 8, 9 and 10.

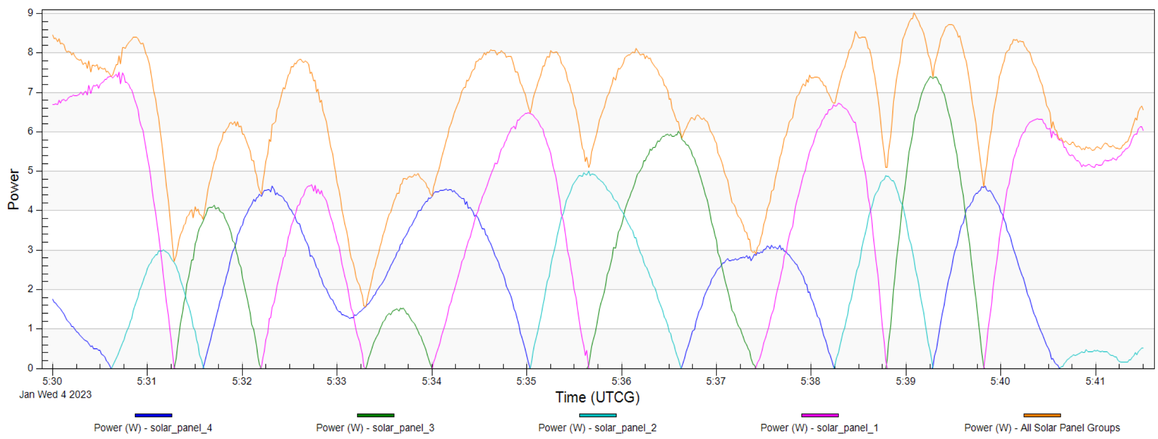

Figure 8. Solar panels power generation for Tumbling mode during « Perihelion ».

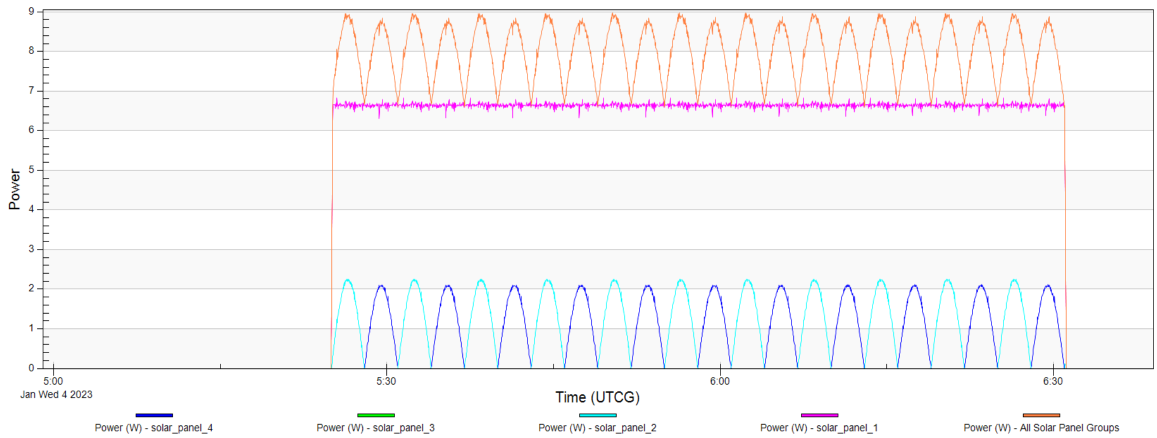

Figure 9. Solar panels power generation for Y-Thomson mode during « Perihelion ».

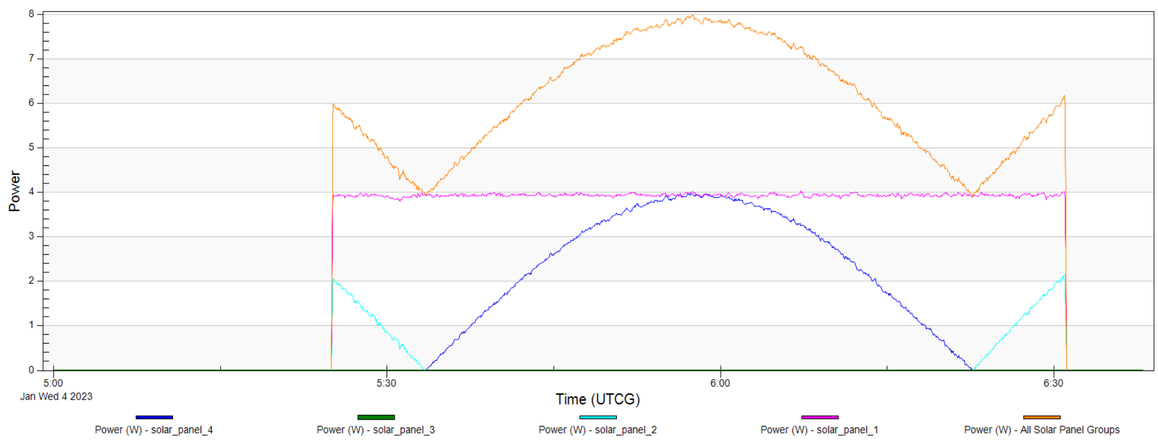

Figure 10. Solar panels power generation for Nadir mode during « Perihelion ».

During the Perihelion time, the average generated power for the three modes, Tumbling, Y-Thomson and Nadir, is much better compared to that produced during the worst-case Beta angle. Since, at this time of the year, the sun position is favorable for the nanosatellite's solar panels. Therefore, it is advisable to schedule the most energy-intensive operations within this date.

TABLE V
AVERAGE GENERATED POWER DURING PERIHELION.

Periods	Modes	Average power (W)
Perilion	Tumbling	6.41
	Y-Thomson	8.00
	Nadir	6.06

4.1.3 Aphelion

The Aphelion is a point in Earth's orbit where the distance between the Earth and the Sun is maximum. For the year 2022, Aphelion will be on July 4th. Simulations of the produced energy for the three modes of nanosatellite are presented in Figures 11, 12 and 13.

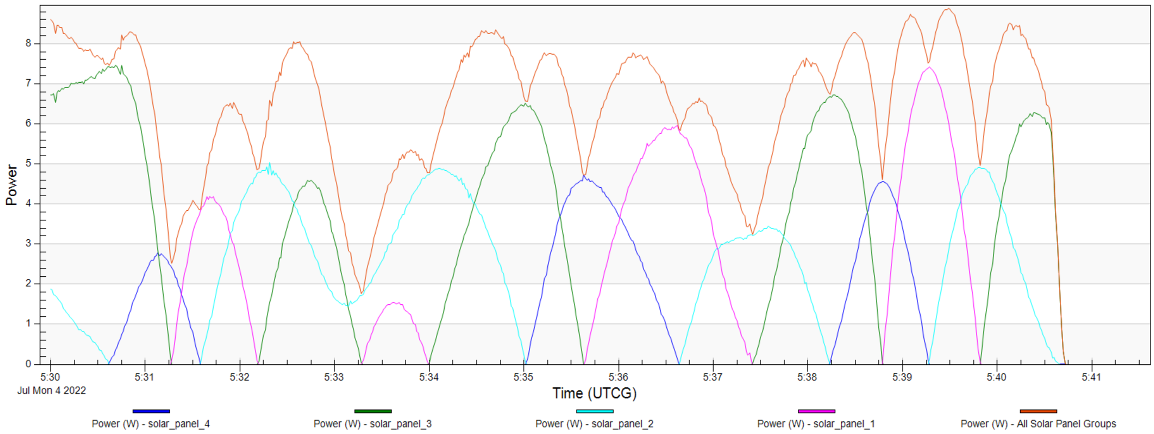

Figure 11. Solar panels power generation for Tumbling mode during « Aphelion ».

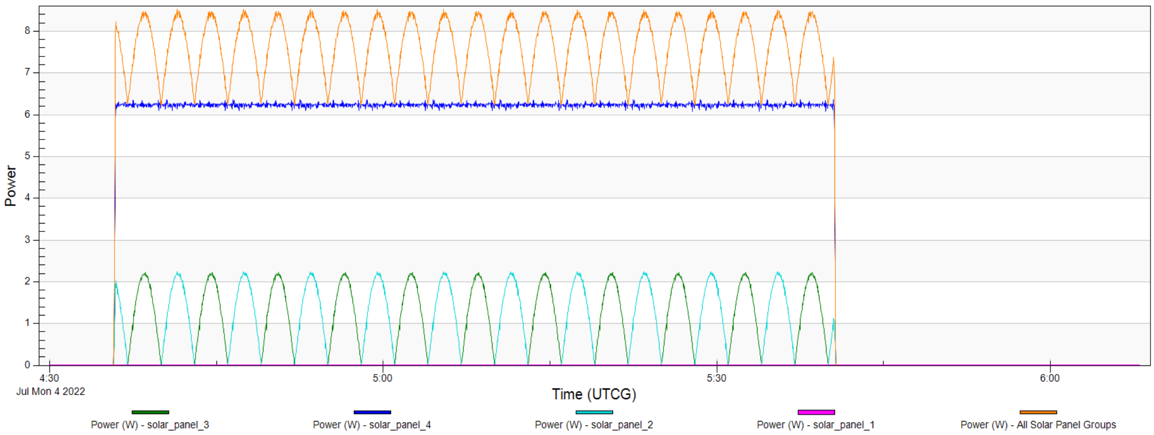

Figure 12. Solar panels power generation for Y-Thomson mode during « Aphelion ».

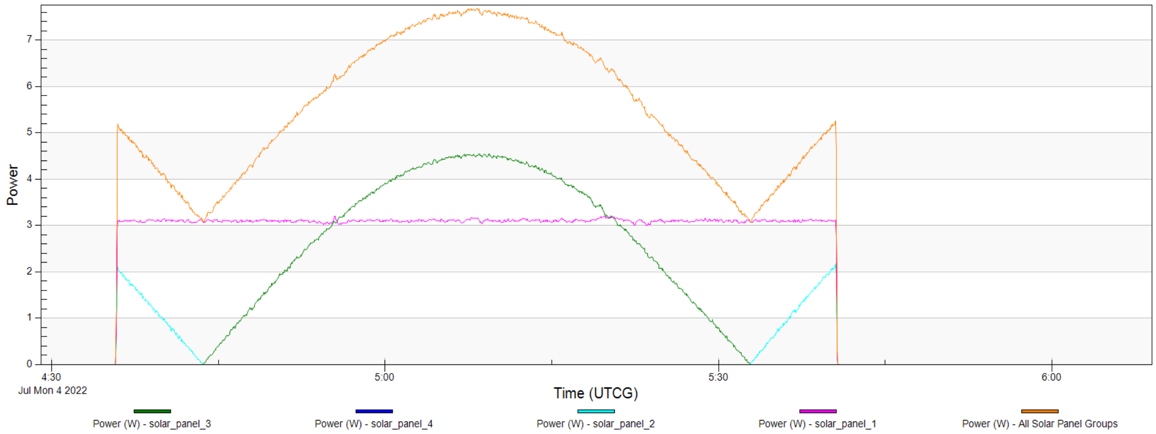

Figure 13. Solar panels power generation for Nadir mode during « Aphelion ».

The simulations results show that the average generated power during the aphelion time, is almost the same as that provided during the worst-case beta angle value, since it occurred one month later. Therefore, it is necessary to be more careful during nadir mode.

TABLE VI.
AVERAGE GENERATED POWER DURING APHELION.

Periods	Modes	Average power (W)
Aphelion	Tumbling	6.49
	Y-Thomson	7.99
	Nadir	5.36

4.2 Simulation of the Nanosatellite's power profiles

The simulation results presented in the previous section made it possible to calculate the average power for each mode in the three different periods. It is concluded that the third June, 2022 (Worst Beta angle value) is the most unfavourable period of the year in terms of energy production. Therefore, the power consumption of the Nano-Satellite must be calculated based on this worst-case date. Figure 14 illustrates the estimated power profiles for the nadir mode based on the power consumption presented in Table. III.

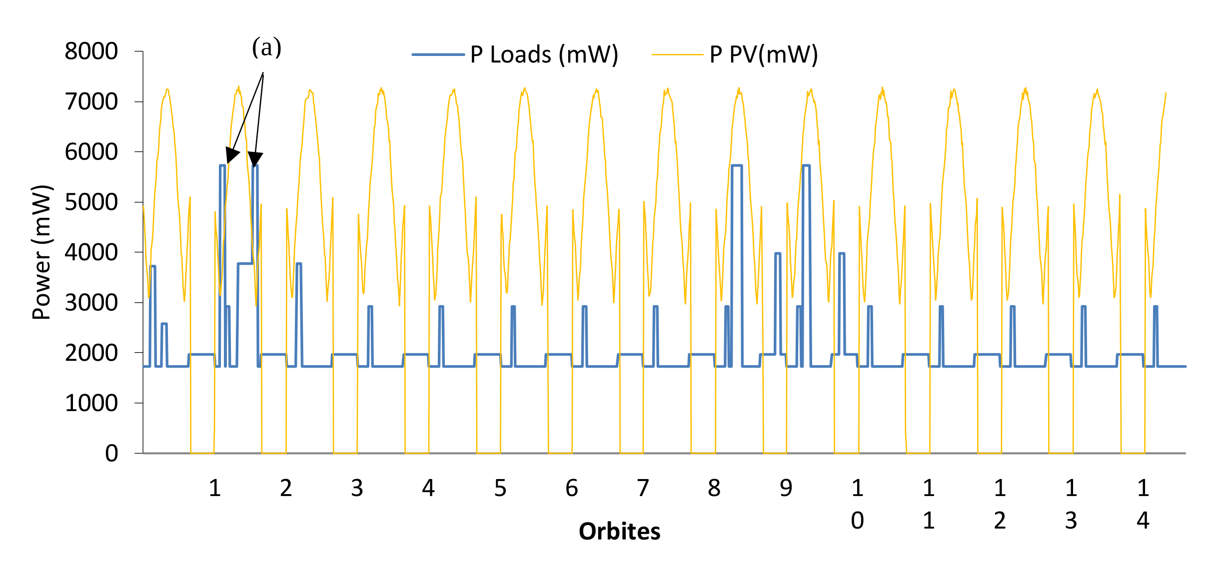

Figure. 14. Power profiles for Nadir mode during « Worst Beta angle value »

Figure 14 illustrates the power profiles of the nanosatellite during the worst-case Beta angle value for the nadir mode. The solar panels are capable to ensuring the nanosatellite energy requirements during the sunlight time for all orbits, except the Orbit n°02, the battery would be solicited twice (at the beginning and the end of the sunlight time) to compensate for the lack of the solar panels produced energy (Figure 14 (a)). This means that two additional cycles per day should be considered for battery life determination.

5 CONCLUSION

The main objective of this study is to illustrate the impact of the Nanosatellite attitudes on the power generation issue. In this paper, were firstly defined the objective and the mission parameters. Then the nanosatellite's systems are presented. In the last part of this study, the simulations of the solar panels power generation are done during the three different periods of the year for the three modes (Y-Thomson, Tumbling, and Nadir). These simulations allow to determine the best and the worst-case period in the year in terms of energy production. the best case for the energy production is used to schedule the most critical operations or modes of the nanosatellite during its lifespan if necessary. While, the worst case for the energy production is used as input for the power budget calculations.

6 REFERENCES

[1] E. Kulu. (June 2019). *Nanosatellite Database*. Available: http://www.nanosats.eu/index.html#database

[2] M. R. Patel, *The International Handbook of Space Technology*: Springer, 2014.

[3] J. J. Rojas, T. Yamauchi, H. Masui, and M. Cho, "Proposal for a Modular Electrical Power System For Nanosatellites," in *title 第37回宇宙エネルギーシンポジウム 37th ISAS Space Energy Symposium*, 2018.

[4] S. A. Kimura, H. Wijanto, F. F. A. Rafsanzani, H. Pranandityia, and A. A. Ichwan, "Development of the electronic power subsystem design for Tel-USat," in *2019 IEEE International Conference on Signals and Systems (ICSigSys)*, 2019, pp. 120-125.

[5] J. L. Wiley and R. W. James, *Space Mission Analysis and Design.Third edition*: Microcosm Pres and Kluwer Academic Publishe, 1999.

[6] GomSPACE, "NanoPower BP4 High Capacity battery pack for nano-satellites featuring four Li-Ion cells," 1013024, Ed., ed. Danmark, 2018.

[7] S. P. GmbH, "30% Triple Junction GaAs Solar Cell, Type: TJ Solar Cell 3G30C," A. SPACE, Ed., ed, 2013.