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SOLAR ENERGY HARVESTING FROM SOLAR POWER SATELLITE

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Abstract- Electronic circuits are now commonly used and the need for power in the future will increase. Solar energy may be considered as substitute for conventional energy resources because of its renewability nature. But the earth receives only 1/100th of complete solar power. There are numerous satellites in space aimed at serving many applications on earth. A Satellite with a particular application for producing power from sun based radiation is proposed, which is utilized to communicate the put away energy to the ground station as microwaves (RF signal). These satellites are set in LEO/MEO so the sun oriented boards of satellite are towards the sun most piece of the day and harvests sun based energy. The Solar boards in the satellite gathers heat energy and changes to DC force and stores in a battery save. This DC power from the battery save is changed to RF energy of required recurrence utilizing a gadget called Magnetron and the changed over power is sent to earth station recieving wire, which is coupled to rectifier circuits that are masterminded as exhibit.Rectifier converts received power (RF) to energy (DC) that is stored in battery. The motive behind the proposed solar powered satellites is to get completely through environmental pollution which is because of the emission of harmful gases from thermal power plants. The proposed work also provides solution for global warming and easy energy generation using natural resource (Solar Energy).

Index Terms:- Rectenna, Solar Power Satellites, Photo Voltaic System, Rectifier, Microwave Wireless Power Transmission Technology, Free space loss

I. INTRODUCTION

It is estimated that a total energy of 56000 tera-watt hour is annually required worldwide. Nuclear power plants provide a vast amount of power, but disasters like Chernobyl nuclear accident (1986) in Russia and Fukushima nuclear accident in Japan (2011) **[1]** made the researchers think of an alternative method for power production. Solar power which is renewable and eco-friendly is the better way for producing power safely. Two methods are mainly employed in harvesting power from solar energy.

1) Terrestrial Solar Power system (TSP) and

2) Solar Power harvesting from space (SSP)

More energy is harvested from SSP, since solar flux density in space is much greater when compared to TSP. Solar power satellite is a giant satellite developed as an electrical power plant that orbits the earth using wireless power to transmit solar energy harvested using SSP method. **[13]**

Mainly four operational units are part of this satellite:

A. Photo Voltaic System used to convert captured solar energy to a DC power

B. System to convert DC power to RF waves.

Number of small antenna elements (Array) to transmit the Radio

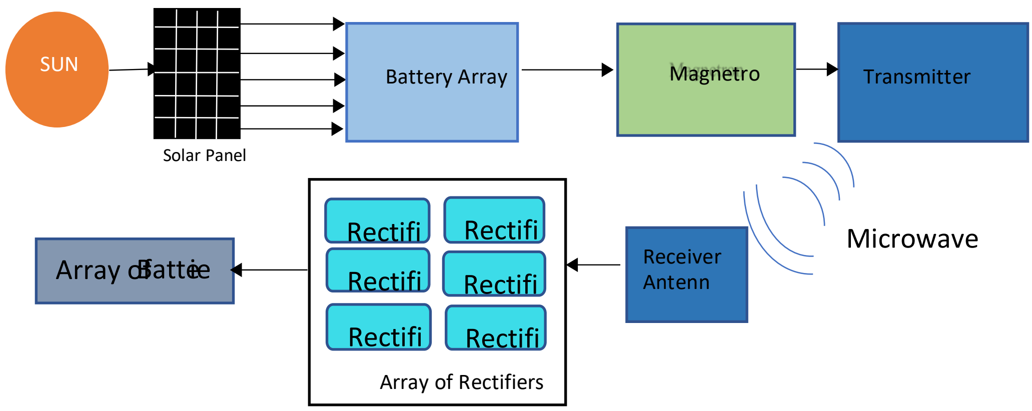

Fig.1 Block diagram of proposed SSP

II. LITERATURE SURVEY

Fossil fuels which are non-renewable pollute the environment and increase global warming. But, the energy from the sun is renewable resource. Solar power satellites have been suggested many years back, but these were not implemented because of several practical and technical roadblocks. Compared to the power produced by the photovoltaic system installed on Earth, the power generated from the satellite will be higher as the sun rays are intense in space. SSP concept incorporates a converter to transfer the collected power from space to the Earth station rectenna. The DC power from space is received as microwave beam (RF signal) by the Earth station. The survey on recent power generation techniques and its pros and cons are as follows:

James.C.Maxwell (1865) proves theoretically that electric field(E) and magnetic field(H) can travel together as waves in space at speed of light**[2]**. Based on Maxwell's work, Nikola Tesla (1890) practically proves that E-field and H-filed can travel through space.

Tesla (1891) experiments with the electrical energy transmission using a radio frequency resonant transformer which produced alternating currents of high voltage and frequency that helped in electrical energy transmission for few meters without using wires. The experiment also successfully verified that it is feasible to illuminate vacuum bulbs without the utilization of wires. **[5]**

W.C. Brown (1961) demonstrates a microwave-powered helicopter. The helicopter receives its power in the form of microwave beam for its flight **[27].** Brown (1967-1975) has successfully beamed 30Kilowatts of electrical energy over one-mile distance with an efficiency of 84%. **[3][17]** The proposed work applies SSP based on Brown's validated theory.

III. IMPLEMENTATION PROCESS OF SPACE SOLAR POWER GENERATION

Solar energy is received by solar panels and it is converted to DC power. After converting the Solar radiation to DC power, it is stored in a battery array. This stored DC energy is again converted to RF power for the purpose of transmission to Earth station antenna. To convert the stored DC power to RF power, three kinds of converters are seen as, for instance, magnetrons, klystrons, strong state enhancers. Among these, magnetrons have high productivity regarding power change . The magnetron's yield power is then given to the satellite transmitter fragment. The communicated power as RF signal is gotten by a low misfortune Half Mode Substrate Integrated Waveguide (HMSIW) rectenna at the earth station. A battery cluster are utilized to save the got power in the request for Giga watts. The detail process of methodology proposed is discussed in the forthcoming sections.

This paper compares the energy harvested using solar panels on earth and the energy harvested from space solar power system. Also, the proposed work proves that energy harvested using SSP is thrice that of the Terrestrial Solar Power (TSP) system. The amout of losses resulting from the satellite height is also analyzed. The magnetron's output power for different frequencies is also calculated and represented quantitatively. Fig.2 depicts the workflow of proposed

SSP

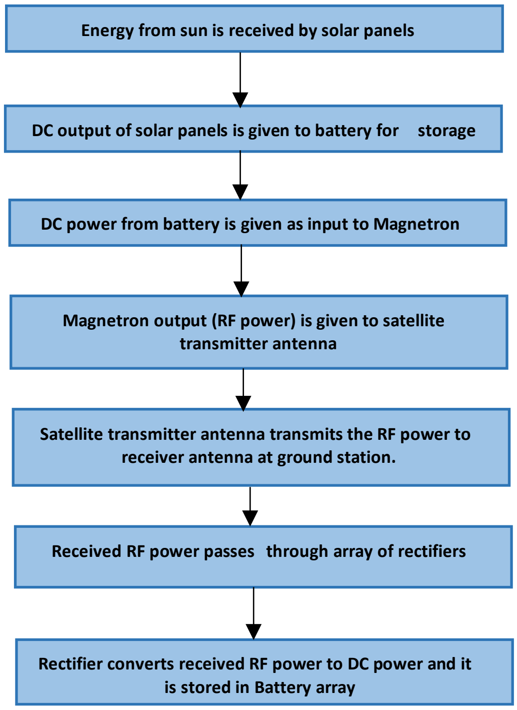

Fig.2 Workflow of the Space Solar Power System

IV. SPACE BASED SOLAR POWER SYSTEM

4.1 Gallium-Antimony (Ga-Sb) Based Solar Cells for harvesting solar power

A solar cell converts the photons from the sun to DC. Efficiency of solar cell(ɳ) given in equation (1) corresponds to the amount of incident solar energy which can be converted to electrical power in terms of percentage.

$$\eta = Pout/Pin (1)$$

P_{in} represents no.of photons incident on the solar cell

P_{out} represents the Direct Current (DC) output from the solar cell

Customary sun based cells are involved silicon and have a maxmium power age proficiency of 33.16 percent. Sunlight based cell execution is improved by sun oriented multi-intersection cells. A multi intersection sun oriented cell is thought to be made on a GaSb substrate that is induced with an improved force age productivity of 44.5%. Utilizing condition (2), the quantity of sun oriented cells and sunlight based board territory is determined based on the force necessity. Number of solar cells = $Area\ of\ Solar\ pane(Estimation)/Area\ of\ solar\ cell(in\ m)$ (2)

Area of a typical PV cell is $0.02233m^2$[7]. Photovoltaic(PV) systems are typically equipped with components called bypass diodes, which redirect the flow of current around impaired

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cells. If a single solar cell in panel is shaded, then overall current output of the PV system will decrease which causes power imbalance and may damage entire PV system [11]. So, to avoid the shading effect, the PV cells are given series connection for low power loss. In general, a satellite has fewer or more PV cells depending on the power requirement to run the satellite's devices / thrusters. The proposed SSP system do not utilize this harvested power for operation of any sensors or devices as this satellite is dedicated to bring all the harvested power to the ground station. Power obtained from a single solar cell is given in equation (3)

$$Ps = A \times \eta \times H \times PR (\text{in watts})$$

Where Ps= Power from single solar cell

A = Area of single solar cell

η = Efficiency of solar cell

H = Solar flux density (Watt/m2)

PR = Performance ratio (0.75)

The power of entire solar array is calculated knowing the power obtained from single solar cell. The converted solar energy is stored in the array of Lithium-ion batteries(LIB). LIBs are used due to lesser cost, lengthy life cycle and lower weight. **[8]**

4.2 DC power to RF conversion

As said above, a device called Magnetron is employed for the process of DC-RF wave conversion because of its good conversion efficiency. The conversion efficiency of magnetron was around 80% The working guideline of Magnetron depends on electrons interacting with the H-field. At the core of the magnetron, there consists of hot cathode in the shape of ring. Electrons moving at fast are beamed from the warmed cathode and go through anode.

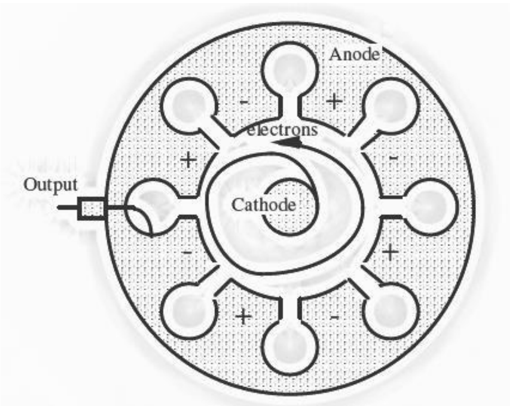

Fig.3 A Magnetron for converting Electric current to Microwave frequency

A resonator which has openings in it for input acts as anode for magnetron. A robust magnet to produce parallel magnetic field to cathode is provided beneath the anode. So, when an electron tries to pass from cathode to anode, they go through both electric field

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and magnetic field at a similar moment of time. When a particle having charge viz.,electron travels under the impact of a H-field, it takes curved path. The cavities resonate because of rapid movement of electrons in the interior of cavity and discharges microwave radiation. A magnetron is proposed which has power conversion efficiency of 75%. At an operating frequency (F) of 2.465GHz, it produced an output 1.04KW for an applied voltage 4.3Kv and anode current 0.33A. The specifications of the proposed magnetron are as follows: radius of cathode (a) is 0.0065m, radius of anode (b) is 0.0069m, magnetic field (B) corresponding to applied input is 0.19T and the no.of resonators (N) is 5 **[12]**. The power output relies upon the operating frequency, the H-field, the resonator number, the cathode and anode radius. The voltage yielded by the magnetron as output is calculated bu using equation (4)

Vo = 2nFB/N (b2.a2)

where 'a' is the cathode radius and 'b' is anode radius.
The output port of magnetron is connected to a coax cable which acts as bridge between magnetron and tuning waveguide section that is used for impedance matching with transmitter antenna. Fig.3 shows the schematic of a magnetron.

4.3 Microwave transmission from satellite to Earth

A 500m (diameter) phased array antenna is considered for microwave transmission from satellite to earth. Since the satellite orbits around earth, phase shifter is used to steer the microwave beam towards the receiver antenna at earth station. Transmitter efficiency is thought to be 80%. Antenna gain(dB) is determined reliant on the necessary efficiency by equation(5).

Gain(dB) = $4\Pi\eta A/\lambda 2$(5)

A=Area of transmitter antenna in meters ($\pi D2/4$) (6)
λ = Wavelength at operating frequency = C/F
C= Speed of light i.e., 3x108
F=Frequency (2.4GHz)
η = Efficiency of Antenna

V. ECONOMIC VIABILITY

The present satellites cost an enormous cost in acspect of the materials used to manufacture them. So as to make the satellite and space solar power financially savvy,APLPHA into 8

lightweight, easy-to-start, install and replace modules. This proposed system utilizes materials based on carbon nanotubes**[29]**.Carbon Nanotubes were utilized to lessen the heaviness of modules to significantly diminish costs**[28]**.
A magnetron that produces 2kW expenses around USD 50. Ground systems are expected to cost ~US$50 million. A single launch of satellite costs around US$135 million.The total expenses for launching, maintaining and entire equipment utilized is around US$337.5

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million. The satellite can pay for itself within 2years of operation by providing annual revenues more than US$120 million.

VI. RESULTS AND DISCUSSION

Table 1. Harvested power comparison: space vs ground

	Altitude		Area	Harvested Energy
Space	5000 Km	1366 W/m^2	200m^2	9Mw/day
		1366 W/m^2	300 m^2	20Mw/day
		1366 W/m^2		36Mw/day
Ground	Location	Sunlight Irradiance	Area	Harvested energy
	Global	3.92kWh/m^{2}day	1 km^2	1.58 Mw/day
	Western Australia	5.90kWh/m^{2}day	1km^2	2.36Mw/day

Table 2. Total kilowatt hour power harvested per day

	400m2 Panel	
	In Space (Per Day)	On Ground (Per Day)
1000Km	1.31Mwh	541Kwh
MEO	2.90Mwh	1.88Kwh
GEO	3.15Mwh	0.54Kwh

Table 3. RESULTS

Area of Solar Panel	400m^2
Area of single solar cell	0.0225m^2
Efficiency of single solar Cell	
Type of solar cell used	GaSb based
No. of solar cells in panel (as calculated)	1.7 x 10^6

Power obtained from single solar cell	10.25Wh
Magnetron operating frequency	2.465 GHz
Magnetron Output Power	26.5Mwh
Total Losses occurred during transmission	115.22dB
Received Power (for the entire day)	100Mw
Total DC power stored after conversion (for Day)	91Mw

VII. CONCLUSION

The increase of demand for power nowadays and increasing global warming because of traditional methods to generate power is the motive for concept of yielding power using solar energy which is abundant in our outer space and transfer the yielded power to earth wherever it is necessary wirelessly. This proposed and simulated concept offers outstanding prospects for space-to-earth solar power transmission with low power losses. The implementation work flow of power production and transmission from space to earth along with losses during transmission to earth is explained in detail. The calculation of antenna downtilt angle to reduce antenna pointing loss is also presented. Power crisis the world is facing today is solved by the proposed model. The estimated costs for implementing the SSP is presented in the paper. This paper proves that yielding power from outer space through solar energy has greater efficiency than terrestrial solar power harvesting from the outcome of simulation. This idea offers greater transmission power possibilities with losses that can be neglected and simplicity in transmission than other previously made invention or discovery

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