

Wireless Power Transmission Using Satellite Based Solar Power System

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ABSTRACT

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.

1. INTRODUCTION

Electricity is the most versatile and widely used form 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 [1]. According to the "Load Generation Balance Report 2013-2014" of India, the energy requirement registered a growth of 6.5% during the year 2012-2013 against the projected growth of 5.1% [2]. This is due to increasing population, advancement in living standard of the people, discovery of new power consuming yet comfort providing devices/appliances and improvement in the life style of the masses. The conventional methods for generating electrical power are insufficient for providing the increasing demand of electrical power. Thus, there is an urgent need to supplement the conventional sources. Solar power generation with its associated technologies has advanced few steps ahead in last several decades. It has been believed and investigated since last four decades that solar energy in space free from the weather conditions is quite different from that on the earth. 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. The solar energy from sun while travelling a path to Earth is lost in the atmosphere because of the effects of reflection and absorption. Therefore, it would be much beneficial to absorb solar energy from the geosynchronous orbit. A geosynchronous orbit is any orbit which has a period equal to the earth's rotational period. Accounting for efficiency, the PV cells produce 5 to 10 % times more power at space than at ground [3]. Thus placing solar cells in space has a competitive advantage over solar power plants on the Earth. A photovoltaic cell can be placed on satellite revolving in geosynchronous orbit to absorb the solar energy. The satellite is called as solar powered satellite. The generated DC by the photovoltaic cell can be converted into microwave by using magnetron, klystron or solid state devices. The generated microwave is transferred to the earth using antenna. The transmitted power is received by a device called rectenna. The received power is converted into DC power by filters and schottky diode. Power transmission using laser beam is also possible but, the power efficiency at both the transmitter and receiver of microwave transmission is more as compared with laser [4].

2. Design of The Satellite Based System

The complete assembly of the satellite based system is shown in figure 1. The solar panels are connected on either sides of the satellite. These solar panels are the main source of DC power. Microwaves are generated using a device called magnetron powered by DC supply. Photovoltaic cells are used for converting solar radiations into DC power. The generated DC power is fed to the magnetron having microwaves in the range 2.45 GHz to 2.54 GHz [4]. The SPS systems use specially designed magnetrons which generate 3 to 5 KW power [5] or more. Waveguide is a structure that guides waves such as electromagnetic waves, sound waves and microwaves.

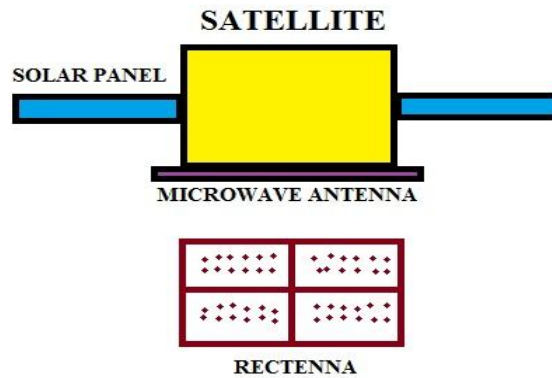


Fig.1. THE SATELLITE BASED SYSTEM

Furthermore, the microwaves that come out from the waveguide need to be transmitted to the receiving rectenna, via space. The schematic diagram of the complete system is shown in figure 2.

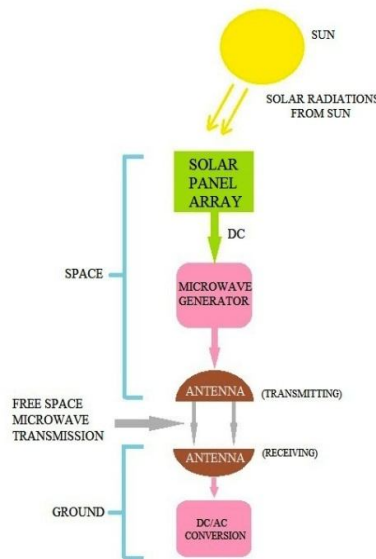


Fig.2 BLOCK DIAGRAM

3. Ground Based Model

The design considerations for the ground based model of the proposed SPS system differs from that used in space. Starting from the DC power source, for space based system; the DC power source is the solar energy. As stated earlier, DC power produced by solar energy in geosynchronous orbit is approximately 3 to 4 times more that can be produced on earth's surface for same duration. The number of solar panels required for ground based model would be more. For an experimental setup, the power supply for the ground based system may be taken from the voltage doubler/multiplier circuit to supply the DC power to magnetron. Instead of this, the magnetron extracted from microwave oven along with its power supply circuit may also be used. The waves generated by magnetron are passed through a waveguide. Further the microwaves from waveguide are guided to the antenna. Horn antenna attached with the waveguide is readily available. Once the microwaves are emitted from antenna, they are free to travel in space along with its assigned direction. This is the complete assembly of the transmitting section. For ground based system, the proposed distance between transmitter and receiver section may be taken between the ranges 0.5 to 1 km. The receiving section consists of receiving antenna, low pass filter, schottky diode and DC bypass filter. Receiving antenna receives the microwave signals coming from the magnetron and transmitting antenna. These microwaves then passed to low pass filter which allows signals having low frequencies only. Schottky diode acts as rectifying circuit which filters out the ripples present. The DC bypass filter bypasses only DC power. The complete assembly of the receiving section is called as rectenna.

4. Components Specifications and Operation

The components required are

4.1 Power Supply

In ground based model, for attaining better efficiency, the DC power that is to be transferred should be 1 kW or more. The source of DC power can be a transformer linked with voltage doubler/multiplier circuit or the magnetron extracted from microwave oven along with its power supply components may be an appropriate alternative.

4.2 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 [5]. However for space use, based on the same principle, special space magnetron is required.

4.2.1 Construction

Figure 3 shows the cut view of magnetron. It consists of a cathode which is placed at the centre. A ring shaped anode surrounds the cathode. In anode structure, there are resonant cavities. A permanent magnet is placed beneath the anode which produces magnetic field along the length of the cathode. The resonant cavities present in anode structure are channelled at one end of the magnetron where the produced microwaves are collected. This channelled section is called as a waveguide.

4.2.2 Working

Generally, in microwave magnetron the maximum anode voltage is 4.5kV and the maximum cathode filament voltage is 3.75 V AC. There is a heated cathode at the centre. Hence electrons are released from it by the process called 'Thermo Ionic Emission'.

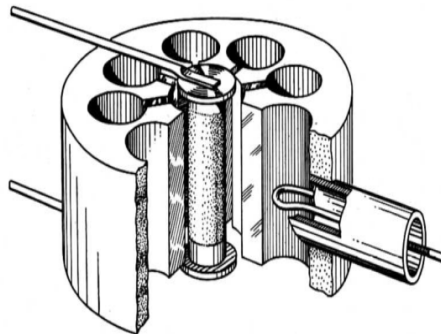


Fig. 3 MAGNETRON

The liberated electrons will try to move towards anode. But, because of the crossed electric and magnetic fields, they move in a circular path around anode. As they move in a circular path they pass the cavities of the anode. The cavities thus resonate and emit microwave radiations. Microwaves from all the cavities are summed up in a channel at the end of the tube. Hence, in this way the microwaves are collected from the one end of the magnetron.

4.2.3 Specifications

Table 1: Magnetron Ratings (Source: LG electronics) [6]

	Minimum	Maximum	Unit
Filament voltage	2.85	3.75	V AC
Peak Anode Voltage	-	4.5	kVp
Output Frequency	2.45	2.75	GHz

4.3 Waveguide

Waves are confined in a waveguide because of total reflection from its inner surface. Magnetrons also have its internal waveguide but for desired wave's area, an external waveguide is required. Waveguides are of different types depending upon their applications.

4.4 Transmitting and receiving antennas

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.

For understanding concept of directivity, it is important to understand an isotropic radiator. An isotropic radiator is defined as a hypothetical lossless antenna having equal radiation intensity in all directions [7]. Although such an antenna is an idealization, it is often used as a reference to express the directive properties of actual antennas. Its radiation intensity U_0 is expressed as,

$$U_0 = \frac{P_r}{4\pi} \tag{1}$$

Where,

P_r = power radiated by the antenna.

Directivity is the figure of merit of an antenna. Directivity is “the ratio of the radiation intensity in a given direction from the antenna to the radiation energy averaged over all directions”. From eq. (1), directivity D can be written as,

$$D = \frac{U(\theta, \phi)}{U_0} = \frac{U(\theta, \phi)4\pi}{P_r} \tag{2}$$

Where,

$U(\theta, \phi)$ = radiation intensity in the direction θ, ϕ .

Gain is probably the most important figure of merit of an antenna. It is defined as “ratio of the radiation intensity in the given direction, to the radiation intensity that would be obtained if the power accepted (input) by the antenna were radiated isotropically.”

From eq. (1), gain is given as,

$$G = \frac{U(\theta, \phi)}{U_0} = \frac{U(\theta, \phi)4\pi}{P_a} \tag{3}$$

Where,

P_a = accepted (input) power to the antenna.

From eq. (2) and eq. (3), the difference between directivity D and gain G is that directivity is based on radiated power and gain is based on accepted (input) power of an antenna. Since the complete input power is not radiated because of losses, the radiation efficiency (ϵ_r) of an antenna is given by,

$$\epsilon_r = \frac{P_r}{P_a} \tag{4}$$

In the receiving section for space based system; the parabolic antenna can be used whereas for the receiving section of ground based model, a horn antenna may be used for a microwave band above 1 GHz. H plane, E plane and pyramidal horn are the three basic types of horn antennas. Out of these, the pyramidal horn antenna is popularly used in microwave frequency ranges from 1 GHz to 18 GHz. The pyramidal horn antenna is shown in figure 4.

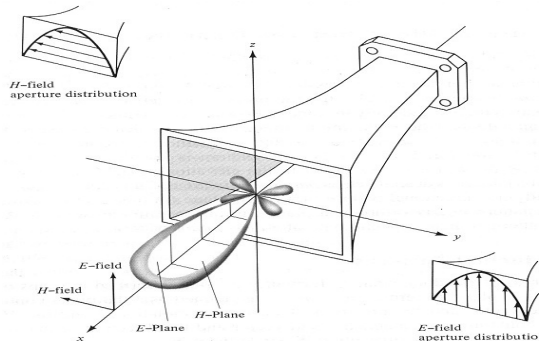


Fig. 4 PYRAMIDAL HORN ANTENNA

4.5 Receiving Section

The rectenna assembly is designed for a frequency of 2.45 GHz. The word rectenna is derived from two individual words, namely rectifier and antenna. The microwaves from the antenna are rectified and filtered. The block diagram of receiving section is shown in figure 5.

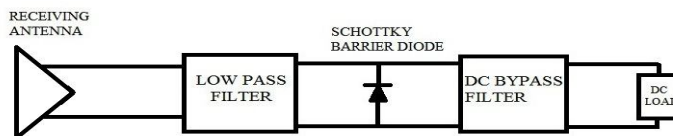


Fig.5 BLOCK DIAGRAM OF RECEIVING SECTION

The DC bypass filter acts as a smoothing filter as it filters out the ripples present in the rectified output from schottky diode. Schottky diodes utilizing silicon and Gallium Arsenide should be used because the rectification efficiency for these diodes is greater than 80%. The diode cut off frequency is given by,

$$f_c = \frac{1}{2\pi R_s C_j} \quad (5)$$

Where,

R_s = series resistance and

C_j = junction capacitance.

5. Experimental Results

W. C. Brown was the pioneer in the field of microwave power transmission (MPT) [8]. Based on the discovery of the magnetron tubes, W. C. Brown started the research on microwave power transmission and developed rectenna. He succeeded in developing wired helicopter in 1964 and to free-flied the helicopter in 1968. The photograph in figure 6 shows the laboratory experiment of MPT.



Fig. 6 MPT LABORATORY EXPERIMENT BY W. C. BROWN IN 1975

In 1975, W. C. Brown and his team succeeded in the largest MPT demonstration at the Venus Site of JPL Goldstone Facility shown in figure 7. Distance between parabolic transmitting antenna and receiving rectenna was 1 mile [8]. The transmitted microwave of 2.388 GHz was 450 kW from klystron and achieved DC power was 30 kW DC with rectifying efficiency of 82.5%.



Fig. 7 FIRST GROUND TO GROUND MPT EXPERIMENT AT VENUS SITE OF JPL GOLDSTONE FACILITY

6. Conclusion

The solar powered satellite transmitting power to the earth wirelessly is expected to be the central attraction of space and technology in coming decades. This concept promises to bridge the gap between the existing power generation and demand. The use of solar cells in space achieves 24 hour sunlight and are unaffected by atmosphere and clouds. The power generated is estimated to be approximately 3 to 4 times more that that can be produced on ground. It needs further study to explore its applications and biological impacts. These technologies will be verified in the ground demonstration within several years and will be fully verified in the space experiments within 10 years.

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