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Motion analysis and trajectory planning of solar tracking of a class of Space Solar Power Station

Qi-Bao Jin, Jin Huang *, Jian-Yu Fan

School of Electromechanical Engineering, Xidian University, Xi'an, Shanxi 710071, China

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Abstract

Space Solar Power Station (SSPS) is a kind of space electrical power system which converts space solar energy into electrical power and transmits it to Earth ground receiving station, the energy from which is a kind of clean and renewable resource. Compared to others, the SSPS with concentrator represents the developing direction of SPSS in the future, among which, Integrated Symmetrical Concentrated system (ISC) proposed by NASA has the advantage of high collecting sunlight efficiency. However, the addition of concentrator system results in complicated mechanism and is more difficult to control in motion than before; therefore, it is particularly important to plan the effective and realizable motion trajectory when travels on its orbit in the space. For the purpose, a method of trajectory planning for this kind of system is proposed in this paper to make concentrator to realize real-time solar tracking by means of the cooperative rotation of transverse truss and concentrator on the Geostationary Orbit (GEO), and the simulation demonstrates its validation and feasibility. Finally, two improved measures especially solution 2 are presented to mitigate the overheating as the result of nonuniformity of the flux distribution on PV array caused by rotation of concentrator.

Keywords: SSPS; ISC; GEO; Trajectory planning; Solar tracking

1. Introduction

With the increase of demand for new and clean energy around the world (Lior, 2001), developing the SSPS has been one of the most efficient paths to solve the human energy problem. SSPS mainly dedicates itself to providing the existing pollution energy alternatives to alleviate challenges caused by increasing energy demand and natural resources decline caused by the energy crisis. In 1969, Glaser (1968) of the Unite State first put forward the idea of building SSPS which pointed out that human beings can make use of the GEO to collect the solar energy. In order to speed up the realization of idea of SSPS, some developed countries, such as US, Japan, France, and Russia, carried out the feasibility research of the space power station. In America, in 1970s, NASA and DOE jointly made a extensively study on feasibility of SSPS which included SPS system and key technology, then come up with the system architecture—"the 1979 SPS Reference System" of 5GW (Department of Energy and NASA, 1978); From 1995 to 1997, NASA launched the Fresh look project research and presented the two more effective kinds of SPS systems: the Sun Tower (Space Solar Power Satellites – Sun Tower, 2011) and the Solar Disc architectures; With the support of the NASA innovation concept project, former NASA engineer John Mankins proposed a new concept of SSPS solution: SPS-ALPHA (Mankins,

* Corresponding author. Tel./fax: +86 029 88203040.
E-mail address: jhuang@mail.xidian.edu.cn (J. Huang).

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2011), which adopts highly modular design and greatly reduces the requirement of control system. At the end of the 20th century, NASA worked with the new study on the SERT and put forward new concepts – Integrated Symmetrical Concentrator or ISC for short (Feingold et al., 1997; Mankins, 1995; Mankins and Howell, 2000), the most characteristic of which is to use the concentrating solar power system to form a more high efficient energy collecting and transmission system. Those results of landmark triggered the studying boom of the SSPS. In Europe, European Space Agency (ESA) proposed the Sail Tower SPS concept (Seboldt et al., 2001) which can significantly reduce the total weight of system; unfortunately, the system was unable to realize the continuous power supply to the ground station as a result of the solar array not keeping real-time direction to the Sun; In Japan, since 1990, JAXA successively put forward the concept of a variety of SSPS, such as JAXA2001 and JAXA2002 scheme, and also, JAXA launched the Tethered-SPS concept (Sasakia et al., 2006) to reduce the complexity of system and quality, but due to the solar array cannot point to the Sun all the time, the power of the whole system will be huge fluctuations, the overall efficiency is very low.

Internationally, the power station with concentrator was generally recognized as representing the developing direction of SSPS, and the concentrator photovoltaic (CPV) technology was early widely used in stationary concentrators of solar energy and SSPS field (Feingold and Carrington, 2003). The solar photoelectric module was invented, which comprised a composite parabolic solar energy concentrator and had an aperture angle and contrived in the form of a sealed gas-filled bulb (Hinterberger and Winston, 1975). The V-trough reflectors had been applied in lower concentration photovoltaic using flat mirrors (Valera et al., 2004). The evacuated solar concentrator had been designed to obtain higher performance and lower material cost and it had been taken into account as the space solar projected area (Ustaoglu et al., 2013). The new compound parabolic light concentrator (CPLC) has been proved to come very close to being an ideal concentrator comparing with a cone concentrator or a paraboloid of revolution concentrator (Winston et al., 2005; Strebkov et al., 2007). And also, Symmetric V-shaped prismatic stationary concentrator had been developed to improve the characteristics of the prismatic concentrators in space (Kivalov and Tver's yanovich, 1999; Kivalov et al., 2000). The development of the concentrator photovoltaic technology lays the solid foundation for study of the SSPS, and the SSPS with concentrator is being given more and more attention in the space power field.

Even so, at present, a lot of work is deserved to be done to improve and perfect the research of the SSPS (Fan and Zi, 2010), for example, how to improve the system operation efficiency to reduce the redundant motion in orbit and how to improve the collecting efficiency of sunlight. To meet the requirement of the good compactness and high flux densities, a class of Symmetrical Cassegrain Concentrators Structure (SCCS) (Fig. 1) (Gordon and Feuermann, 2005; Feuermann and Gordon, 2001) which is studied in this paper, the concept is based on an unusual structural configuration consisting of two symmetrical concentrators and two reflectors. This system scheme adopts two-stage concentration which can greatly reduce dimensions, quality and costs of the PV array; the two structures rotate cooperatively so that concentrator can continuously point to the Sun to trace the seasonal motion of 23.5° on the GEO (Carrington and Feingold, 2002); on the other hand, the electricity from PV panel can be converted into electromagnetic energy and then be transmitted to transmitter, which avoids the demand for high-power conductive slip ring and long distance power transmission between PV array and transmitter (Carrington and Feingold, 2002). However, although this solution has those advantages and has been regarded as higher energy conversion and transmission characteristics (Neil Johnson, 2009), the complex concentrator mechanism system makes the control become extremely complicated (Carrington et al., 2000), and the inevitable disadvantage of the ISC lies in the thermal control problem on PV array caused by the rotation of the concentrators during the time of the solar tracking (Carrington et al., 2000), and at the same time, in order to improve the collecting sunlight efficiency, it is very necessary to adopt real-time trajectory planning. The latest Alpha SPS (Mankins et al., 2012) is composed of numerous hexagonal reflectors that act as individually pointing heliostats. The effect of structure parameters on energy flow density uniformity and concentration ratio had been discussed (Meng et al., 2014), which is based on the static status without the analysis of the orbit motion in the condition of solar tracking. However, for above especially the SCCS structure, the orbital tracking methods and trajectory planning have been never studied.

For this purpose, a trajectory planning method for solar tracking is introduced in this paper in which the emphasis is placed on the motion analysis and posture planning of the system, and simulation verifies its validity and feasibility. Finally, negative effect of concentrators caused by rotation is analyzed and corresponding improved measures to mitigate the flux distribution nonuniformity are presented.

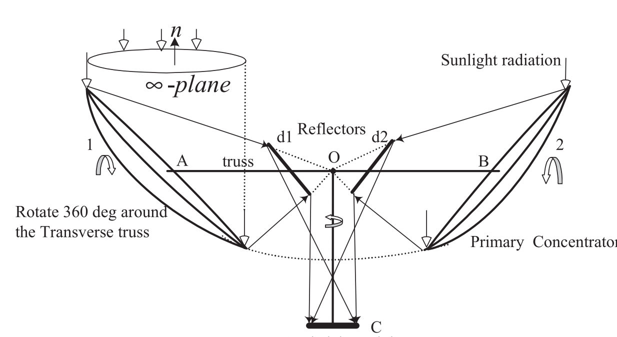

Fig. 1. Overall structure of SCCS.