Design Study for a 5 GW Base Load Power Drawn from Satellite Solar Power Station

Deepak Kumar and Kalpana Chaudhary

Abstract In this work, satellite solar power station as base load plant model estimated analysis has performed. SSPS base load power plant for 5 GW model has investigated, and its feasibility prospects are studied. The SSPS essential components sizes have estimated for 5 GW power productions on the ground. A microwave power transmission with high beam efficiency approach is adopted in this work and beam energy effect on transmitting antenna size has examined.

Keywords Microwave · Power · Antenna · Rectenna · Satellite solar power station

1 Introduction

There is imperativeness crisis around the globe [1]. The possibility augmentation in the quantities of tenants in developing countries like "India" requires an exponential addition in the usage of essentialness, sustenance, resources. This way the condition in developing countries is falling apart due to nonappearance of essentialness resources. In India, power plants for the most part in perspective of conventional resources which give 80% of the total fundamental essentialness supply. This kind of electrical imperativeness transform technique has overall issues like an unsafe environment harming, physiological change and a quick decrease of fossil storehouse [2]. With time, India is gaining industrialized and computerized, so more electrical power need than other essentialness outlines.

We are scanning for ecologically well-disposed power imperativeness headways which do not release carbon dioxide into the air, or they are renewable. Natural

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Sun-based imperativeness; hydropower essentialness, wind imperativeness, and other renewable essentialness are reliable essentialness source [1, 2]. The Sun-based imperativeness is flawless essentialness. Sun-based imperativeness falling on the Earth each hour is adequate to give world essentialness yearly demand. Consequently, research is in advance of the time for growing modifies capability from natural Sun obtainable enlightenment and heat to electrical power [1–5]. There are moreover price related, and site condition issues in commercializing Sun influenced energy plants. Sun accessible radiance reduces while coming to the Earth. It cripples on shady or stormy days furthermore daylight is missing at evening time [2].

2 Overview of SSPS

In a satellite solar power station, space satellite collects Sun irradiance and photovoltaic transform it into electrical energy [1]. This electrical power changes into the microwave and transmitting that microwave power remotely to receiving antenna on the Earth. The receiving antenna associated rectifiers turn over microwave power back to electrical power [4]. This way, the space energy is available on the earth to supply in the commercial grid after appropriate dispensation [1–3]. Consequently, it is apposite to supplant routine wellsprings of imperativeness. In many aspects, SSPS rides over terrestrial Sun situated power due to unobstructed and undistorted daylight irradiance available in space. On the Earth-based solar framework, the SSPS has added three-cover increases in power accessibility. Regardless, SSPS has some development troubles and major cost-related issues to execute [3].

2.1 SSPS as a Base Load Power

There is an essential of the base load power plant as shown in Fig. 1, for the developing imperativeness sustainability [2]. Natural daylight-based power is brilliant for unpredictable power use, yet it is not sensible for base load power. On another side, the upside of SSPS is it can be utilized for base load demand. There is a necessity of large size rectenna on the Earth to gain power from space. The rectenna mounted ground is free for agriculture and diverse purposes [1].

SSPS Power cost could be viable or less costly than other essentialness sources. With the advancement to lessen the satellite dispatch cost and supplementary technology improvements, SSPS is feasible in coming future. An inventive advance in radio wave innovation is going on around the world in this direction [1, 2].

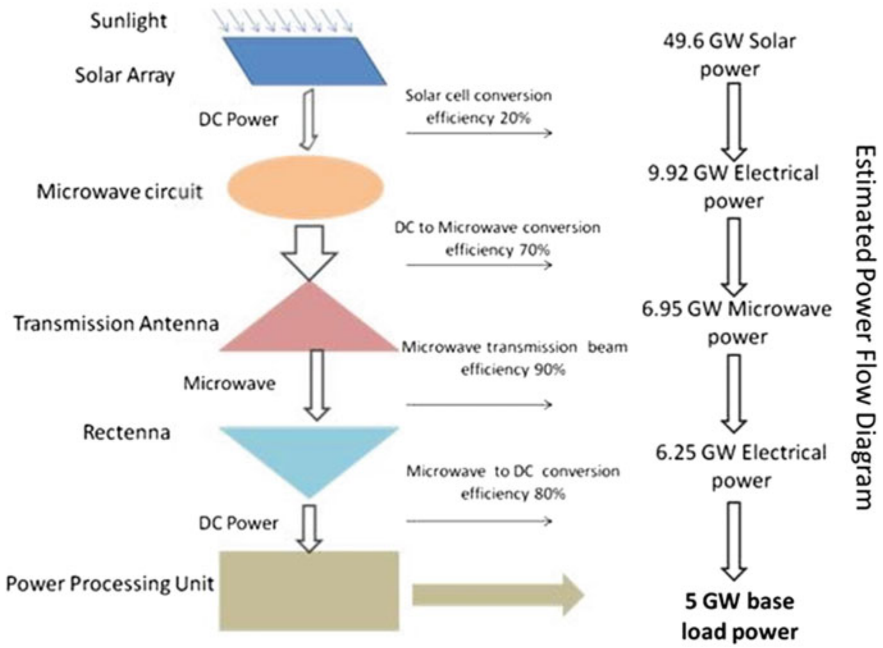

Fig. 1 A 5 GW SSPS base load plant model [1]

3 History of SSPS

SSPS advancement is in the creating stage. Diverse space workplaces are looking at and reported SSPS as a sustainable imperativeness source. In any case, there are various mechanical challenges and preservationist issues in SSPS application. The deep research was performed by NASA-DOE in the USA and gave reference model of SSPS [2]. In spite of the way that in 1997, the Fresh-Look-SSPS thought was a change in SSPS reference design. It gave “Sun Tower,” SSPS to have a couple of innovative approaches for managing to diminish SSPS operation and life cycle cost. In 2001, Japanese aeronautics examination association (JAXA) demonstrated 5.8 GHz 5 GW SSPS model using microwave development [6]. The preferred frequency 5.8 GHz is noticeable all around decreasing system dimension. The SSPS application in base load and non-base load power plant, a relative study, and examination were performed by “European space investigates office” in 2005. The study examined SSPS and land-based Sun arranged thermal with hydrogen stockpiling. It completes up, for far-reaching size (more than 5 GW), SSPS is conceivable and cost-related identical with land-based influence plant [5, 6].

4 SSPS Microwave Power Transmission Effects on the Atmosphere and Space

For the considered SSPS base load plant, the microwave transmission impacts in the space and environment must study. The microwave Power disaster on account of normal climatic ingestion over the partition from a geostationary hover to the ground is thought to be underneath 2% [7]. Along these lines, it is an insignificant condition in an air space if microwave arrangement prosperity and security purpose of repression is associated. At lower frequencies diminishing is more progressive in the atmosphere and at higher frequency ionosphere correspondence is more effectual. Radio waves are experiencing ionosphere diminished due to digestion as shown in Fig. 2. This wonder is called ohmic warming [7]. In subordinate level ionosphere, the higher electron density is accessible making more ohmic warming. Unfortunately, electron warming estimation on account of high power microwaves is not available in the written work, and merely speculative results had been presented. High-power microwave in space causes plasma waves. The reason behind plasma wave period is through full participation. Plasma Precariousness creates discretionary EM waves; these assistant waves support have electron warming effect and electron density irregularity [7, 8].

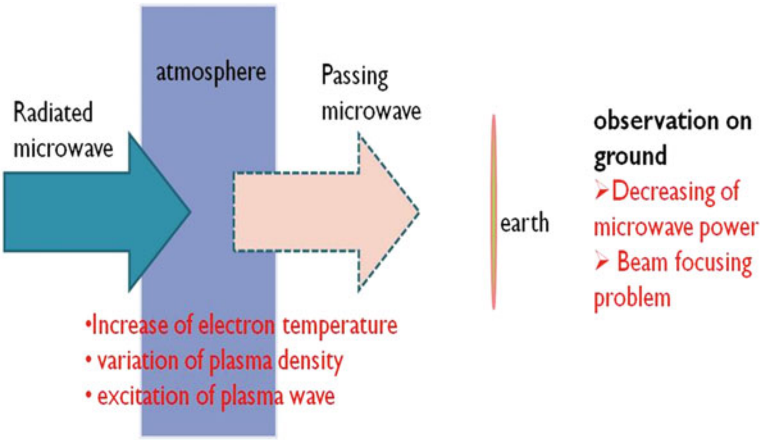

Fig. 2 Microwave transmission impact in space [8]

5 Estimation of 5 GW SSPS Base Plant Model

The consideration of SSPS 5 GW base load power has established in this work. In this condition, 5 GW of electrical imperativeness is offered on earth is acknowledged. There is ground rectenna yield electrical power; consider rectenna efficiency 80%. Therefore, 6.25 GW of microwave power is required on the ground rectenna site to convey this much electrical yield. The microwave compels of 6.25 GW on the ground transmitted from space satellite transmitting antenna. Assuming beam capability of 87%, the required microwave power at transmitting antenna is 6.95 GW. In space satellite, there is DC to microwave change units are available to change over DC power into the microwave. In this manner, required DC power is 9.92 GW for DC to microwave change efficiency 70%. Photovoltaic are used to change over Sun-based imperativeness into DC power in space. Photovoltaic have Sun situated essentialness to DC power transform adequacy of 20%. Therefore, 49.6 GW of Sun arranged imperativeness required at the space end. In this work, we consider 5 SSPS module of 1 GW power that collectively provides, 5 GW of electrical essentialness available on the earth.

5.1 SSPS Size Estimation

The photovoltaic array size required making 10 GW DC power yield is around 50 km^2 (5 km $\times$ 10 km). There is an unsavory estimation of photovoltaic array size need. To establish rectenna measurement, we have to consider microwave power density existing on the rectenna site. There is a microwave power density limit for human prosperity and security. The microwave presentation security limit picked by agencies is 10 mW/cm^2 [7].

Considering normal microwave power flux density at rectenna = 100 W/m^2 for 1 GW unit.

$$100\,\mathrm{W/m^2} \times \text{Rectenna area} = 1.25\,\mathrm{GW}$$

Therefore, rectenna diameter = 4 km (approximate size). However, we require 6 km diameter around considering Gaussian distribution.

5.2 Microwave Power Transmission

This work is to consider the transmission of 1.44 GW of microwave vitality from geostationary circle to the Earth for 1 GW base load control. The separation in between is 36,000 km.

Friis transmission equation [9]

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi D} \right)^2 \tag{1}$$

where G_t, G_r are the antenna gains, λ is the wavelength, and D is the distance between the antennas [9].

For microwave power transmission, Friis condition has commonly used. While applying the above Friis transmission condition, to send 5 GW microwave power from Geo partition to the Earth. The found out microwave power got on the earth surface is low 1.5 MW. In fact, notwithstanding for this circumstance, we consider high gain and directivity of transmitting and receiving antenna. For this situation to assemble 5 GW microwave power, the rectenna measure essential is 1000 km. The above situation is not reliable in a veritable case. Along these lines here we made a conclusion; The Friis transmission condition is not reliable for the circumstance [9–11]. Besides, it is merely applicable to the far field condition.

Transformed Friis transmission condition in near field condition [10]

$$\frac{P_r}{P_t} = \frac{A_t A_r}{\lambda^2 D^2} = \tau^2 \tag{2}$$

In the transformed transmission equation, one can look at getting power is greater than the broadcasting power for $\tau > 1$. These unfeasible conditions raise in light of the way that $D < 2d_t^2/\lambda$, this is the nearby field or Fresnel zone condition. In the nearby field condition

Beam Efficiency [10]

$$\eta = 1 - e^{-\tau^2} \tag{3}$$

For this circumstance, the beam profitability is varying in the range 80–90%; in this way, the estimation of τ gets the opportunity to be more than one [10].

$$\tau = \frac{\sqrt{A_t A_r}}{\lambda D} \tag{4}$$

6 Results and Discussion

In SSPS, transmit power from geo to the Earth; near field condition is kept up. Since in the near field condition, the transmitting antenna estimate relies on upon the frequency utilized. Concerning the higher frequency, the transmitting antenna dimension prerequisite declines. Hence, acknowledgment of higher frequency power transmission SSPS is financially beneficial, notwithstanding, there

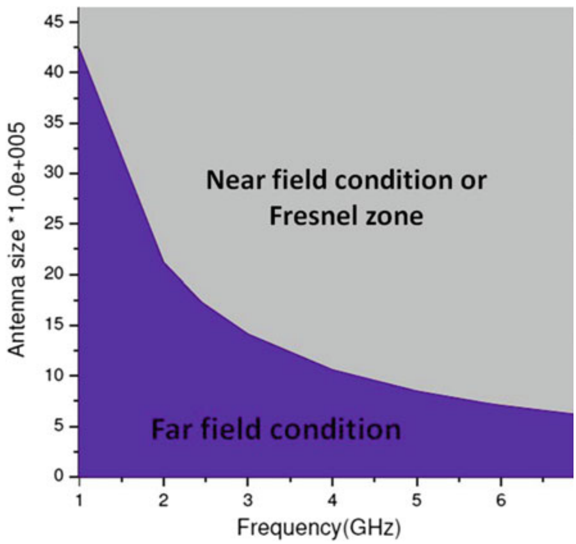

Fig. 3 Antenna size variation with frequency and near field region

are certain points of confinement in a practical situation [8]. In this way, frequency 2.45 and 5.8 are a predominant choice. Figure 3 illustrates near field operation region with frequency.

The microwave beam effectiveness is a significant feature in power transmission. For the state of exchange given power, the beam productivity, the receiving antenna estimate, the separation between and frequency will choose the transmitting antenna measure necessity [9]. In this work, one SSPS unit of 1 GW has considered and the rectenna effective area calculated values is 1×10^7 m^2. The transmitting antenna estimates deviation with the beam proficiency appears in Fig. 4. Figure 4

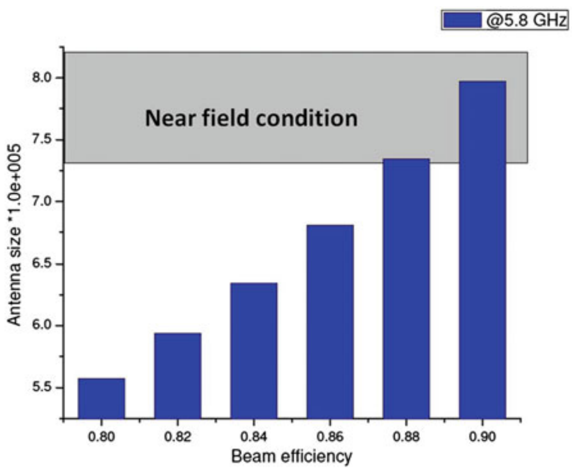

Fig. 4 Antenna size variation with beam efficiency

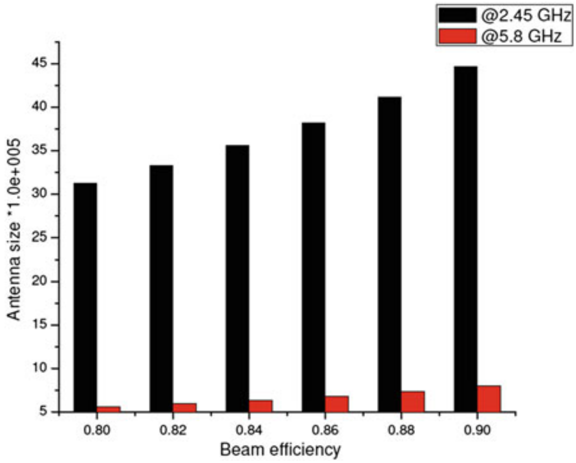

Fig. 5 Antenna size at 2.45 and 5.8 GHz

demonstrates the worthy esteem for transmitting reception apparatus measure that falls in the near field region. A comparison result for frequency 2.45 and 5.8 GHz appears in Fig. 5.

7 Conclusion

In this work, satellite solar power station as base load plant evaluated investigation has performed. For the ground section, the rectenna evaluated measure kept more than computed estimate considering Gaussian distribution. Space fragment photovoltaic size evaluated for continuous power supply of 5 GW on the ground. A microwave power transmission with high beam effectiveness approach embraced in this work and diverse ways conferred. The beam productivity is the critical parameter for choosing transmitting antenna measure. The regularly utilized Friis transmission condition for remote power transmission is not any more legitimate in this work as it lies in near field condition. For near field condition; transmitting antenna measure estimation utilizing reformed friis transmission condition gives exact results. The frequency 2.45 and 5.8, which is in the environmental window, is broadly decided for examination investigation. Along these lines, it has observed that 5.8 GHz frequency has cost-benefit more than 2.45 GHz in satellite solar power station.

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