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CONSTELLATION DESIGN FOR SPACE-BASED SOLAR POWER PLANAR SATELLITE ARRAYS

Abstract

With the growing global energy demand, amid escalating concerns about climate change and the limitations of existing renewable energy alternatives, the concept of space-based solar power has been considerably researched for terrestrial power generation. Particularly, significant advancements in wireless power transmission along with decreasing launch costs have improved the viability of space-based solar power concepts. As a result, several modular space-based solar power systems have been proposed over the last decade, with considerable investigation into the planar sandwich configuration. The planar sandwich configuration has led to several advantages compared to historical systems in terms of streamlined manufacturability, reduced system mass, and enhanced stowability within launch vehicles. However, it has simultaneously introduced unique challenges to the orbital and attitude design, chief among which are the intrinsic coupling of solar collection and power beaming on opposing sides of flat planes. Furthermore, the motivation for continuous, dispatchable, and distributed power to various locations around the globe requires an optimal constellation design of the modular planar sandwich satellite arrays. However, the Earth's rotation, the Sun's movement in the ecliptic plane, and the orbital precession due to the Earth's oblateness cause a continuous change of the relative constellation geometry, and render the constellation design an optimization problem. Therefore, this paper develops an optimization approach using a constrained genetic algorithm to maximize the daily average power delivery, while ensuring continuous and distributed power to multiple locations on the ground. The design variables for the optimization include the constellation parameters, such as the number of orbital planes, the number of satellite arrays in each orbital plane, the phasing parameters between the satellite arrays in adjacent planes, as well as the ground station locations. A dynamic model of the nonlinear coupled orbital-attitude motion is incorporated into the optimization, including the gravitational effect of Earth's oblateness. Numerical simulations are performed to verify the effectiveness of the proposed optimization approach in highly-inclined, elliptical orbits, such as Molniya and elliptical Sun-Synchronous orbits, with a comprehensive analysis of the power-beaming constraints including the minimum elevation angle and the maximum allowable power-beaming squint angle performed using Monte Carlo methods. The proposed methodology provides a framework for evaluation and design of optimal constellations for space-based solar power systems, which is demonstrated through case studies using specific highly-included, elliptical orbits. The optimal constellation results for the case studies are presented and discussed, with consideration of the sensitivity to the design constraints.