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POWER MANAGEMENT TOOL DEVELOPMENT FOR GEOSTATIONARY COMMUNICATION SATELLITES

Yavuz Andac[1], Sukru Can Ozer[2] and Ahmet Burak Koc [3]
Türksat A.Ş.
Ankara, Turkey

Umit Cezmi Yilmaz[4]
Türksat A.Ş.
Ankara, Turkey

ABSTRACT

Communication satellites have multiple coverages in different regions of the world with requirements, which create an obligation to provide uninterrupted broadcasting services, internet and more. Satellite's electrical power system is a very crucial subsystem, which provides required electrical power for all equipment during the satellite's lifetime. It has to be monitored during whole life of satellite. Ability to monitor, estimate and manage electrical power budget has key role to manage communication channels in payload and to make use of payload resources efficiently. Hence, Electrical Power Management of a satellite is a challenge to operations team to make maximum benefit from existing communication payload. In order to understand the remaining capacity on the satellite, satellite operators need tools for calculations. We propose an Excel based tool as a viable alternative for power budget calculations. The motivation of this tool is to make is possible for GEO satellite operators a quick confirmation on the current and future payload consumptions reliable for uninterruptable service.

GLOSSARY

ADCS : Attitude and Determination Control System
BCR : Battery Charge Regulator
BDR : Battery Discharge Regulator
DHS : Data Handling Subsystem
DOD : Depth of Discharge
EPC : Electronic Power Conditioner
EPS : Electrical Power System
OBO : Output Back Off
PPS : Plasmic Propulsion System
PSR : Power Supply Regulator
TWTA : Traveling Wave Tube Amplifier

[1] Satellite Platform Subsystem Staff, Satellite Programs Directorate, Email: yandac@turksat.com.tr
[2] Satellite Platform Subsystem Staff, Satellite Programs Directorate, Email: scozer@turksat.com.tr
[3] Satellite Platform Subsystem Staff, Satellite Programs Directorate, Email: abkoc@turksat.com.tr
[4] Director, Satellite Control Directorate, Email: cyilmaz@turksat.com.tr

INTRODUCTION

Telecommunication satellites are operated on geosynchronous orbit above 35,786 km above Earth's equator with the same direction of Earth. Ideally, this orbit has zero inclination with respect to equator. The advantages of such an orbit are that no tracking is required from the ground station since the satellite appears at fixed position in the sky. Due to the fixed position over one point on the Earth, this kind of satellites are used for telecommunications by operators that have assembled fleets covering the Earth. [Borthomieu, 2014]

Typical mission is comprised of three operational components: space, ground and user segments as illustrated in Figure 1.

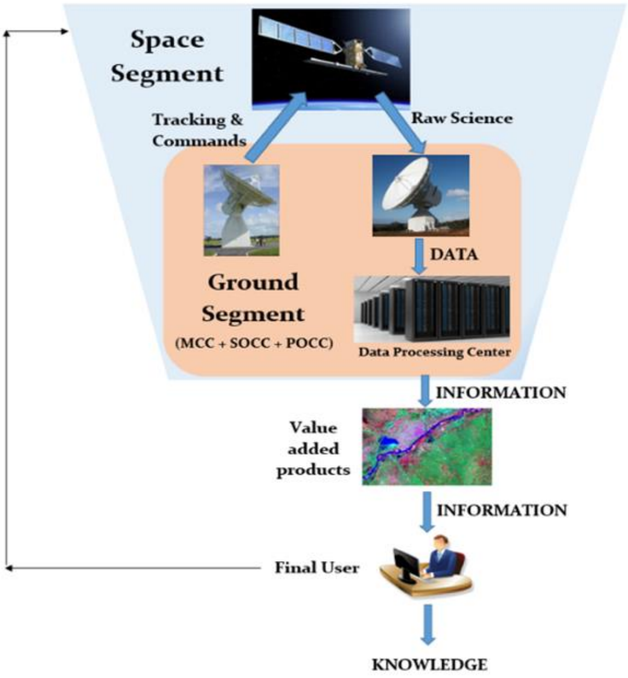

Figure 1: Mission components [NASA, 2021]

The space segment consists of the payload and spacecraft bus system and it relies on its ability to maintain operational stability in order to receive and transmit information. The ground segment includes all the ground-based elements, that are used to collect and disseminate information from the satellite to the user. Ground stations provide the communications link with the satellite. Some of their goals are listed below. [Garcia, 2006]

- Maximize performance of the satellite
  - Fuel efficiency, payload output power, payload reconfiguration
- Support Mission Control activities
  - Launch, Injection, Orbit raising and drift
- Support In-Orbit Satellite Test
  - Initially after Launch and during operations
- Support Normal operations

For maximizing performance of a satellite, power budget calculations and power management plays an important role during both satellite design phase and operational on-mission phase. In the design phase of a satellite, it is important to know electrical power requirements to size solar panel and battery. During mission, electrical power generation and power consumption of satellite equipment varies. In order to assure mission continuity, ground station monitors electrical power system together with the payload traffic since they have very close relation.

Most of the satellites can be divided into two parts, the payload and the platform. Payload includes main mission equipments for the satellite, as it enables the function and core use of the satellite for the mission. The platform is the carrier of the payload, and it provides payload with necessary support functions such as commanding, data handling, thermal control, attitude control, orbit control and electrical power lot only in sunlight but also during Earth or Moon eclipses. For this work, we focused on telecommunication satellites electric power system. Generic power system architecture can be seen in Figure 2. It comprised of solar panel, battery, power control and distribution units. The function of the power control module is to regulate the power transfer between the solar array and the subsystems. It consists in a battery charge regulator (BCR), a battery discharge regulator (BDR) and main bus regulator to maintain voltage within limits.

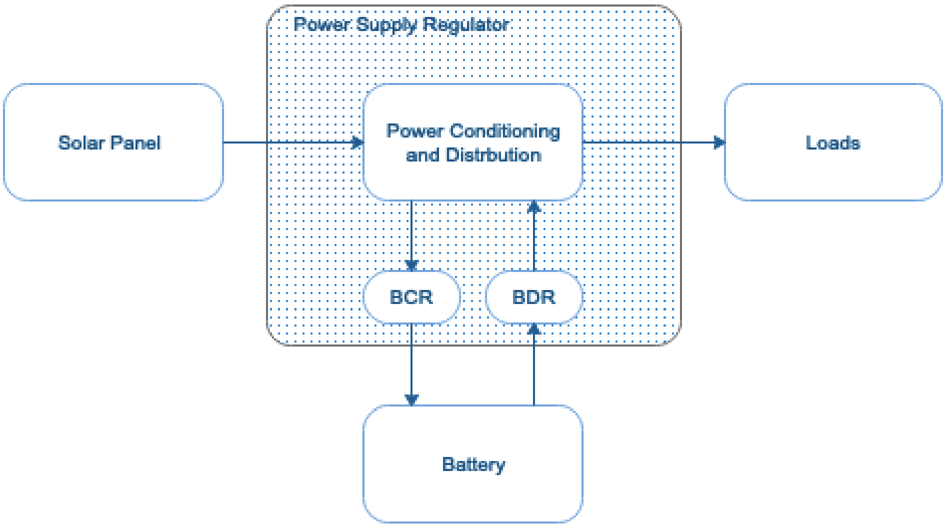

Figure 2: Generic power architecture

In this work, we want to manage power budget so as to execute different payload configuration as well as platform system configuration. All calculations are considered the requested margins and constraints all along the transfer and throughout the satellite on station lifetime. The main goal of our tool is to allow satellite operators to manage and optimize the on-board amplifiers reconfiguration and satellite power consumption.

METHOD

The tool is developed based on Microsoft Excel. It can be used not only to calculate power budget, but also to analyze remaining power and energy balance in the satellite during the mission. Thanks to this tool, operators can ensure that there will be no excitation of limits or they can know how much margin they have for the calculation time or for any time in future.

Power budget depends on lots of parameters such as orbital parameters, mission types (scientific, observation, telecom) and mission duration. Mission duration affects the equipment degradation. That's why all worst-case calculations have to be performed for end of the mission. This tool considers degradation of solar panels and battery as well as losses such as harness loss, voltage drops and losses due to equipment efficiency.

The main logic for DoD calculation can be seen in Figure 3. While some parameters are used in calculations of power generation (colored in blue), others are used in calculations of power consumption (colored in red).

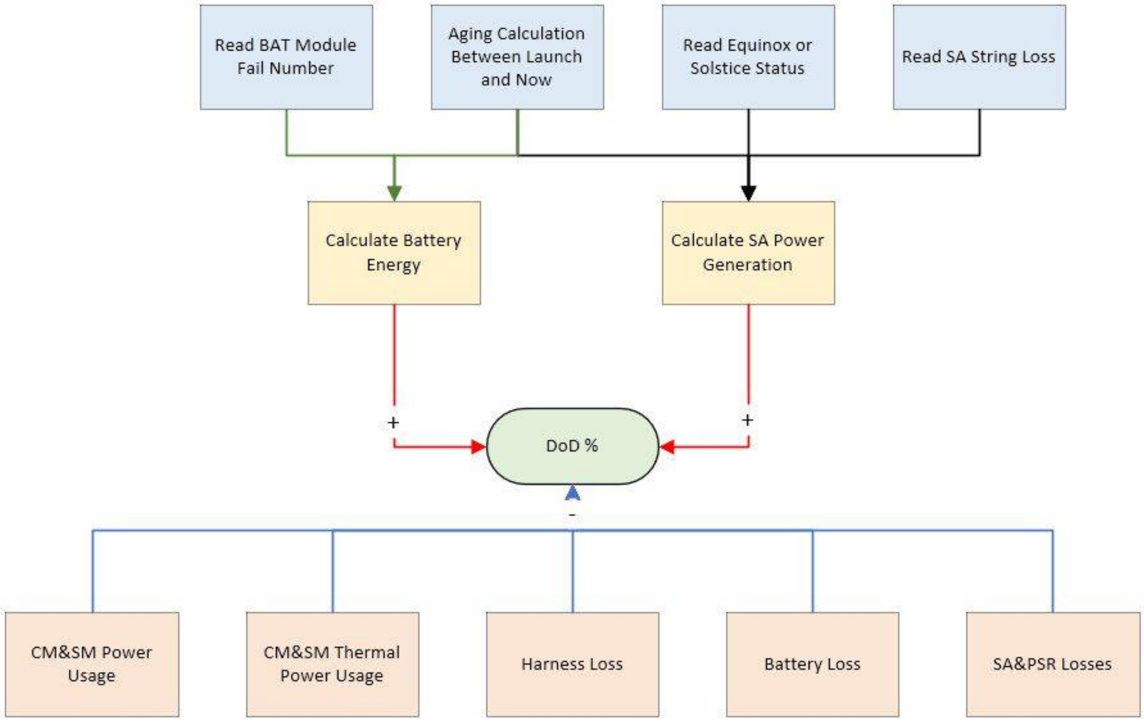

Figure 3: DoD calculation method

In order to calculate the power generated and available battery energy, the failures and degradations must be included. The first parameter to be checked is the season. Equinox and Solstice seasons are important to calculate solar array generated power, due to change of solar flux constant in orbit. Solar array generated power varies throughout the year as a result of this effect. Another important parameter is the number of solar array string loss. This type of failure occurs due to space environment. Since solar arrays are directly exposed to space environment, susceptibility is increased [Leung, Scott, Seki and Schwartz, 2010]. That can lead to arcs on solar cells or debris can collide and damage the cells. Battery Module failures which indicate the number of batteries that are lost during mission must be also considered. Also, a minimum DoD must be remaining in the battery cell at the end of designed life. Ageing is another considered parameter for equipments which are exposed to space environment. Both solar arrays generated power and battery cell energy are degrading from beginning of life to end of life satellite. Battery degradation example is given in Figure 4.

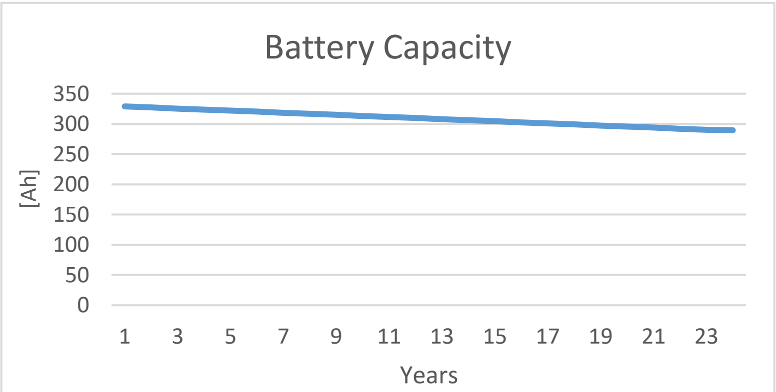

Figure 4: Battery capacity degradation over time

There are also several losses due to inefficiencies. Harness loss is occurred due to diodes and wiring resistance. Power supply regulator has losses due to battery charge and battery discharge regulators. There is also battery loss between the PSR and battery harness.

Platform Power Usage

Electric propulsion is becoming more and more common in communication satellite industry. Satellite equipped with electric propulsion systems require high amount of energy. Therefore, the use of electric propulsion strongly affects the management of power system. Especially during electric orbit raising or eclipse, depth of discharge of the battery is greatly affected.

Same manufacturer uses same type of platform for similar missions/orbits. Due the repeated usage, this provides a great deal of heritage on their platform. The power usage of the platform may not be great as the payload, nevertheless this part cannot be put aside. Not all equipment's are operational in every phase or season. The calculation tool is focused on the worst case rather than live data calculations so equipment power consumptions are assumed in average values. Power statuses of main platform subsystems are listed in Table 1.

Table 1: Equipment power statuses over different phases

	Phase		
Equipment	**Orbit Raising**	**On Station/Solstice**	**On Station/Eclipse**
EPS			
Power Supply Regulator	*Always ON*	*Always ON*	*Always ON*
PPS			
Plasmic Propulsion Unit	*High Power*	*Low Power*	*OFF*
DHS			
Control Unit	*Always ON*	*Always ON*	*Always ON*
Drive Electronics	*Always ON*	*Always ON*	*Always ON*
ADCS			
Star Tracker	*Always ON*	*Always ON*	*Always ON*
Reaction Wheels	*Mostly ON*	*Mostly ON*	*Mostly ON*
Gyro	*Sometimes ON*	*Sometimes ON*	*Sometimes ON*

Payload Power Usage

Payload power requirement can be as high as 70-75% of the total power and this makes it very important for the tool. It can also change according to payload usage by the customers. Payload chain has several different equipment's their effect on the power budget can also change drastically. Main elements of this chain can be seen in Figure 5. [Sauvan, 2012]

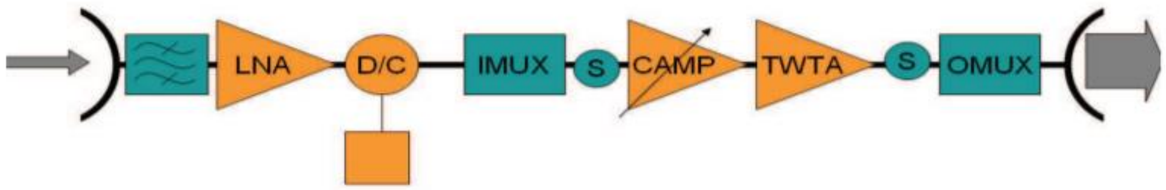

Figure 5: Generic payload chain

LNA (Low Noise Amplifier): Just near the reception antenna, it amplifies the signal and impacts it with a minimal noise.

D/C (Down Converter): Shift the received frequency into the emitting one in order to avoid any interference.

IMUX (Input Multiplexer): Separation of the different signal frequencies.

CAMP (Channel amplifier): This amplifier can be modulated from Earth.

TWTA (Travelling Wave Tube Amplifier): It is the heart of the payload. It uses more than 90% of the satellite total energy to amplify the signal at a narrow bandwidth. All TWTA's have maximum output power capacity. This is referred to as an amplifier's saturated power.

OMUX (Output Multiplexer): It recombines the signal before emission.

EPC (Electronic Power Conditioner): EPC provides DC voltages required by TWTA. [Braun, 2012] On the demand side, the choice of the EPC does not depend on the frequency band of the TWTA but on the input voltage and output power of the TWTA, and the satellite platform bus. [European Commission, 2009]

Calculation Method

First, the solar array generated power is determined by the number of series and parallel cells. Solar array section power is calculated by using equation 1. [Park and Cha, 2016]. This power can be calculated by multiplying the I/V characteristic of one solar cell assembly including the specified loss factors, seasonal variation of sun intensity, the harness resistance and the voltage drop at blocking diodes.

$$P = \left[V_{op}.K_{volt}.N_{ser} - \left(I_{op}K_{cur}R_{har} + V_{diode}\right)\right].I_{op}.K_{cur}.N_{par} \tag{1}$$

P : Section Power [W]
V_{op} : Operation voltage of solar cell assembly [V]
I_{op} : Operation current of solar cell assembly [A]
R_{har} : Harness resistance [Ω]
K_{volt} : Loss Factor, applicable on voltage
K_{cur} : Loss Factor, applicable on current
N_{ser} : Solar cell assemblies in series
N_{par} : Solar cell assemblies in parallel

Depth of discharge is calculated by using equation 2 [Patel, 2004]. Calculation includes the losses due to battery harness and energy fading.

$$DoD = \frac{P_e.T_{ecl}}{n_b.n_{dis}.\{(n_c - 1)V_{cdis} - V_d - V_{hdis}\}.Ah_b} \tag{2}$$

Ah_b : Capacity of each battery [*Wh*]
P_e : Load power demand during eclipse [W]
T_e : Eclipse duration [h]
n_{dis} : Discharge converter efficiency
n_b : Number of batteries in parallel
n_c : Number of series cells per battery
V_d : Voltage drop in bypass diode in case a cell failed [V]
V_{cdis} : Voltage per cell, average during discharge [V]
V_{hdis} : Voltage drop in harness from battery to PSR [V]
DoD : Depth of Discharge of the battery

RESULT AND DISCUSSION

Purpose of this tool is to check depth of discharge margin and determine the possibility for more capacity allocation. In order to find DoD, main parameter should be selected/entered by the user. To calculate solar panel generation power, user should select the season and if it is in equinox season, daylight or eclipse. If there are any number of string loss in solar panel or any loss in battery modules, this tool includes the solar power loss in calculated power and calculate the overall battery power including the losses and obtain DoD. Flowchart of user steps are given in Figure 6.

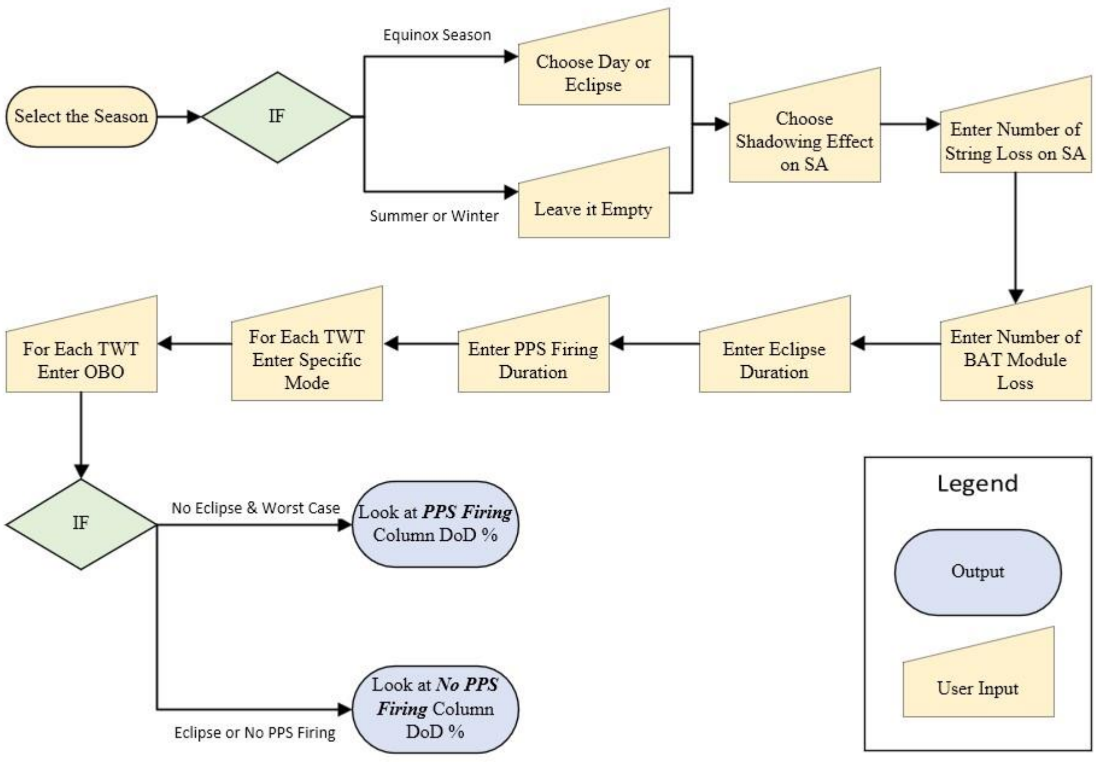

Figure 6: User selection flowchart

TWTA mode and OBO selection interface can be seen in Table 2. Yellow marked boxes require a user input.

Table 2: TWTA selection interface

Frequency 1			Frequency 2		
TWTA No	Specific Mode	OBO (dB)	TWTA No	Specific Mode	OBO (dB)
1	Nominal	0,9	1	Nominal	0,5
2	Nominal	1,5	2	Nominal	0,5
3	Nominal	0,3	3	Nominal	0,3
4	Over Drive		4	Nominal	0,3
5	Off		5	No Load	
...	...	...	...	...	...

Off : TWTA is turned off (No power consumption)
No Load : TWTA is turned on but no input signal.
Nominal : TWTA is turned on (driven in linear zone)
Over Drive : TWTA is turned on (driven in saturation zone)

Table 3 provides power usage for different subsystems and also generated power by the solar array. The results are obtained for a communication satellite with plasmic propulsion system. The Input parameters are;

- <u>Season:</u> Winter Solstice
- <u>Shadowing Effect:</u> Yes
- <u>Number of String Loss in Total:</u> 4
- <u>Number of Battery Module Failure:</u> 0
- <u>Mission Year:</u> 0 years

Table 3: Winter solstice DoD results

	PPS Firing	No PPS Firing
CM Power Usage	7156,2	7156,2
CM Thermal Power Usage	45	45
SM Power Usage	2942,6	212,5
SM Thermal Control Usage	452,1	452,1
Harness Loss	72	55
Battery Charging	0	30
Battery Loss	15	15
SA Charging Loss	105	102
SA/PSR Loss	246	205
Total Power Consumption [W]	11033,9	8272,8
SA Generated Power [W]	15245	15245
Remaining Power Available [W]	4211,1	6972,2
DoD [%]	0,0	0,0

Even with PPS firing for station keeping maneuver, the generated power is enough and there is no need for battery usage. Table 4 shows that when the season is changed to equinox with a 72 min. of eclipse, the DoD percentage jumps to 58,2%. This value will be increasing through mission duration. Due to decrease in efficiency of solar arrays, the generated power will decrease but the passive cooling system will also degrade and the required thermal control power will decrease in eclipse.

Table 4: Equinox/Eclipse DoD results

	PPS Firing	No PPS Firing
CM Power Usage		7156,2
CM Thermal Power Usage		140
SM Power Usage		212,5
SM Thermal Control Usage		626,1
Harness Loss		55
Battery Charging		0
Battery Loss		15
SA Charging Loss		310
SA/PSR Loss		0
Total Power Consumption [W]		8514,8
SA Generated Power [W]		0
Remaining Power Available [W]		-8514,8
DoD [%]		58,2

CONCLUSIONS

This paper introduces an alternative tool to help satellite power management operation by calculating power budget in different seasons with losses and failures. Thanks to this tool, operators are able to predict and verify power system's parameters such as depth of discharge, generated solar array power and etc. In further studies, real time satellite telemetries will be used to update user inputs for real time evaluation and it will possible to update interpolated data for more realistic future predictions.

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