Satellite Electrical Power Supply System

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ABSTRACT

In this paper, a satellite electrical power supply (EPS) system has been discussed. The EPS system's main function is to provide other satellite components with the electrical power as they need to operate effectively. Since, satellites cannot directly receive fuel from the earth, they are generally equipped with solar panels and rechargeable battery cells, which have special power-supply features. The size, weight, and operational requirements of other subsystems and cargo are always the key factors that satellite designers strive to balance. The satellite power supply system consists of two units: a generation unit and a storage unit. Thereafter, we discussed about how to make electrical power generation units more efficient by employing the maximum power point tracker (MPPT). The best capacity and size, as well as the size of the solar array, are significantly influenced by the energy storage unit's efficiency. The need for energy generation decreases as storage system efficiency increases. As a result, solar array size decreases. Additionally, the flywheel energy storage (FES) system has been described. Due to their many advantages over electrochemical batteries, the FES system is gaining significant interest from the National Aeronautics and Space Administration Glenn Research Center (NASA's GRC) in satellite applications for many satellite applications. At last, management of the satellite power system has been discussed.due to their multiple advantages as an energy storage solution over the alternatives.

Keywords: Satellite Electrical Power Supply system, battery, solar array, flywheel storage system.

INTRODUCTION

Satellites have become vital for numerous tasks, including broadcasting, communications, weather forecasting, navigation, earth/space observation, and scientific research. Satellites have been thoroughly investigated, mostly concentrating on their physical and communication characteristics, due to their considerable impact on human lives, business, and scientific discovery [1]. Since about the beginnings of the Space Age and up to the present day, the majority of satellites have relied on electrical power supply systems composed of solar cells and batteries to generate and store the needed power [2]. The key focus of the Electrical Power System (EPS) is to provide the other systems in the satellite with the electrical power they require to function effectively and efficiently. The performance of the satellite's EPS system is improved by lighter batteries and smaller arrays. Solar panels work by converting sunlight into an electric current after orienting the solar cells in the direction of the sun to maximize light absorption. When it is daylight, the solar panels directly power the vehicle, along with charging the energy storage system, represented by nickel and hydrogen. The batteries are distinguished by their capacity to be recharged to supply the satellite with the required power when the satellite is in the shade. Satellites are typically placed in low Earth orbit, which extends the time they spend in the shade from their 92-minute orbit to up to 36 minutes. These batteries are consequently constantly discharged and recharged. The satellite power supply system consists of two units: a generation unit and a storage unit. Satellites are typically built with solar panels and rechargeable battery cells, which have special characteristics of power supply because no fuel can be delivered from Earth to power satellites. Solar panels can only generate power and charge batteries when they are exposed to the sun or during the sun phase (when there is sunlight), according to a satellite's revolution around the earth. The satellite's position, the solar panels' deteriorating efficiency with time, and temperature all affect how much power is produced [5].

INCREASING EFFICIENCYOFTHE EPS SYSTEM

Satellites are indispensable for broadcast, weatherforecast, navigation and many other applications but their design entails a number of stringent requirements such as limited space and weight, impossible or costly repairs, severe radiation and a wide range of temperature they have to withstand. [1] Partial Shedding (PS) is one of the most potent elements that systematically influences the amount of power that can be extracted from any PV system. One of the factors that contributes to multiple peak points, which result in multiple maximum peak power points (MMPPP) and global maximum power points (GMPP), is partial shading. Partial shading can lead an annual 10-20% reduction in power production or more in residential installations [5].

Considering the unique characteristics of satellite power supply and demand, the efficiency of EPS System can be increased by taking the following two points into account:

A. Design: The satellite design should be such that its solar panel should absorb the maximum solar arrays so as to generate maximum power. For this to occur, Maximum Power Point Tracking System is adopted [2], discussed in detail in section 2.1.

B. Energy Storage Management: To increase the efficiency of the energy storage system, the battery charge efficiency and charging route efficiency should be increased. Later, FES system is introduced for the same [3].

Electrical Power Generation Unit

Periodically, solar panels deliver power to a satellite while it revolves the earth. This means that each panel can only generate power during the sun phase, which alternates with the phases of the eclipse. The angle formed by sunlight and a solar panel determines how much power it will produce, and the position and altitude of the satellite affect this angle. The maximum amount of electricity that can be generated by the solar array should be absorbed in order to maximize the efficiency of the electrical power generation unit. The maximum power point is a distinct location on the solar arrays' voltage power curve (MPP), as shown in Fig 1 (in terms of radiations) [2].The maximum power will be absorbed if the operating point of the solar array is changed in accordance with the MPP.

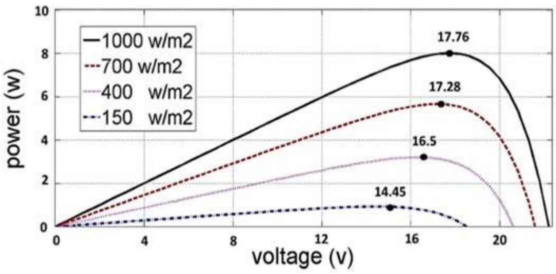

Fig. 1 . MPP voltage variations in terms of radiation. **[2]**

In space missions, a variety of circumstances influence the electrical characteristics of the array, which cause an MPP shift and therefore lower the solar array's efficiency. The following are the variables affecting an array's electrical characteristic curve:

- **Environment**: As radiation rises, the solar cell's short circuit current increases, and as temperature rises, the solar cell's open circuit voltage decreases. MPP movement is caused by these two events.

- **Shadow**: If a part of an array is shadowed by an antenna or other component of satellite hardware, the voltage-power curve of the array will change substantially, with as many peaks as the number of radiations.

- **Damage**: A huge potential difference develops between the surfaces of the solar array and the satellite body when the satellite is subjected to a high-energy flow of electrons. An electrical discharge is produced as a result, which can damage several solar cells.

- **Weariness**:As a result of collisions with space radiations, the electrical properties of the solar cells deteriorate throughout the satellite mission. As a result, the MPP shifts [2].

The electrical power generation unit's efficiency should be maximised by absorbing the maximum amount of solar array power. On the voltage-power curve of the solar array, there is a specific point known as the maximum power point (MPP). If the operational point of the solar array is changed in line with the MPP, the maximum power will be absorbed. To make sure that a solar array's operating point is at MPP, a maximum PowerPoint tracker is employed [2].

MPPT controllers have been essential in determining the maximum power point, which has helped to increase the efficiency of PV systems. The first PV system incorporating MPPT for a space system was released in 1968. After that, MPPT controllers' dependability, accuracy, tracking speed, efficiency, and simplicity all quickly increased.

Following then, MPPT controllers' dependability, precision, tracking speed, efficiency, and simplicity have rapidly improved. An ideal MPPT algorithm frequently moves rapidly, oscillates less around the MPP, and responds to changes in output power quickly [5].

To index MPPT controllers, a number of classifications have been suggested in the literature. MPPT is often divided into two categories: conventional methods and advanced (soft computing) methods. Conventional MPPT techniques have been around for a while and are therefore quite well-liked. These have several benefits, but simplicity and ease of use are the key ones. These techniques can only follow a single MPP in conditions of uniform irradiance. Soft computing, bio-inspired (BI), and artificial intelligence (AI) approaches are examples of advanced MPPT methods. The tracking performance of these methods is better than that of the traditional methods despite their complexity [5].

The standard MPPT techniques known as perturb and observe (P&O), incremental conductance (INC), parasitic capacitance (PC), constant voltage (CV), and constant current (CC) are the ones that are most frequently used. These methods, however, have a number of drawbacks. Conventional methods consume a lot of time, have poor tracking accuracy, and exhibit huge oscillations, making it difficult to monitor the GMPP. Because of their strength, adaptability, and dependability, soft computing techniques are therefore very ideal for extracting optimal GMPP.

To determine whether the MPPT method can match the desired application, it is typical to examine the tracking performance, speed, accuracy, cost, efficiency, and complexity of the application. These are not the only aspects that need to be taken into consideration; additional factors, such as oscillation around the MPP, tracking in normal and peak conditions, system independence, and other factors, are crucial when deciding on the best technique.

So far, several MPPT algorithms have been created. However, the look-up table [10], curve adaptation [11], open-circuit voltage [6], and open-circuit current [7] methods have a low precision and they demonstrate a significant error over time because they are unable to pinpoint the exact location of the MPP since they operate based on the array characteristics at the start of the mission. Because of how the power-voltage (P-V) curve is shaped, hill climbing-based techniques are frequently used.

There are three subcategories of this technique:

1. Perturb & Observe Algorithm (P&O)
2. Modified Adaptive P & O Method
3. Incremental Conductance Algorithm (INC)

The effectiveness of the P&O and INC algorithms is 96.5% and 98.2%, respectively [12]. When applying conventional hill climbing MPPT, it is discovered that energy extraction increases by 16% to 43% on average [12]. According to this technique, the power converter's duty cycle can vary by one unit at any time, and more power is taken from the array than at a previous stage. When power is increased, the duty cycle shifts in the previous direction; when power is decreased, it shifts in the other way. Due to its high precision, simplistic design, direct investigation of power, high reliability, and independence from sensors like radiation and temperature sensors, it is the most popular MPPT method used in space applications [2]. Nevertheless, this technique has three major defects:

1) Tracking local peaks of the solar array voltage-power curve
2) Oscillations around the MPP
3) Low speed

Battery capacity and size, as well as the size of the solar array, are significantly affected by the energy storage unit's efficiency. The higher the efficiency of the storage system, the lesser the requirement for energy generation. As a result, the solar array's dimensions are reduced [2].

Electrical

Energy Storage Unit

When the satellites pass through the shadow of Earth during each orbit, they store their energy in electrochemical batteries. The batteries are distinguished by their capacity to be recharged in order to supply the required energy when the satellite is in the region of partial shadow [3].

For storing energy, lithium-ion batteries are employed. This battery is charged utilizing the constant-current, constant-voltage charging method. Given their properties and manufacturing process, batteries typically have charging rate restrictions. Usually, the highest current that won't damage the battery is used to charge batteries. However, because it highly depends on the charging rate in this scenario, the charging efficiency is low. This is caused due to the battery's internal resistance.

In light of this, it is difficult to consider the charge rate to be a constant. The charging efficiency increases with a decrease in charging rate. The loss in battery internal resistance grows in direct proportion to the charging rate. This also happens at a nearly constant rate. Therefore, the least amount of current should be used during charging [2].

Electrochemical batteries, like rechargeable nickel and hydrogen batteries, have a number of significant drawbacks, including a limited number of cycles for discharging and recharging, which demands the replacement of worn-out batteries in the space shuttle. When considering the actual cost of the batteries, the amount of charge space lost, and the cost of installation, this technique becomes expensive [3].

Flywheels have recently risen to the top of the list of storage technologies in electrical energy storage applications, owing to benefits like high energy efficiency and density. The efficiency, longevity, dependability, operating temperature, weight, volume, and system cost of flywheel energy storage systems (FESS) for satellite applications are all key parameters. Flywheel systems further serve the same purpose as rechargeable electrochemical batteries. FESS was planned for electric vehicles, fixed power backup, and space missions in the 1960s and 1970s. The use of flywheels has not been substantial and has decreased with the growth of the electric grid, despite major breakthroughs during their early stages. Nonetheless, FESS have become a reliable choice for energy storage applications as a result of recent advancements in materials, magnetic bearings, power electronics, and the development of high-speed electric machines [13].

The following section provides an explanation of the flywheel energy storage technology.

FLYWHEEL ENERGY STORAGE SYSTEM

A flywheel energy storage system is a mechanical storage device that transforms electrical energy into mechanical energy to simulate the storage of electrical energy [13]. In comparison to other storage options, flywheel energy storage (FES) devices have a long lifespan and require minimal maintenance. They are an alternative to lead-acid batteries for electricity storage [3]. A flywheel stores energy in the form of rotating kinetic energy. Typically, the FESS is powered by an electrical supply obtained from the grid or any other source of electrical energy. In accordance with the principle of conservation, the flywheel slows down when it is discharging to deliver the stored energy and speeds up as it stores energy. An electrical motor-generator (MG) converts electrical energy into mechanical energy and mechanical energy back into electrical energy to drive the rotating flywheel. Due to their coaxial connection, the flywheel and MG can both be controlled by shifting the MG [13].

Flywheel Description

The FESS is composed of a containment or housing, MG, bearings, a power electronics interface, and a rotating rotor [13] specified as in Fig.2 [3]. Basically, a flywheel is a device that stores electrical energy and rotates quickly. It can be either a disc or cylinder suspended in an airtight container. A flywheel supported by a rolling element magnetic bearing connected to a motor- generator enclosed in a vacuum chamber makes up the present generation of FES satellite systems. The magnetic bearing is essential for reducing friction and energy loss. The rotor, on the other hand, is constructed from high-strength carbon fibre composites, which spin at up to 50,000 rpm in a vacuum container and have a higher tensile strength, therefore can store significantly more energy for the same mass. Furthermore, the flywheel can reach its full capacity in a matter of minutes. Brushless DC (BLDC) motors are the most popular type utilized in flywheel energy storage systems because of their light weight, high energy density, high efficiency, high reliability, and fast speed [3].

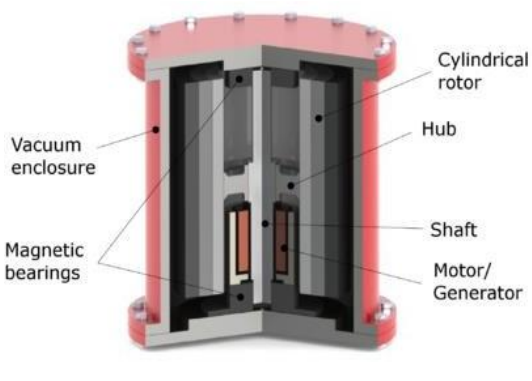

Fig. 2: The main components of the satellite FESS as approved by NASA. **[3]**

FESS is the optimum technology for applications that necessitate these specifications since it has the unique attributes of a very high cycle and calendar life. Additional significant advantages include easy recycling, high power capability, and quick reaction. Given that there is a significant increase in the demand for ESS and that FESS has these distinct characteristics, the future of FESS is very promising, even as the cost of Li-ion and other chemical battery technology continues to decline [13].

MANAGEMENT OF SATELLITE POWER SYSTEM

The considerable impact that satellites have on human life demands a number of stringent design constraints, including limited space and weight, costly maintenance, etc. [1]. A satellite's subsystems must all fit within a constrained space and weight budget, be resistant to extreme radiation and a wide range of temperatures, and be extremely reliable because it is either impractical or extremely expensive to replace (broken) physical parts after launch. This entails the efficient, reliable design of physical components and their cognitive controls, solving the challenges of concurrently designing computer (control) and physical components. Thereby, Satellites, in other words, are a prototypical example of a Cyber-Physical System (CPS).

Designing and managing satellite power systems is of highest relevance among the different CPS concerns of satellites. Each sub-system, such as the on-board computer, receiver, transmitter, camera, magnetorquer, and magnetometer, uses power and is simulated with periodic power-consumption tasks in different versions [2]. Given the special characteristics of satellite power supply and demand, satellite designers aim to achieve the best configuration, which is the number, arrangement, and type of solar panels and battery cells, that can ensure that all tasks are carried out without a power shortage until the end of the satellite's mission lifetime and manage power online so that tasks are carried out with the highest Quality of service versions without compromising the power sufficiency [1].

CONCLUSION

This paperdescribes the satellite's electrical power supply system, which serves as the main source of electrical power for all other systems within the satellite. Thereafter, ways to enhance the efficiency of the electrical power generating unit utilising MPPT have been researched, including hill climbing methods and flywheel energy storage systems, due to their various advantages as an energy storage solution over electrochemical batteries, which have a finite number of discharging and recharging cycles. Finally, the management of the satellite power system has been covered, introducing numerous strict requirements that a satellite design entails, like restricted weight and space, expensive repairs, harsh radiation, and a broad range of temperature they have to tolerate. Each satellite's physical and control components may be effectively and sustainably integrated to meet these requirements, making them prototypes of cyber-physical systems.

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