Space Energy Internet System

ChunFeng,Wang
Qian Xuesen Laboratory of Space Technology
China Academy of Space Technology
Beijing, China
Jessen_wang@163.com

Junwei Cao
Tsinghua University
Beijing, China
jcao@tsinghua.edu.cn
Fulu Li
Tsinghua University
Beijing, China
fulu@media.mit.edu

***Abstract*—Global Energy Internet is emerging as one of the hottest research fields recently. It is a further development and enhancement of the smart grid system. However, the energy Internet is different from the smart grid in several aspects. Energy Internet is a new type of ecological energy system that is integrated with traditional energy system after the information has evolved into a new means of production, especially with the introduction of the concept of energy micro-grid. To supplement the traditional smart grid systems and architectures, Energy micro-grid is based on distributed energy network system that can achieve efficient energy supply and consumption. In this paper we present a new concept of energy micro-grid, the concept of solar power station and the definition and description of space energy Internet system. Major components of the system such as the distributed satellite constellation energy network architecture, wireless energy transmission technology, energy and information integrated transmission and joint scheduling technology will be discussed thoroughly. We also elaborate some design challenges and solutions of the key technologies for the construction of such a system. These studies lay the theoretical and engineering foundations for the future space energy Internet system.**

Keywords—Energy Internet; Energy micro-grid; Solar power station; Space Energy Internet;

I. INTRODUCTION

The integration of the Internet and the power grid will be a form of the energy of the Internet (Energy Internet) [1] to provide services and consuming energy. Energy Internet is the use of distributed energy collection system, with the full collection of decentralized renewable energy. The use of the Internet and intelligent terminal technology to enable energy and information flow in intelligent energy networks to realize the distribution, transformation and sharing of energy in the whole network. The Energy Internet transforms the traditional centralized, unidirectional, producer-controlled energy systems into a large number of distributed grids, less centralized and with more interactions between consumers and energy networks. Energy Internet can achieve intermittent energy regulation and access, production and storage of the customized energy demand. The Energy Internet is a backbone grid and consists of many energy micro-networks.

Solar energy is currently the fastest-growing, most extensive, renewable clean energy sources. With the advancement of wireless energy transmission technology [2], we envision the construction of the space energy network, with solar energy being transmitted to the ground by wireless transmissions. Space energy Internet acts as a space energy supply as well as the Internet to achieve the integration of terrestrial energy distribution and the world power supply intelligent energy network system.

The Earth is surrounded by dozens of kilometers of the atmosphere, where the energy from the Sun to the ground on the Earth has been greatly attenuated. Solar power per square meter of space is about 1360kw/m^2, while the ground on the Earth in sunny conditions is about 600-700W/m^2. Due to the very differences of regional, meteorological and other environmental conditions, solar power varies greatly. Notably, more than 60% of the Earth's surface is covered by clouds, which has great negative impact on the collection of the terrestrial solar energy. In addition, the biggest shortcoming of the ground solar energy can't be collected normally more than half of a day. Space energy network system, compared to the solar energy on the ground, has great advantage, where it can provide power from the daylight to the night conditions, much less impacted by the atmosphere and the weather.

Space energy networks can easily complete transmission regulation and control if we establish the ground receiving stations in different regions. These terrestrial receiving stations control the amount of electricity consumed in different areas through the management of the space energy Internet, rather than building huge amounts of electricity from one area to another on the ground.

II. FROM SOLAR POWER PLANTS TO SPACE ENERGY INTERNET

A. Energy Micro-grid

Energy micro-grid is for the distribution of energy into electrical energy, which is the basic unit of the power generation, energy storage and deployment in the energy internet. Distributed energy itself has the characteristics of energy production intermittent and output instability, if not for processing and controlling, its large-scale access will affect the stability of the main power grid. Energy micro-grid is a main way of large-scale distributed energy access, which can realize independent and flexible dispatching of electric power in a regional scale. Energy micro-grid is a complete sub-unit of self-contained and autonomous energy system, which can content requirements of different users for energy quality and reliability. It is mainly composed of intelligent energy management equipment, distributed renewable energy, energy storage devices, converter devices and loads.

Energy micro-grid is the basic component of energy Internet. It is an effective supplement to the large power grid

by new energy generation, micro-energy collection, aggregation, sharing, and energy storage of the micro-grid or energy consumption to form the energy local area network.

B. Space Solar Power Stations

Space Solar Power Station (SSPS) [3], also known as solar power generation satellites, refers to the space in the solar energy into electricity, and then transmitted through the wireless energy transmission to the ground power system. Space solar power station consists of three major components, as shown in Figure 1, including solar power generation, energy conversion and emission devices, ground receiving and conversion devices.

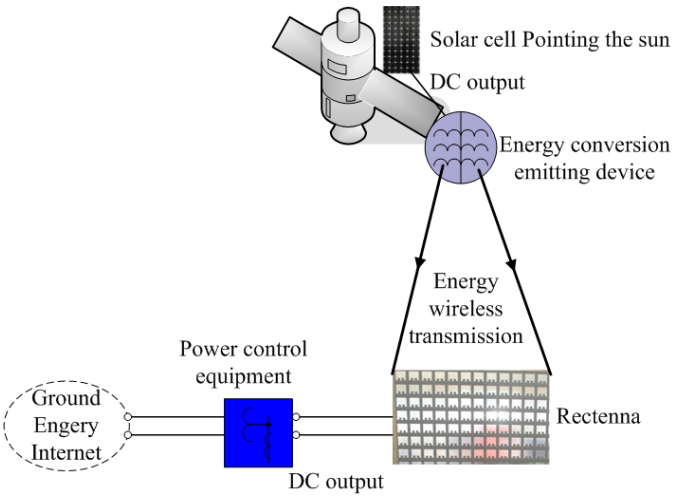

Fig.1 Sketch map of space solar power station

Since the 1970s, a number of countries, including the United States, have conducted extensive research on space solar power stations and wireless energy transmission technologies, and proposed many concepts and methods, including the 1979 SPS benchmark system [4], solar sail and solar tower power station system [5], distributed rope system power system [6], arbitrary phased array space solar power station [7], laser solar power station [8]. These systems use the structure of the condenser and non-condenser, power generation mode is generally photovoltaic, energy transmission, including microwave energy transmission and laser energy transmission mode.

C. Space Energy Internet

Space Energy Internet is based on satellite platform to achieve the integration of space power grid (Space Power Grid) and information network system design, through the establishment of space energy network and information network integration system, make the solar power station be a node in the energy Internet space. This node supplies power to other satellites while transmitting energy to the ground. Space solar energy transform and transmit the collective energy to the ground, the it will integrate with the ground energy Internet, to achieve full distribution, space and earth integration of intelligent energy supply network system, as an energy micro-network access to the ground energy in the Internet.

When Space Energy Internet is in the process of energy and information transmitting, energy and information can be transmitted by using independent radio channels or by the same radio channel. In the use of the same wireless channel for simultaneous information and energy wireless transmission system, is a complete energy and information integration of the transmission system, so that space can be set up to wireless portable network system.

III. THE KEY TECHNOLOGY OF SPACE ENERGY INTERNET

Space Energy Internet involves many technologies such as distributed energy collection system architecture, energy storage, energy wireless transmission, energy and information integrated wireless transmission, energy micro-network control and so on.

A. Energy Network System Architecture Based on Distributed Satellite Constellation

A hybrid constellation space energy network composed of GEO and LEO satellites was established by using distributed constellation design method. In terms of path loss effects, wireless energy transmission from LEO to terrestrial receivers has lower losses. LEO satellites and GEO satellites can collect energy, and through the wireless transmit energy to the ground. While LEO satellites have energy storage functions. In order to more convenient, we can control the function of space energy Internet to a region of the ground energy receiving station for power control. There are two cases when the LEO is transmitting energy to the ground. A constellation is within the field of view (FOV) of the ground receiving station, as shown in Figure 2. The other one is there is only one satellite in the field of view of the ground receiving station. The others satellites are transmitted to the satellite by wireless energy and then transmitted to the ground station, as shown in Fig.3. GEO and LEO satellites through the establishment and inter-satellite wireless energy transmission link to the ground power transmit and supply power for satellite.

B. Wireless energy transmission technology

Wireless energy transmission technology is the key to the realization of Space Energy Internet, space solar energy can only be collected and converted through the wireless energy transmission to the ground before they integrated into the ground power grid for using, or transmitting the energy to other satellites. Wireless energy transmission generally includes microwave wireless energy transmission and laser wireless energy transmission. Microwave wireless energy transmission system mainly consists of three parts: microwave power generator, microwave transmitting antenna, microwave receiving and rectifying antenna. At the transmitting end, the DC electric energy is converted into microwave and transmitted through the free space. At the receiving end, the DC electric energy is converted again by the rectifying antenna. Microwave power generator is the role of the DC into microwave, microwave generators are commonly used in tubes, semiconductors and hybrid solid-state devices, which include magnetron tube, traveling wave tube, klystron and so on.

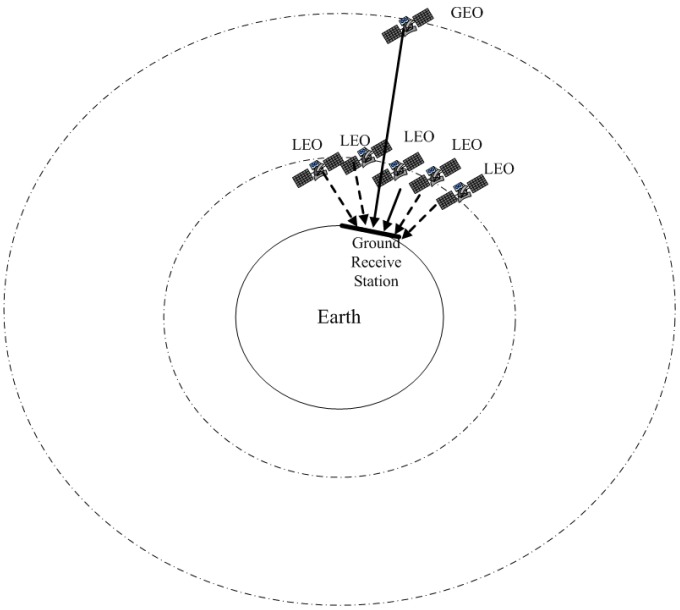

Fig.2 GEO and LEO hybrid satellite space energy network transmission (FOV ground receiving station)

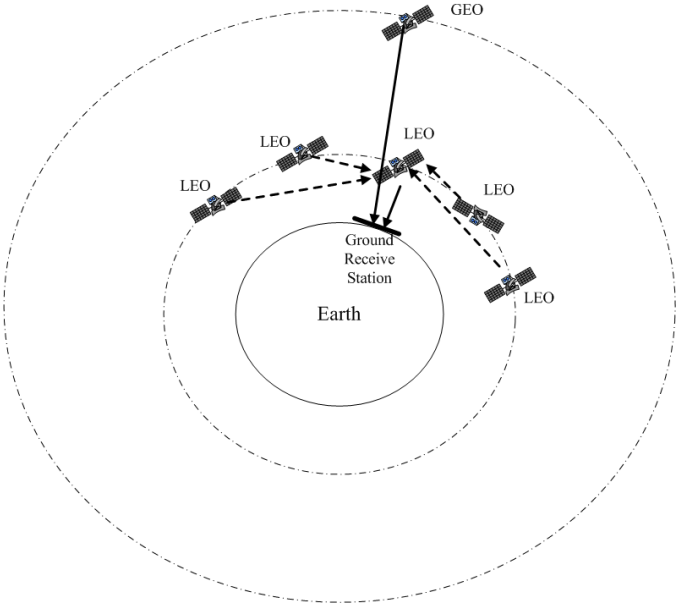

Fig.3 GEO and LEO hybrid satellite space energy network transmission (non-FOV ground receiving station)

C. *Wireless portable network technology*

Wireless portable network technology is to carry out wireless energy transmission at the same time to processing information transmission, using the same signal at the same time the integration of information and energy transmission.

In the receiver it has the RF, rectifier module and the voltage divider network, respectively, after the wireless energy collection and data information received, as shown in Figure 4.

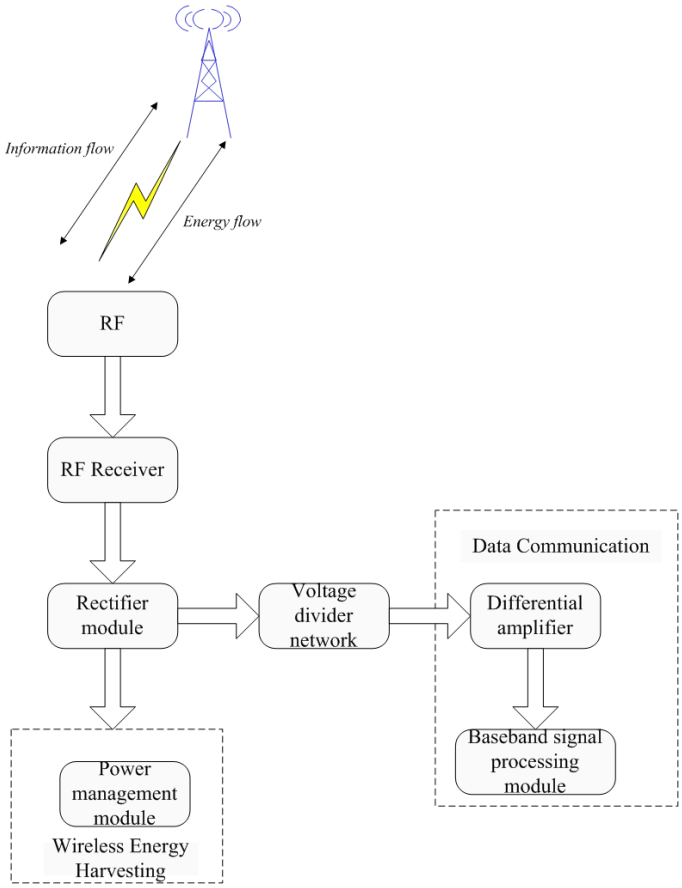

Fig.4 Wireless Portable Network System Architecture

IV. Challenge and Countermeasure of Space Energy Internet Design

A. *Challenges and Solutions of Distributed Energy Collection Technology*

Based on the energy collection and reception of LEO satellites, it is necessary to transmit energy to the ground by multiple satellites and wirelessly transmit power between satellites. Due to the relative motion of satellites, the Doppler effect will lead to difficulties in power synthesis. In addition, the Doppler effect between the satellites will cause the ground receiving station Doppler effect of transmission loss, greatly reducing the wireless transmission efficiency. All these pose great challenges for the satellite-to-earth and inter-satellite wireless power transmission. We need to consider the influence of satellite constellation Doppler shift on microwave wireless transmission and analyze the modeling and propose possible solutions. Such as the use of inter-satellite dynamic measurements for frequency drift feedback to eliminate the Doppler effect of wireless energy transfer between satellites. By exploring the synchronization method of multiple satellites, the transmission loss of the Doppler effect at the ground receiving station formed by the Doppler effect between the satellites is reduced based on the satellite relative velocity and the relative distance. By designing a multi-satellite coordinated microwave wireless energy transfer method which based on frequency dynamic compensation to improved the wireless energy transmission efficiency of multi-satellite coordination. When the wireless transmission signal arrives at the ground

receiving station, the long transmission distance between the satellite and the ground receiving station also leads to different phase angles. Based on the analysis of the inter-satellite Doppler effect, different initial phases are transmitted through the satellites Angle of the wireless transmission design, to achieve optimal wireless energy transmission and reception efficiency.

B. Challenges andSolutions of Radio Frequency DC Conversion Technology for Wireless Energy Transmission

Designing an optimization of the rectifier circuit module to improve the conversion efficiency of RF DC is the bottleneck for the wireless transmission of microwave energy, the solutions of which include a high-gain microwave rectifier antenna array, using the optimized Schottky diode and circuit, the design of efficient RF-DC converter rectifier module, considering the operating frequency and system loss, the detailed analysis of component modeling and matching efficiency. The use of self-bias technology to reduce the power required by the rectifier, the design low-power rectifier module, the application of multi-port receive technology to design a new multi-port receiver structure to achieve simultaneous wireless power transmission and data communication, the low power consumption, the compact structure, the low cost requirements also play important roles. In the millimeter wave, the design of rectifier circuit, the nonlinear rectifier process, and the harmonic collection can be used to improve the efficiency of the rectifier module.

C. Challenges and Solutions of Joint Scheduling Technology of Energy and Information Integrated Transmission

Energy and information can be integrated based on time division, power segmentation, energy modulation integration techniques [9]. Energy and information joint scheduling involves the downstream transmission of energy and information as well as the uplink energy-saving information transmission quality requirements. In the energy and information integration joint scheduling, the antenna designing, coding and modulation methods are different from the transmission of the communication network method, which needs to address the common channel interference, and dual distance and other issues. Channel fading leads to voltage level instability conditions as well as the integrated energy and information transmission reliability. For MIMO multi-antenna configurations, energy beam-forming is used to achieve priority energy requirements for certain users while space division multiple access (SDMA) and multi-user detection can be used by the energy center station to allow multiple access. The user can transmit the same time-frequency resource blocks and energy beam-forming and SDMA can be combined with dynamic time-frequency resource allocation to improve the performance of the system.

CONLUSION

The Global Energy Internet is one of the hottest research topics in the energy field. The deep integration of energy and the Internet and the distributed energy micro-grid are future development directions for global energy systems. This paper discusses the concept and the principles of Space Energy Internet from space solar power station perspective. Space Energy Internet not only provides spacecraft with power supply, but also acts as an energy micro-grid, through wireless energy transmission technology, beaming energy back to the Earth. We intend to explore the key technologies of space energy Internet and describe the challenges and solutions for the design of space energy Internet, which can be the basis for future research endeavors.

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