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Space Based Solar Power – An Step to Wireless Energy Transfer

Alka[1], Bipul Kumar[2], Amita Singh[3]

Student, EE, RCEW, Jaipur, India[1]

Assistant Professor, EE, RCEW, Jaipur, India[2]

Lecturer, EE, THAPAD University, Punjab, India[3]

Abstract: In this paper, we present the concept of transmitting power without using wires i.e., transmitting power as microwaves from one place to another is in order to reduce the transmission and distribution losses. A wireless power transmission using microwave is a system which contains satellite based solar power system (SPS), microwave generator, microwave transmitter (magnetron) and microwave receiver (rectenna). The DC power received on earth is converted into AC for various useful purposes. This paper gives a comprehensive study of various components of satellite based SPS and projects this technology as a bulk source of power generation in future.

Keywords: Wireless power transmission, microwave, magnetron, rectenna.

I. INTRODUCTION

In 1864, James C. Maxwell predicted the existence of radio waves by means of mathematical model. In 1884, John H. Poynting realized that the Poynting Vector would play an important role in quantifying the electromagnetic energy. In 1888, bolstered by Maxwell's theory, Heinrich Hertz first succeeded in showing experimental evidence of radio waves by his spark-gap radio transmitter. The prediction and Evidence of the radio wave in the end of 19th century was start of the wireless power transmission. A major problem facing planet earth is provision of an adequate supply of clean energy. It has been that we face "three simultaneous challenges – population growth, resource consumption, and environmental degradation all converging particularly in the matter of sustainable energy supply." It is widely agreed that our current energy practices will not provide for all the world's people in an adequate way and still leave our earth with a livable environment. Hence, a major task for the new century will be to develop sustainable and environmentally friendly sources of energy. The global demand for electricity is continuously growing. Of the total generation worldwide, more than 60 percent of energy is generated using coal-fired station resulting in carbon dioxide emission threatening the global warming. To mitigate the consequence of the climate change, the generation systems need to undergo significant changes.

The installed capacity over the last century is a clear picture of growing economy. To satisfy the increasing demand for power and reducing CO2 emission, the future generation system must meet the demand, reliability, efficiency and sustainability. This has accelerated the generation using solar, wind, tidal, and many more. The objective of such initiative is to investigate on the feasibility, financing and development of new plans. The SPS system has great potential to harness solar power using bulk photovoltaic (PV) array in space and transmit it to the earth using microwave.

II. SOLAR POWER

Solar power is produced by collecting sunlight and converting it into electricity which is shown in fig 1. This is done by using solar panels, which are large flat panels made up of many individual solar cells. Space-based solar power (SBSP) is the concept of collecting solar power in space (using an "SPS", that is, a "solar-power satellite" or a "satellite power system") for use on Earth. It has been in research since the early 1970s.

SBSP would differ from current solar collection methods in that the means used to collect energy would reside on an orbiting satellite instead of on Earth's surface. Some projected benefits of such a system are a higher collection rate and a longer collection period due to the lack of a diffusing atmosphere and night time in space.

Part of the solar energy (55-60%) is lost on its way through the atmosphere by the effects of reflection and absorption. Space-based solar power systems convert sunlight to microwaves outside the atmosphere, avoiding these losses, and the downtime (and cosine losses, for fixed flat-plate collectors) due to the Earth's rotation.

Besides the cost of implementing such a system, SBSP also introduces several new hurdles, primarily the problem of transmitting energy from orbit to Earth's surface for use. Since wires extending from Earth's surface to an orbiting satellite are neither practical nor feasible with current technology, SBSP designs generally include the use of some manner of wireless power transmission.

The collecting satellite would convert solar energy into electrical energy on board, powering a microwave transmitter or laser emitter, and focus its beam toward a collector (rectenna) on Earth's surface. Radiation and micrometeoroid damage could also become concerns for SBSP.

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A. Basic Components of Wireless Power Transmission – Generator, Antennas and Transmitters

1) Microwave Generator

The cavity magnetron is a high-powered vacuum tube that generates microwaves using the interaction of a stream of electrons with a magnetic field while moving past a series of open metal cavities (cavity resonators) Unlike other microwave tubes, such as the klystron and traveling-wave tube (TWT), the magnetron cannot function as an amplifier, increasing the power of an applied microwave signal, it serves solely as an oscillator, generating a microwave signal from direct current power supplied to the tube. In a conventional vacuum tube, electrons are emitted from a heated cathode and are attracted to the anode as it is positive with respect to the cathode. The components are normally arranged concentrically, with the cathode at the centre, giving them their traditional cylindrical shape. In vacuum tubes (valves), the current can flow only from the cathode to the anode, providing rectification although this function is usually performed by the diode. A triode adds a control grid which allows the flow of current to be further controlled in magnitude, and thereby provides an amplification function when the magnetron was operating at the critical value that it would begin to give off radio frequency signals. This occurred because the path, when properly adjusted, would cause some of the electrons to circle between the cathode and anode. Due to an effect now known as synchrotron radiation, this causes the electron to radiate. The effect was not very efficient; eventually the electrons would hit one of the electrodes, so the number in the circulating state at any given time was a small percentage of the overall current. Construction of microwave generator is shown in fig 2.

2) Transmitting and receiving antennas

An antenna (or aerial) is an electrical device which converts electric power into radio waves, and vice versa. It is usually used with a radio transmitter or radio receiver. In transmission, a radio transmitter supplies an electric current oscillating at radio frequency (i.e. a high frequency alternating current (AC)) to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic (radio waves). Typically an antenna consists of an arrangement of metallic conductors (elements), electrically connected (often through a transmission) to the receiver or transmitter. An oscillating current of electrons forced through the antenna by a transmitter will create an oscillating magnetic field around the antenna elements, while the charge of the electrons also creates an oscillating electric field along the elements. These time-varying fields radiate away from the antenna into space as a moving transverse electromagnetic field wave. Antenna is a structure which transmits, receives and directs the waves. For space based system, a parabolic antenna is highly recommended. The parabolic antenna uses a parabolic reflector curved surface with cross sectional area of parabola to direct the waves. It is most commonly known as dish antenna. The important parameters of an antenna while considering it for a particular system are its directivity and gain. All antennas can be applied for both the MPT system and communication system, for example, Yagi-Uda antenna, horn antenna, parabolic antenna, microstrip antenna, phased array antenna or any other type of antenna. To fixed target of the MPT system, we usually select a large parabolic antenna which is shown in fig 3.2. However, we have to use a phased array antenna for the MPT from/to moving transmitter/receiver which include the SPS because we have to control a microwave beam direction accurately and speedy. The phased array is a directive antenna which generate a beam form whose shape and direction by the relative phases and amplitudes of the waves at the individual antenna elements. It is possible to steer the direction of the microwave beam. The antenna elements might be dipoles, slot antennas, or any other type of antenna, even parabolic antennas. All SPS is designed with the phased array antenna. We consider the phased array antenna for all following MPT system which is shown in fig 3.1.

3) Transmitters

The microwave transmitting devices are classified as Microwave Vacuum Tubes (magnetron, klystron, Travelling Wave Tube (TWT), and Microwave Power Module (MPM)) and Semiconductor Microwave transmitters (GaAs MESFET, GaNpHEMT, SiC MESFET, AlGaN/GaN HFET, and InGaAS). Magnetron is widely used for experimentation of WPT. The microwave transmission often uses 2.45GHz or 5.8GHz of ISM band. The other choices of frequencies are 8.5 GHz, 10 GHz and 35 GHz. The highest efficiency over 90% is achieved at 2.45 GHz among all the frequencies. The technology employed for the generation of microwave radiation is an extremely important. Phased Array Used in Japanese Field MPT Experiment (Left: for MILAX in 1992, Right: for SPRITZ in 2000) subject for the MPT system. We need higher efficient generator/amplifier for the MPT system than that for the wireless communication system. For highly efficient beam collection on rectenna array, we need higher stabilized and accurate phase and amplitude of microwave when we use phased array system for the MPT. There are two types of microwave generators/amplifiers.

One is a microwave tube and the other is a semiconductor amplifier. Threw reviewed microwave generators/amplifiers, frequency vs. averaged power as shown in. These have electric characteristics contrary to each other. The microwave tube, such as a cooker-type magnetron, can generate and amplify high power microwave (over kW) with a high voltage (over kV) imposed. Especially, magnetron is very economical. The semiconductor amplifier generate low power microwave (below 100W) with a low voltage (below fifteen volt) imposed.

It is still expensive currently. Although there are some discussions concerning generation/amplifier efficiency, the microwave tube has higher efficiency (over 70%) and the semiconductor has lower efficiency (below 50%) in general. We have to choose tube/semiconductor case by case for the MPT system.

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4) Magnetron

Magnetron is a high powered vacuum tube device that generates microwaves owing to the motion of clouds of electrons in a crossed electric and magnetic fields. Magnetron originally developed in 1916 as an alternative to grid control in vacuum tubes. It was discovered during the DEO/NASA study of SPS that the microwave oven magnetron along with the external passive circuitry can perform as phase locked high gain of 30dB amplifier for direct use in the transmitting section. For ground based transmitter, the microwave oven magnetron can be used directly. However for space use, based on the same principle, special space magnetron is required.

B. Wireless Electricity Transmission (WET) technology

Wireless power transmission is a process that takes place in any type of system in which electrical current is conveyed from a power source to an electrical load. What makes this process unique is that there is no usage of any type of wiring to connect the system to a source of power. Wireless electricity (Power) transmission basically is the transmission of electricity with the help of microwaves and there is no need to use cables, towers and grid stations there are three methods or approaches which can be developed. These are as given below:

1) Short range (Induction)

This ranges few centimeters e.g. transformer in which transfer takes place due to mutual induction.

2) Moderate range (Adaptive Inductive Coupling)

Wireless power transfer technology can be used to charge the electronic objects automatically. The ability of our technology to transfer power safely, efficiently, and over distance can improve products. This principle of wireless electricity works on the principle of using coupled resonant objects for the transference of electricity to objects without the use of any wire.

1) Power from mains to antenna, which is made of copper
2) Antenna resonates at a frequency of about 10MHz, producing electromagnetic waves
3) Tails' of energy from antenna 'tunnel' up to 2m (6.5ft)
4) Electricity picked up by laptop's antenna, which must also be resonating at 10MHz. Energy used to re-charge device
5) Energy not transferred to laptop re-absorbed by source antenna. People/other objects not affected as not resonating at 10MHz

3) Long range

Plans for wireless power involve moving electricity over a span of miles. Long distance wireless power is the technology of sending power to earth.

There are many new techniques but we use only two here. 300 kW power to tesla coil resonated at 150 kHz. The RF potential at the top sphere reached 100 MV. Unfortunately he failed due to diffusion in all directions.

By using Solar Power Satellite (SPS) :-

This task is often completed by using solar power satellite (SPS), placed in high earth orbit. This satellite converts the sunlight into energy; this energy is composed of microwaves.

These microwave signals are transmitted to an antenna on ground/Main grid station (MGS). From MGS these waves are transferred to BGS (Base grid station) so called rectenna which convert microwaves into DC electricity. Fig 4 is shows are that all terms.

There will be energy receiver box or energy router in each home. The information of the electricity or power required for each home will be available with the grid station. At the grid station the electricity will be converted into energy packets likewise internet data packets and the header of that energy packet will include the address of the energy receiver that is mounted on the wall of the house of consumer.

The energy packet will then reach the energy receiver and will be stored in that energy receiver after that the consumer can use that stored energy any time he wants. We used the same concept as we do in telecom sector and through this act we can buy electricity according to our need.

Space-based solar power (SBSP) :-

It is the concept of collecting solar power in space for use on Earth. It has been in research since the early 1970s. SBSP also introduces several new hurdles, primarily the problem of transmitting energy from orbit to Earth's surface for use. SBSP designs generally include the use of some manner of wireless power transmission. It mainly consists of three segments Solar energy collector (To convert Solar energy into DC current), DC to microwave converter and Large antenna array to beam down (Microwave) power to ground.

- Solar energy collector (Photovoltaic cell, solar thermal turbine).
- DC to microwave converter (Microwave tube system and /semiconductor system).
- Antenna
- FIGURES

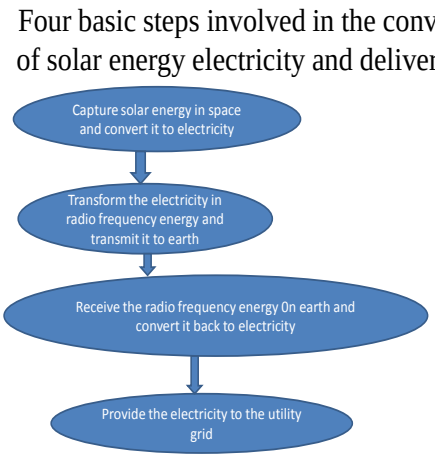

Fig.1 converting solar energy into electricity

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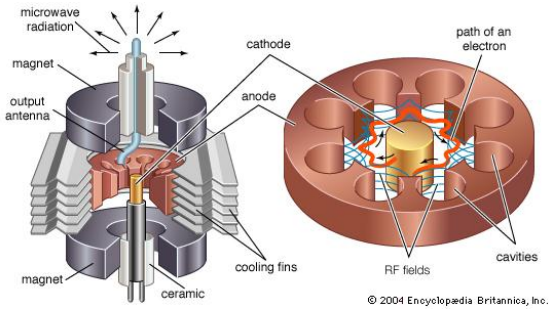

Fig.2 construction of microwave generator


Fig.3.1 large rectena array


Fig.3.2 parabolic antenna

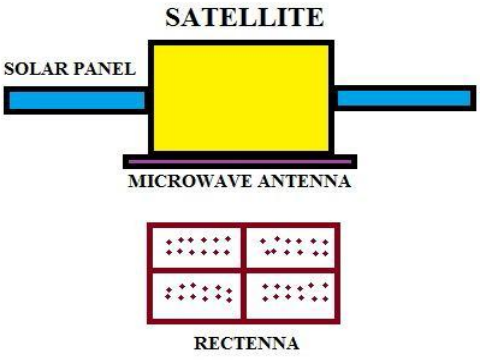

Fig.4 the satellite based system

III. CONCLUSION

Space energy is not the only option for solving the world's future energy needs, but it is one of the most promising. The idea of satellites sending clean continuous power from the sun may still sound like science fiction, but many of today's technological marvels in the past likely did as well. The realization of SBSP will not happen overnight; in fact it is an idea over 40 years in the making. Launch costs need to be lowered. The international legal regime needs to develop further to accommodate SBSP. SBSP will likely also require substantial cooperation between different countries and private companies. All are difficult challenges but will be rewarded with a worthy prize.

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