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Solar Power Transmission (Wireless) Through Satellites (SPS)

Mrs. G.Kavitha[1]
Technical Assistant
JNT University Hyderabad
Hyderabad, TS, India
kavitha.gugulothu@gmail.com

Dr.B Balu Naik[2]
Professor, Department of Mechanical Engineering
JNT University Hyderabad
Hyderabad, TS, India
banothbn@rediffmail.com

Abstract: **This paper reports on the futuristic advances in power transmission through microwaves. Sun is a limitless source of energy. A space power satellite (sps) orbiting round the earth traps solar energy & generates electric power using photovoltaic cells of sizable area. Sps transmits the generated power via a microwave beam to the receiving rectenna site on earth. A rectenna (rectifying antenna) comprises of a mesh of dipoles & diodes for absorbing microwave energy from a transmitter & converts it into electric power. We can in fact directly convert solar energy into electrical energy with the use of solar cells, but this process will be affected by day/night cycles, weather, & seasons. We are aware of the fact that light is an electromagnetic wave. Light rays never diffuse in space & if by any means these rays can be transmitted from space to earth then it will be a perfect solution for our desired need of 24 hrs power supplies. The approaches for establishing human race in space can come true only if the basic requirement of human beings is satisfied i.e. 24HRS power, which can be efficiently served by rectenna. A wireless power transmission using microwave is a system which contains satellite based solar power system (SPS). The use of solar cells in space achieves 24 hour sunlight & are unaffected by atmosphere & clouds. The power generated is estimated to be approximately 3 to 4 times more than that can be produced on ground. The DC power received on earth is converted into AC for various useful purposes. My concept is a comprehensive study of various components of satellite based SPS & projects this technology as a bulk source of power generation in future.**

Keywords: **WPT, RF, JAXA, SPS, Antenna, Rectenna, SBSP, Cells**

1. INTRODUCTION

The present electricity generation system is not very efficient in terms of energy transfer. About 20 to 30% energy is lost during the distribution of the electricity. Therefore the scientists are working on the projects to improve the ultimate electricity supply. Scientists are looking for alternate & efficient technologies to provide 100% electricity transfer. The change & development in the various fields have brought more client satisfaction & output. Therefore the wireless transmission of electricity is also on move .

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. The prediction & evidence of the radio wave in the end of 19th century was start of the wireless power transmission. During the same period of Marchese G. Marconi & Reginald Fessenden who are pioneers of communication via radio waves. Nikola Tesla is known as the father of wireless transmission. The most famous wireless technology known as Wardenclyffe tower also known as the Tesla tower is the first was designed merely for wireless transmission of electricity. He made electric coil which was a 3 feet diameter ball at its top. He fed300 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.

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, & 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 peoples in an adequate way & still leave our Earth with a livable environment. Hence, a major task for the new century will be to develop sustainable & environmentally friendly sources of energy.

Projections of future energy needs over this new century show an increase by a factor of at least two & one Half, perhaps by as much as a factor of five. All of the scenarios from references indicate continuing use of fossil sources nuclear, & large hydro. However, the greatest increases come from "new renewable" & all scenarios show extensive use of these sources by 2050. Indeed, the projections indicate that the amount of energy derived from new renewable by 2050 will exceed that presently provided by oil & gas combined. This would imply a major change in the world's energy infrastructure. It will be a Herculean task to acquire this projected amount of energy. Thus, unlike systems for the terrestrial capture of solar, a space-based system would not be limited by the vagaries of the day-night cycle. Furthermore, if the transmission frequency is properly chosen, delivery of power can be carried out essentially independent of weather conditions. Thus Space Solar Power could provide base load electricity.

2. WIRELESS ELECTRICITY TRANSMISSION (WET) TECHNOLOGY

Wireless power transmission [4, 5] 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 & there is no need to use cables, towers & grid stations [4, 5]. There are three methods or approaches which can be developed. These are as given below:

2.1. Short range (Induction): This ranges few centimetres e.g. transformer in which transfer takes place due to mutual induction [4, 5].
2.2. Moderate range (Adaptive Inductive Coupling) Witricity [2] (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, & 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 [4, 5].

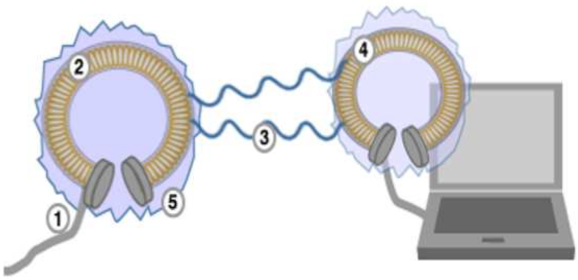

Figure 1. Working of Wireless Electricity.

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

2.3. 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 [4, 5]. There are many new techniques but we use only two here.
2.3.1. By using Solar Power Satellite (SPS). This task is often completed by using solar power satellite (SPS) [6, 7], 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. 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 & 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 & 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 & through this act we can buy electricity according to our need.
2.3.2. By using WET Technology (Without SPS). Another method is very simple. We can produce electricity at MGS by (hydropower, Thermal ,Wind, Solar) & convert this electricity into microwaves by using inverse rectennas or Microwave generator & transfer it to base grid station(BGS) so called RECTENNA through transmitting Antennas & from here electricity is transmitted to home wirelessly likewise as explained in section 2.3.1.
2.4. Component detail of WET Technology The Primary components of Wireless Power Transmission are Microwave Generator, Transmitting antenna & Receiving antenna (Rectenna).
2.4.1. Microwave Generator. The microwave transmitting devices are classified as Microwave Vacuum Tubes (magnetron, klystron) & Microwave Power Module (MPM)) & Semiconductor Microwave transmitters & amplifiers (GaAs MESFET, SiC MESFET, HFET, & InGaAs). Cooker type Magnetron is widely used for experimentation of WPT.
2.4.2. Transmitting antenna. The slotted wave guide antenna, micro strip patch antenna, & parabolic dish antenna are the most popular type of transmitting antenna. The slotted waveguide antenna is ideal for power transmission because of its high aperture efficiency (> 95%) & high power h&ling capability.
2.4.3. Rectennas. A rectenna is a rectifying antenna; a special type of antenna that is used to directly convert microwave energy into DC electricity. This concept is discussed in SPS detail.

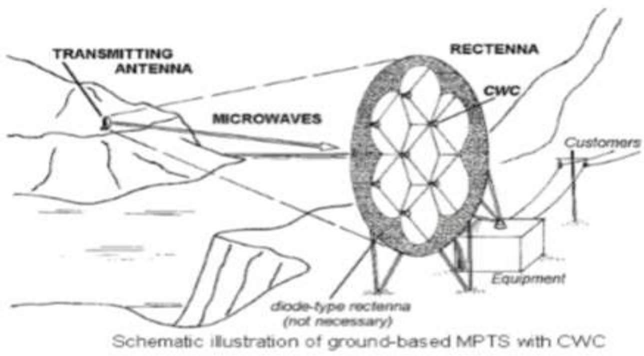

Figure 2. Detail of MPTS.

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2.5. Component details of WET using SPS system The primary components of WET using SPS involve microwaves, solar power satellite, rectenna, dengyo, etc.

2.5.1. Microwaves. Microwaves [3] are electromagnetic waves with wavelengths ranging from as long as one meter to as short as one millimeter, or equivalently, with frequencies between 300 MHz (0.3 GHz) & 300 GHz. For Wireless power transfer we use high power microwaves namely 1-10GHz radio-waves [3, 4, 8].

2.5.2. Microwave power transmission (MPT). Microwave power transmission (MPT) [7, 9] is the use of microwaves to transmit power through outer space or the atmosphere without the need for wires. It is a sub-type of the more general wireless energy transfer methods. Microwaves are widely used for point-to-point communications because their small wavelength allows conveniently-sized antennas to direct them in narrow beams, which can be pointed directly at the receiving antenna [4, 5]. This allows nearby microwave equipment to use the same frequencies without interfering with each other, as lower frequency radio waves do. Microwave Power transfer (MPT) [2.45 GHz or 5.8GHZ] of ISM b& is used. (ISM= Industry, Science & Medical).

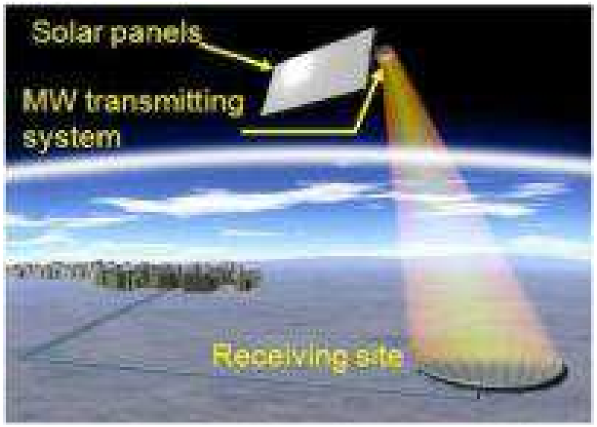

Figure 3. Microwave Power Transfer.

2.5.3. Solar Power Satellites. Space-based solar power (SBSP) [6, 7] 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 & Large antenna array to beam down (Microwave) power to ground [6, 7].

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

SPS will be expected to operate in 2025-2030.

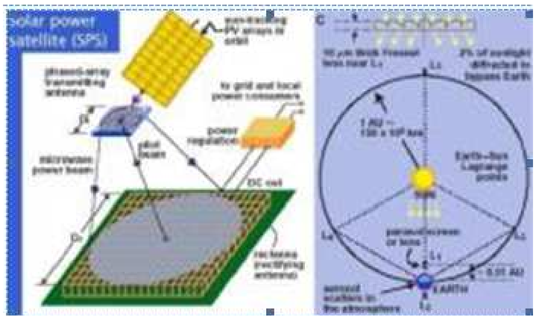

Figure 4. SPS detailed review.

2.5.4. Rectennas. A rectenna [7, 9] is a rectifying antenna, a special type of antenna that is used to directly convert microwave energy into DC electricity. Its elements are usually arranged in a multi element phased array with a mesh pattern reflector element to make it directional. Rectennas are being developed as the receiving antennas in proposed microwave power transmission schemes, which transmit electric power to distant locations using microwaves. Rectennas are used in RFID tags; the energy to power the computer chip in the tag is received from the querying radio signal by a small rectenna. One possible future application is a receiving antenna for solar power satellites.

A simple rectenna element consists of a dipole antenna with a Schottky diode placed across the dipole elements. The diode rectifies the AC current induced in the antenna by the microwaves, to produce DC power. Schottky diodes are used because they have the lowest voltage drop & highest speed & therefore waste the least amount of power due to conduction & switching. Large rectennas consist of an array of many such dipole elements.

Rectennas are highly efficient at converting microwave energy to electricity. In laboratory environments, efficiencies of over 85% have been observed. Some experimentation has been done with inverse rectennas, converting electricity into microwave energy, but efficiencies are much lower only in the area of 1%. Rectenna conversion efficiencies exceeding 95% have been realized. The efficiency of first Rectenna in 1963 was 50% at output 4W DC & 40% at output 7W DC respectively.

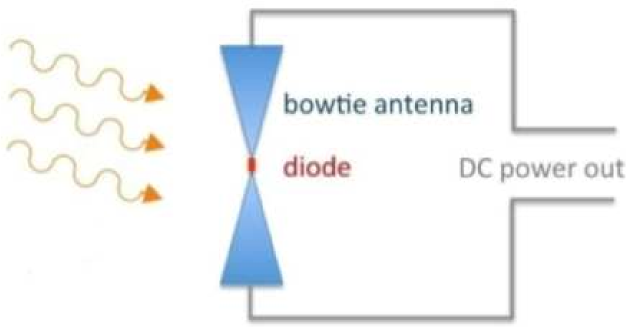

Figure 5. Rectenna.

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2.5.5. Dengyo Dengyo newly developed a microwave-b& rectenna & a rectifier circuit & achieved a power conversion efficiency of 90% or higher in the 2GHz b&. Dengyo has its strengths in antenna & filter technologies. & the company utilized its know-how in the development of the new technology though it did not disclose details. By using a low-loss filter, it reduced the reradiating of spurious waves from the rectifier circuit to -50 dBc or less.

With the high conversion efficiency, it becomes possible to convert electric waves that have not so far been used by devices using high frequency waves into electricity. Specifically, when the new technology is applied to a microwave heating device, energy that has been discharged as heat can be recycled. & the power consumption of such a device can be reduced by up to 40%.

Because the new technology uses electric waves, electricity can be fed to a distant place. Also, by combining a wireless sensor & the rectenna, it becomes possible to collect data by activating the sensor only when it is necessary. As a result, it eliminates the needs for power wires & primary batteries for wireless sensors.

Nihon Dengyo Kosaku Co Ltd (Dengyo) announced May 16, 2011, that it has developed a technology to convert electric wave into electricity with high efficiency. Specifically, Dengyo achieved a conversion efficiency of 90% or higher by using a rectenna technology that converts the energy of microwave into direct-current (DC) electricity, it said. The company expects that the new technology will be used to reduce the power consumption of microwave heating devices, harvest energy, etc. This time, Dengyo newly developed a microwave-b& rectenna & a rectifier circuit & achieved a power conversion efficiency of 90% or higher in the 2GHz b&.

Figure 6. Dengyo.

3. THEORETICAL BACKGROUND

It is known that electromagnetic energy also associated with the propagation of the electromagnetic waves. We can use theoretically all electromagnetic waves for a wireless power transmission (WPT). The difference between the WPT & communication systems is only efficiency. The Maxwell's Equations indicate that the electromagnetic field & its power diffuse to all directions. Although we transmit the energy in the communication system, the transmitted energy is diffused to all directions. Although the received power is enough for a transmission of information, the efficiency from the transmitter to receiver is quiet low. Therefore, we do not call it the WPT system.

Typical WPT is a point-to-point power transmission. For the WPT, we had better concentrate power to receiver. It was proved that the power transmission efficiency can approach close to 100%. We can more concentrate the transmitted microwave power to the receiver aperture areas with taper method of the transmitting antenna power distribution. Famous power tapers of the transmitting antenna are Gaussian taper, Taylor distribution, & Chebychev distribution. These taper of the transmitting antenna is commonly used for suppression of sidelobes. It corresponds to increase the power transmission efficiency. Concerning the power transmission efficiency of the WPT, there are some good optical approaches in Russia[5][6].

Future suitable & largest application of the WPT via microwave is a Space Solar Power Satellite (SPS). The SPS is a gigantic satellite designed as an electric power plant orbiting in the Geostationary Earth Orbit (GEO). It consists of mainly three segments; solar energy collector to convert the solar energy into DC (direct current) electricity, DC-to-microwave converter, & large antenna array to beam down the microwave power to the ground. The first solar collector can be either photovoltaic cells or solar thermal turbine. The second DC-to-microwave converter of the SPS can be either microwave tube system &/or semiconductor system. It may be their combination. The third segment is a gigantic antenna array. Table 1.1 shows some typical parameters of the transmitting antenna of the SPS. An amplitude taper on the transmitting antenna is adopted in order to increase the beam collection efficiency & to decrease sidelobe level in almost all SPS design. A typical amplitude taper is called 10 dB Gaussian in which the power density in the center of the transmitting antenna is ten times larger than that on the edge of the transmitting antenna.

The SPS is expected to realize around 2030. Before the realization of the SPS, we can consider the other application of the WPT. In resent years, mobile devices advance quickly & require decreasing power consumption. It means that we can use the diffused weak microwave power as a power source of the mobile devices with low power consumption such as RF-ID. The RF-ID is a radio IC-tug with wireless power transmission & wireless information. This is a new WPT application like broadcasting.

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Table 1 Typical parameters of the transmitting antenna of the SPS

Model	Old JAXA model	JAXA1 model	JAXA2 Model	NASA/DOE model
Frequency	5.8 GHz	5.8 GHz	5.8 GHz	2.45 GHz
Diameter of transmitting antenna	2.6 km^	1 km^	1.93 km^	1 km^
Amplitude taper	10 dB Gaussian	10 dB Gaussian	10 dB Gaussian	10 dB Gaussian
Output power (beamed to earth)	1.3 GW	1.3 GW	1.3 GW	6.72 GW
Maximum power density at center	63 mW/ cm^2	420 mW/cm^2	114 mW/cm^2	2.2 W/ cm^2
Minimum power density at edge	6.3 mW/ cm^2	42 mW/ cm^2	11.4 mW/cm^2	0.22 W/ cm^2
Antenna spacing	0.75 k	0.75 k	0.75 k	0.75 k
Power per one antenna (Number of elements)	Max. 0.95 W (3.54 billion)	Max. 6.1W (540 million)	Max. 1.7 W (1,950 million)	Max. 185 W (97 million)
Rectenna Diameter	2.0 km^	3.4 km^	2.45 km^	1 km^
Maximum Power Density	180 mW/cm^2	26 mW/cm^2	100 mW/cm2	23 mW/cm^2
Collection Efficiency	96.5 %	86 %	87 %	89 %

JAXA: Japan Aerospace Exploration Agency, NASA: National Aeronautics & Space Administration, DOE: U.S. Department Of Energy.

4. BASIC STRUCTURE OF SOLAR POWER SATELLITE

The concept of the Solar Power Satellite (SPS) is very simple. It is a gigantic satellite designed as an electric power plant orbiting in the Geostationary Earth Orbit (GEO) as shown in Fig. 1. & fig 2. It consists of mainly three segments.

1) Solar energy collector to convert the solar energy into DC (direct current) electricity
2) DC-to-microwave converter.
3) Large antenna array to beam the microwave power to the ground.

The solar collector can be either photovoltaic cells or a solar thermal turbine.

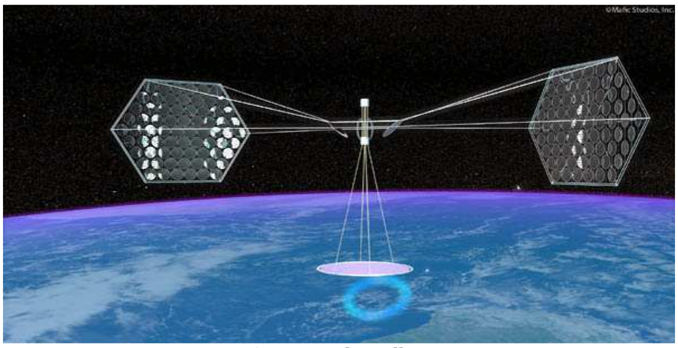

Figure7. Solar collectors

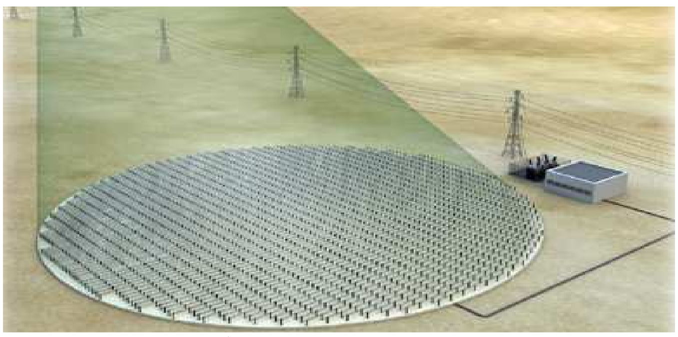

Figure8. Receiving antenna

The DC-to-microwave converter of the SPS can be either a microwave tube system or a semiconductor system, or their combination. The third segment is a gigantic antenna array. The SPS system has that advantage of producing electricity with much higher efficiency than a photovoltaic system on the ground.

Since SPS is placed in space in GEO, there is no atmospheric absorption, the solar input power is about 30% higher density than the ground solar power density, & power is available 24 hours a day without being affected by weather conditions.

It is confirmed that the eclipses would not cause a problem on a grid because their occurrences are precisely predictable.

5. TRANSMISSION

Solar power from the satellite is sent to Earth using a microwave transmitter. This transmission is transmitted to the relevant position via an antenna. The transmission is transmitted through space & atmosphere & received on earth by an antenna called the rectenna. Recent developments suggest using laser by using recently developed solid state lasers allow efficient transfer of power. A range of 10% to 20% efficiency within a few years can be attained, but further experimentation still required taking into consideration the possible hazards that it could cause to the eyes.

In comparison to laser transmission microwave transmission is more developed, has high efficiency up to 85%, beams is far below the lethal levels of concentration even for a prolonged exposure. The microwave transmission designed has the power level well below the international safety st&ard (Frequency 2.45 GHz microwave beam).

The electric current generated from the photovoltaic cells is passed through a magnetron which converts the electric current to electromagnetic waves. This electromagnetic wave is passed through a waveguide which shapes the characteristics of the electromagnetic wave. Effectiveness of Wireless Power Transmission (WPT) depends on many parameters.

Only a part of WPT system is discussed below, which includes radiating & receiving antennas & the environment between them. The wave beam is exp&ed proportionately to the propagation distance & a flow power density is increased inversely proportional to the square of this distance. However the WPT has some peculiarities, which will be mentioned here. WPT systems require transmitting almost whole power that is radiated by the transmitting side. So, the useful result is the power quantity at the receiving antenna, but not the value of field amplitude as it is usually required. Efficiency of WPT systems is the ratio of energy flow, which is intercepted.

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6. SOLAR POWER SATELLITE

There are several advantages to SPS. Solar radiation can be more efficiently collected in space, where it is roughly three times stronger than on the surface of the Earth & it can be collected 24 hours per day (since there are no clouds or night in high Earth orbit). SPS does not use up valuable surface area on the Earth & can be beamed to areas with the highest dem& at any particular time. Most of these systems would utilize photovoltaic (PV) cells similar to those on Earth-based systems (such as those used by home power systems & highway sign panels). Others would utilize reflectors & mechanical collectors similar to those used in special large-scale solar facilities in France & the California desert (Barstow).

Most of these systems collect solar energy in space & transmit it via a microwave energy beam to an Earth-based rectenna which converts the beam into electricity for use on Earth. In fact, telephone companies have been beaming microwaves through the atmosphere for over thirty years without any known problems.

High launch costs, which can run roughly between $1,000 to$10,000 per pound, are the greatest barrier to the development of SPS. Most SPS proposals require launch costs of about $200 per pound to compete with your local utility company . However, growing dem& for electric power could outstrip traditional production capability, driving prices up to the point where SPS would be competitive. If limits on producing electricity by burning coal (in order to reducepollution) are enacted, SPS could become competitive even earlier. Four basic steps involved in the conversion of solar energy to electricity & delivery
are:

- Capture solar energy in space & convert it to electricity
- Transform the electricity to radio frequency energy & transmit it to Earth
- Receive the radio frequency energy on Earth & convert it back to electricity
- Provide the electricity to the utility grid

7. LEO instead of GEO

A collection of LEO (Low Earth Orbit) space power stations has been proposed as a precursor to GEO (Geostationary Orbit) space power beaming systems. There would be both advantages (much shorter energy transmission path lengths allowing smaller antenna sizes, lower cost to orbit, energy delivery to much of the Earth's surface, assuming appropriate antennas are available, etc.) & disadvantages (constantly changing antenna geometries, increased debris collision difficulties, requirement of many more power stations to provide continuous power delivery at any particular point on the Earth's surface, etc.).

It might bepossible to deploy LEO systems sooner than GEO because the antenna development would take less time, but it would certainly take longer to prepare & launch the number of required satellites. Ultimately, because full engineering feasibility studies have not been conducted, it is not known whether this approach would be an improvement over a GEO installation.

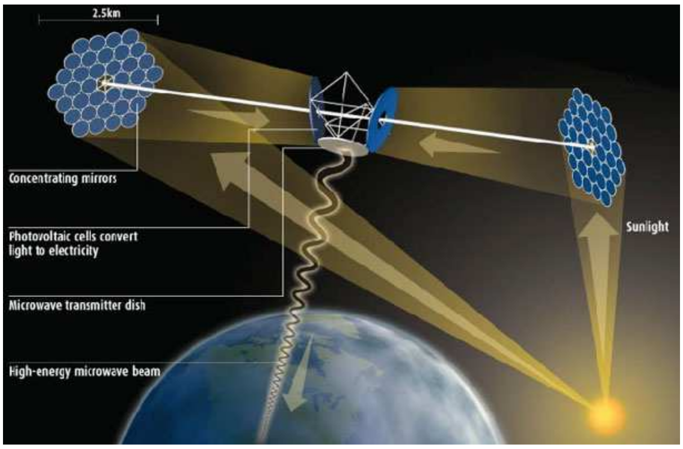

Figure9: Solar power satellite

8. MERITS & DEMERITS

8.1. Merits The major benefits are as follows:

- Remove physical infrastructure "Grids & Towers" [1].
- Cost effective (Remove cost of towers & cables).
- During rain & after natural disaster it is often hard to manage cables & towers so it removes this.
- Losses during transmission & distribution can be removed.
- Microwaves (electricity) are more environments friendly. It does not involve emission of carbon gases.
- Electricity bills using conventional supply can be cut to very low.
- Zero fuel cost [1].

8.2. Demerits

- Biological effects associated with the wireless transmission of electricity due to the high frequency microwave signals is the first demerit of this technology [1, 7].
- This project is a onetime expense but it involves a lot of initial expenditure. It is expected that the price of receive electricity through this technology would decline overtime [7].
- This technology is limited to the use of few technologies like solar satellites & Tesla grid.
- The transmission of electric current through this mode is susceptible to security risks like cyber war fare [1].

9. CONCLUSION

This paper provides an overview about the most under discussion technology nowadays. In this paper we, not only tried to overcome the current issues but also discussed the pros & cons of WET technology. Through this paper we have tried to inculcate the concept of Wireless electricity Power transmission in the mind of readers that by utilizing the power of this technology fully, we can get an efficient, cost effective, wireless(free from wires),losses free environment. Fossil fuel electric power plants generate greenhouse gases which are responsible for global warming. Wireless electricity transmission can overcome these problems well. In the nutshell, this technology will change the concept of Electricity in near future & make people able to acquire the most efficient, effective, pollution free & healthy way of getting electricity.

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About the authors:

Mrs. G.Kavitha has completed her B.Tech in EEE Department from Mother Theressa College of Engineering and Technology, Karimnagar, JNTUH received her M.Tech in Energy System from JNTUH College of Engineering, Hyderabad, presently working as an Technical Assistant in the JNT University Hyderabad, TS, India.

Dr. B Balu Naik, Professor of Mechanical Engineering & Director, UGC-HRDC JNTUH, Kukatpally, Hyderabad has completed B.Tech. (Mech.) from J.N.T. University, Hyderabad in the year 1992, received his M.Tech. (Prod. Engg.) From J.N.T. University, Hyderabad in the year 1999, received his Ph.D. (Energy Systems) from J.N.T. University, Hyderabad in the year 2006.
Total Academic & Administrative Experience-23 Years.