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A Sunbeam: A Comprehensive Review of Wireless Microwave Power Transmission via Solar Power Satellites

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A B S T R A C T

Long-range microwave power transmission (MPT) has emerged as a solution for remotely powering satellites, drones, and mobile facilities, eliminating the need for a wired power network. However, challenges such as overall efficiency, robustness, and directional radiation (DR) persist, hindering its widespread application and further research. This paper addresses the key challenges in transmitter, directional radiation, and receiver design to ensure high efficiency and precise tracking for long-range MPT. Despite its complexity, the design of MPT systems remains an open research question. By focusing on existing constraints, this paper discusses current research topics, development trends, and design approaches proposed in the state of the art for long-range MPT. The significance of MPT in daily life applications is highlighted, and the current research status and development prospects are presented. A solar power satellite (SPS) is a renewable energy system designed to harness solar energy in space and transmit it to Earth using microwaves. Initially proposed in 1968 in the United States, the SPS concept has garnered increased public attention as a potential solution to global environmental and energy challenges. Microwave power transmission from geostationary orbit to the ground poses one of the most significant technological hurdles for SPS implementation. While microwave power transmission technologies have been under study for over 40 years since their initial demonstrations in the 1960s, significant research is still required, particularly in achieving high-efficiency power conversion between direct current (DC) and radio frequency (RF), as well as ensuring precise microwave beam control over long distances. This paper provides an overview of the SPS concept, discussing the associated technologies and challenges related to microwave power transmission from space to the ground. Additionally, it highlights the current research status and outlines future development prospects for microwave power transmission, aiming towards the commercial utilization of SPS technology.

Keywords: Long-range microwave power transmission, Satellites, Wired power network, Robustness, Directional radiation (DR), Transmitter design, Receiver design, Development trends, Solar power satellite (SPS), Renewable energy, Solar energy, Geostationary orbit, Microwave power transmission (MPT), Direct current (DC), Radio frequency (RF), Power conversion efficiency, Microwave beam control, Commercial utilization.

1. Introduction

The conventional method of wired power transmission stands as a cornerstone in the advancement of the electrical era, being widely adopted for its reliability. Through transmission cables, energy from significant sources fuels various industries. However, as technology progresses and human lifestyles evolve, the shortcomings of traditional wired transmission become increasingly conspicuous: rigidity, compatibility issues (e.g., with implanted medical devices), and occasional safety risks. Consequently, there's a growing and pressing desire for wireless power transmission (WPT) to eliminate the need for physical connections during charging processes. Wireless Power Transmission (WPT) is progressing along two main avenues: near-field techniques like Capacitive Power Transmission (CPT) and Inductive Power Transfer (IPT), and far-field techniques such as the Solar Power Satellite (SPS) concept. The SPS, envisioned as a solar energy converter in space transmitting electricity to Earth, emerged from initial proposals by the National Aeronautics and Space Administration (NASA) in the 1970s. In long-range power transmission, various strategies could potentially be employed with SPS technology. The Japanese Aerospace Exploration Agency (JAXA) has conducted significant research towards practical implementation. Microwave Power Transmission (MPT) systems generally exhibit higher efficiency in both transmission and reception compared to Laser Power Transmission (LPT), with lower atmospheric attenuation. This paper primarily focuses on a comprehensive review of Microwave Power Transmission (MPT) systems. India's electricity grid registers the highest transmission and distribution losses globally, with estimates ranging from 27% according to the World Resources Institute (WRI) to figures exceeding 40% as reported by various Indian government sources. These losses stem from technical inefficiencies within the grid and widespread theft. Leveraging state-of-the-art technology presents a viable solution to this pressing issue.

Automation is today’s fact, where things are being controlled automatically, usually the basic tasks of turning ON/OFF certain devices and beyond, either remotely or in close proximity [5]. Wireless technology is one of the most widely used in Internet of Things (IOT). Wireless system can be use in different ways i.e., voice communication, remote control [5]. Exploring alternative methods of power transmission offers the potential for significantly higher efficiency, reduced transmission costs, and mitigation of power theft. Microwave Power Transmission emerges as a promising technology in this regard, offering a compelling alternative for efficient power delivery.

Nomenclature

MPT - Microwave Power Transmission

WPT – Wireless Power Transmission

DR - Directional Radiation

SPS - Solar Power Satellite

DC - Direct Current

RF - Radio Frequency

1.1 About Solar Power Satellite

Files The fundamental concept behind Solar Power Satellites (SPS) involves harnessing solar energy in orbit and transmitting it to Earth using microwave, laser beams, or similar methods. These systems entail deploying massive satellites adorned with extensive arrays of solar cells into geosynchronous orbit around 22,300 miles above the Earth's equator. Each satellite enjoys uninterrupted sunlight for most of the year due to its position, with minimal shadowing during equinox periods. Sunlight captured by the solar cells is converted into electricity, then transformed into radio-frequency energy by an onboard transmitting antenna before being directed to a receiving site on Earth. Upon reception, the energy is converted back into electricity by a receiving antenna and integrated into the conventional electric grid for widespread use. This approach offers a significant advantage over ground-based solar cells, as it ensures continuous energy availability, with the satellite receiving four to five times more solar energy than any terrestrial location and 15 times more than the average site. Extensive testing has confirmed the feasibility of wireless energy transmission to Earth at remarkably high efficiencies, with measures in place to ensure the safety of the transmitted radio-frequency beam for all life forms. While the concept is straightforward, the necessary technology is readily available [1].

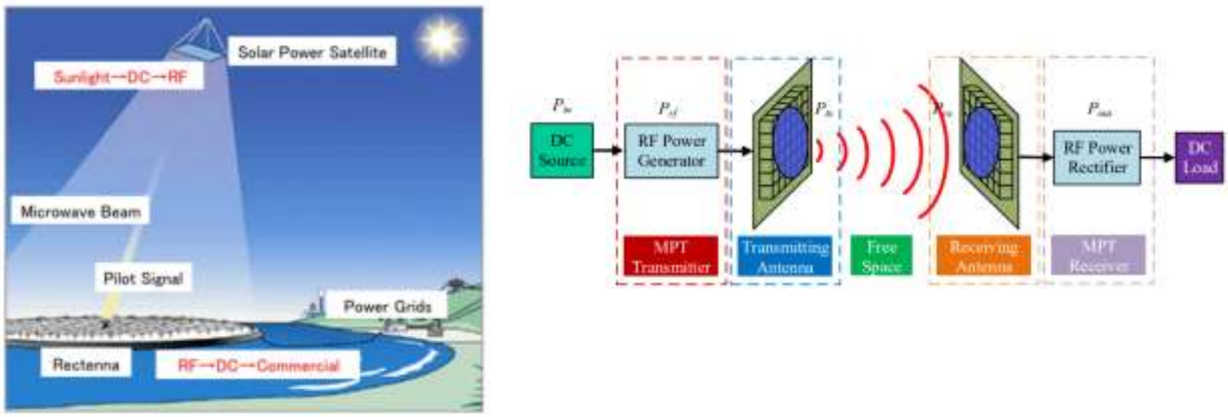


Fig. 1 - (a) Configuration of the SPS system, consisting of a flight segment

‘‘solar power satellite’’ and a ground segment ‘‘rectenna’’ [2]; (b) MPT system architecture [3].

Among the potential contenders for meeting our energy needs, the Solar Power Satellite (SPS) emerges as a particularly viable and perhaps the most practical solution. This technology entails harvesting solar energy in space and transmitting it back to Earth. Unlike ground-based solar installations, which are subject to weather fluctuations and diurnal cycles, space-based solar harvesting benefits from the sun's uninterrupted and abundant energy supply. The solar radiation available in space averages five to ten times greater per unit area compared to ground-level conditions. For instance, while Tokyo experiences an average solar radiation of about 140 W/m² throughout the year, solar radiation remains constant at approximately 1400 W/m² in a geosynchronous orbit. The conceptual layout of the SPS system, comprising both the airborne and ground segments, is depicted in Figure 1 (a) [1]. The component in orbit, termed the solar power satellite, transforms sunlight into direct current (dc) electricity through photovoltaic cells before generating a microwave beam directed towards the ground segment. Anticipated advancements suggest an efficiency of 80% in converting the generated direct current into microwave energy in the foreseeable future. On the ground, the segment of the system converts the received microwave power into direct current (dc) electricity using rectifying antennas known as rectennas. Subsequently, this power is integrated into commercial power grids. Anticipated advancements suggest that the conversion efficiency from microwave to dc will surpass 80% in the near future. While the wireless transmission and reception processes add complexity compared to ground-based solar power plants, the anticipated power loss during microwave transmission and reception is projected to be less than 50%. This estimation takes into account factors such as the efficiency of conversion between direct current and radio frequency, as well as propagation attenuation. Consequently, the Solar Power Satellite (SPS) holds a competitive edge over ground-based solar power plants, even when considering transmission losses from space to ground. Figure 1(b) illustrates a schematic diagram of the Microwave Power Transmission (MPT) system. In this setup, a direct current (DC) power source with a power input of Pin is supplied to an MPT transmitter. The transmitter then converts this DC input power into radio frequency (RF) output power, which serves as excitation for the transmitting antenna. Typically, a phased array antenna is used as the transmitting antenna, shaping the RF power into an intensified microwave beam and emitting it into free space. Subsequently, the receiving antenna captures the emitted beam and transfers its energy to a rectifier. This receiver, functioning essentially as an RF rectifier, transforms the received RF power into a DC output, denoted as Pout. Frequently, the receiving antenna and rectifier are integrated into a single unit known as a rectenna, a common component in MPT systems.

2.1 Component of WPT System

All Wireless Power Transmission comprises three primary components: the Microwave Generator, Transmitting Antenna, and Receiving Antenna (Rectenna), all integral to its operation.

- Microwave Generator: This component converts the direct current (DC) power generated by solar cells into radiated radio frequency (RF) output. It typically consists of a DC-RF conversion oscillator, followed by a gain stage and a power amplifier (PA). Microwave generating devices are commonly categorized as microwave tubes (such as klystrons, magnetrons, TWT, etc.) or semiconductor MW devices.
- Transmitting Antenna: Popular types include the slotted waveguide antenna, microstrip patch antenna, and parabolic dish antenna. The slotted waveguide antenna is particularly favored for its high aperture efficiency (>95%) and robust power handling capabilities. In Microwave Power Transmission (MPT) systems, a more efficient generator/amplifier is required compared to wireless communication systems. The phased array system demands higher stability and accuracy in microwave phase and amplitude for optimal beam collection on the rectenna array.
- Rectenna: Coined by W.C. Brown of Raytheon Company in the early 1960s, the Rectifying Antenna (Rectenna) directly converts microwave energy into direct current (DC) electricity. Typically arranged in a multi-element phased array with a mesh pattern reflector element for directional purposes, rectennas serve as receiving antennas in proposed microwave power transmission schemes, transmitting electric power to distant locations via microwaves.

Beyond power transmission, rectennas find applications in RFID tags, where they receive energy from querying radio signals to power computer chips. Future possibilities include their use as receiving antennas for Solar Power Satellites. A basic rectenna element comprises a dipole antenna with a Schottky diode across its elements, rectifying the AC current induced by microwaves to produce DC power. Schottky diodes are preferred for their low voltage drop and high-speed characteristics, minimizing power loss during conduction and switching. Large rectennas consist of arrays of such dipole elements. Rectennas are highly efficient at converting microwave energy to electricity. In laboratory environments, efficiencies of over 85% have been observed [4].

2.2 Progress and Demonstration Of Microwave Power Transmission Towards SPS

Progress1:

Caltech Launched Space Solar Power Technology Demo into Orbit in January 23 (The Transporter-6 mission successfully launched at 6:55 a.m. PT on January 3.)

In January 2023, the Caltech Space Solar Power Project (SSPP) is poised to launch into orbit a prototype, dubbed the Space Solar Power Demonstrator (SSPD), which will test several key components of an ambitious plan to harvest solar power in space and beam the energy back to Earth.

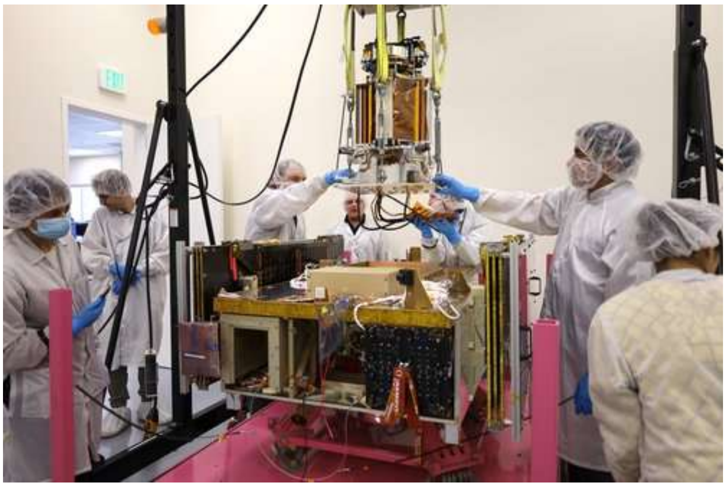
Space solar power provides a way to tap into the practically unlimited supply of solar energy in outer space, where the energy is constantly available without being subjected to the cycles of day and night, seasons, and cloud cover.

The launch, currently slated for early January, represents a major milestone in the project and promises to make what was once science fiction a reality. When fully realized, SSPP will deploy a constellation of modular spacecraft that collect sunlight, transform it into electricity, then wirelessly transmit that electricity over long distances wherever it is needed—including to places that currently have no access to reliable power.

A Momentus Vigoride spacecraft carried aboard a SpaceX rocket on the Transporter-6 mission will carry the 50-kilogram SSPD to space. It consists of three main experiments, each tasked with testing a different key technology of the project:

- **DOLCE** (Deployable on-Orbit ultraLight Composite Experiment): A structure measuring 6 feet by 6 feet that demonstrates the architecture, packaging scheme and deployment mechanisms of the modular spacecraft that would eventually make up a kilometer-scale constellation forming a power station;
- **ALBA**: A collection of 32 different types of photovoltaic (PV) cells, to enable an assessment of the types of cells that are the most effective in the punishing environment of space;

- **MAPLE** (Microwave Array for Power-transfer Low-orbit Experiment): An array of flexible lightweight microwave power transmitters with precise timing control focusing the power selectively on two different receivers to demonstrate wireless power transmission at distance in space.



Engineers carefully lower the DOLCE portion of the Space Solar Power Demonstrator onto the Vigoride spacecraft built by Momentus.*Credit: Caltech/Space Solar Power Project*

An additional fourth component of SSPD is a box of electronics that interfaces with the Vigoride computer and controls the three experiments.

SSPP got its start in 2011 after philanthropist Donald Bren, chairman of Irvine Company and a lifetime member of the Caltech Board of Trustees, learned about the potential for space-based solar energy manufacturing in an article in the magazine *Popular Science.* Intrigued by the potential for space solar power, Bren approached Caltech's then-president Jean-Lou Chameau to discuss the creation of a space-based solar power research project. In 2013, Bren and his wife, Brigitte Bren, a Caltech trustee, agreed to make the donation to fund the project. The first of the donations to Caltech (which will eventually exceed $100 million in support for the project and endowed professorships) was made that year through the Donald Bren Foundation, and the research began.

"DOLCE demonstrates a new architecture for solar-powered spacecraft and phased antenna arrays. It exploits the latest generation of ultrathin composite materials to achieve unprecedented packaging efficiency and flexibility. With the further advances that we have already started to work on, we anticipate applications to a variety of future space missions," Pellegrino says.

"The entire flexible MAPLE array, as well as its core wireless power transfer electronic chips and transmitting elements, have been designed from scratch. This wasn't made from items you can buy because they didn't even exist. This fundamental rethinking of the system from the ground up is essential to realize scalable solutions for SSPP," Hajimiri says.

The entire set of three prototypes within the SSPD was envisioned, designed, built, and tested by a team of about 35 individuals. "This was accomplished with a smaller team and significantly fewer resources than what would be available in an industrial, rather than academic, setting. The highly talented team of individuals on our team has made it possible to achieve this," says Hajimiri.

"Many times, we asked colleagues at JPL and in the Southern California space industry for advice about the design and test procedures that are used to develop successful missions. We tried to reduce the risk of failure, even though the development of entirely new technologies is inherently a risky process," says Pellegrino.

Progress 2:

As the world increasingly aims to transition away from fossil fuels and meet emissions reduction goals, Australia stands in a favorable position to leverage clean, cost-effective, and abundant space-based solar power.

A report commissioned by the UK government in September 2021 explored space-based solar options after a comprehensive study by experts in science, technology, and economics. The report evaluated two leading designs for baseload power: SPS Alpha by Mankins Space Technologies and Solar Space Technologies, and CASSIOPeiA by Ian Cash in the UK. Consultants Frazer-Nash determined both designs to be technically and economically feasible. It's worth noting my association as the director of Solar Space Technologies, the company collaborating with Mankins on the SPS Alpha design.

Following this assessment, the UK launched its space energy initiative in March 2022 to spearhead space-based solar power development. The US is also contemplating this technology through a draft presidential policy directive, instructing nine government departments on a national strategy for space solar power.

In December 2021, the Australian House of Representatives Standing Committee on Industry, Innovation, Science, and Resources advocated for exploring innovative space proposals like space solar power technology in Australia.

In March, the European Space Agency initiated the SOLARIS initiative, signing contracts for concept studies on commercial-scale space-based solar power plants. China has already commenced preliminary tests on space-based solar power stations, aiming to address power shortages through satellite trials of microwave and laser power transmission.

Russia's space agency, Roscosmos, proposed a space solar power plant in January 2022, also intending to recharge satellites. A space solar power station in geosynchronous orbit, generating 2 gigawatts of power, could cost as much as a Virginia-class submarine, with an estimated revenue of $53 billion over 30 years for an SPS Alpha Satellite.

This initiative presents a promising opportunity for Australia, aligning with the AUKUS technology-sharing agreement and offering immediate benefits, particularly in addressing climate change and providing clean, baseload power. The potential for job creation, economic growth, and energy security is substantial, with implications for industries like mining and manufacturing.

Furthermore, space-based solar power could support human activities in space, including on the moon and Mars, aiding in oxygen generation from lunar water deposits. The return on investment for the final operational design of SPS Alpha Mark III is projected to be five to seven years once deployed in geostationary orbit.

In essence, space-based solar power technology is poised for implementation in Australia, offering a transformative, nation-building opportunity for the 21st century, reminiscent of the ambitious spirit of exploration exemplified by John F. Kennedy's moonshot vision. This bold endeavor promises nearly limitless clean energy at an affordable cost, heralding a new era of sustainable power generation.

Progress 3:

China is poised to pioneer the world's inaugural space-based solar power station, aiming to provide an everlasting source of clean energy, as reported in Science and Technology Daily, the official publication of China's Ministry of Science and Technology.

According to Pang Zhihao from the China Academy of Space Technology, the envisioned solar power system orbiting Earth at an altitude of 36,000 kilometres would harness solar energy without interruption from atmospheric interference or nighttime darkness.

Initial tests are reportedly underway, with plans to construct the station by 2050. Xie Gengxin, deputy head of the Chongqing Collaborative Innovation Research Institute for Civil-Military Integration, disclosed to China Daily that a testing facility in Chongqing's Bishan district is under development to assess the theoretical feasibility of a space-based solar power station.

The 33-acre test site will focus on advancing space transmission technologies and evaluating the impact of microwave transmission on living organisms upon return to Earth. The Bishan district government is set to invest 100 million yuan ($15 million) in the project, with an estimated construction timeline of up to two years. Once operational, scientists and engineers will utilize tethered balloons equipped with solar panels to experiment with microwave transmission technologies.

"We plan to launch four to six tethered balloons from the testing base and connect them to establish a network at an altitude of around 1,000 meters," stated Gengxin. "These balloons will capture sunlight and convert it into microwave energy, which will then be transmitted back to Earth. Ground-based receiving stations will convert the microwaves into electricity and integrate it into the power grid."

2.3 Roadmap For the Commercialization of Space-Based Solar Power (SPS)

- **Research and Development (R&D):** Invest in extensive research and development to address key technological challenges and optimize system efficiency. Focus areas include:

1. Advanced solar panel technology to maximize energy capture.
2. Microwave transmission systems for efficient power beaming.
3. Robust space infrastructure for satellite deployment and maintenance.

- **Prototype Demonstration:** Build and test small-scale prototypes to validate design concepts and assess performance under real-world conditions. Conduct experiments to refine system components and operational procedures.
- **Partnerships and Collaboration:** Forge partnerships with government agencies, research institutions, and private sector entities to leverage expertise and resources. Collaborate on joint R&D projects, technology sharing, and regulatory advocacy.
- **Regulatory Framework:** Work with policymakers and regulatory bodies to establish clear guidelines and standards for space-based solar power deployment. Address concerns related to safety, environmental impact, and international cooperation.
- **Commercialization Strategy:** Develop a comprehensive commercialization strategy, including market analysis, pricing models, and customer outreach. Identify target industries and regions with high demand for clean, reliable energy solutions.

- **Scaling Up Production:** Ramp up production capacity to meet growing demand. Streamline manufacturing processes and supply chain logistics to reduce costs and improve scalability.
- **Deployment and Operations:** Launch operational satellites into orbit and establish ground-based receiving stations. Implement robust monitoring and control systems to ensure continuous performance optimization and maintenance.
- **Market Expansion:** Explore opportunities to expand into new markets and applications beyond terrestrial energy generation. Consider potential applications in space exploration, telecommunications, and remote sensing.
- **Public Awareness and Education:** Engage with the public to raise awareness about the benefits of space-based solar power and address misconceptions. Educate policymakers, industry stakeholders, and the general public about the technology's potential to address global energy challenges.
- **Continuous Innovation:** Foster a culture of innovation and continuous improvement to stay ahead of technological advancements and market trends. Invest in ongoing R&D efforts to enhance system efficiency, reliability, and affordability.

By following this roadmap, stakeholders can work together to accelerate the commercialization of space-based solar power and unlock its potential to provide clean, sustainable energy for the future.

2.4 Safety issues of MPT system and biological impacts.

Safety is paramount in Microwave Power Transmission (MPT) systems.

- **Electromagnetic Radiation Exposure:** MPT systems involve the transmission of electromagnetic waves, which may pose health risks if not properly controlled. It's essential to adhere to established safety standards and regulations to limit exposure levels and ensure the safety of personnel and the general public.
- **Interference with Electronic Devices:** The high-power microwave beams used in MPT systems can potentially interfere with electronic devices and communication systems. Careful planning and coordination are necessary to mitigate these risks and prevent disruptions to essential services.
- **Environmental Impact:** MPT systems may have environmental impacts, such as disrupting wildlife habitats or affecting ecosystems. Environmental assessments should be conducted to identify potential risks and develop mitigation measures to minimize adverse effects.
- **Accidental Exposure:** Accidental exposure to microwave radiation can cause burns and other injuries. Safety protocols, warning signs, and protective barriers should be implemented to prevent unauthorized access to MPT facilities and minimize the risk of accidents.
- **Weather Conditions:** Adverse weather conditions, such as heavy rain or fog, can affect the performance of MPT systems and increase the risk of accidents. Systems should be designed to withstand environmental challenges and incorporate fail-safe mechanisms to ensure continued operation under varying conditions.
- **Security Risks:** MPT facilities may be vulnerable to security threats, such as vandalism, sabotage, or terrorist attacks. Security measures, including surveillance systems, access controls, and emergency response plans, should be implemented to safeguard against potential threats.
- **Public Perception and Acceptance:** Addressing public concerns and promoting awareness of the safety measures in place is crucial for gaining public acceptance of MPT systems. Transparency, community engagement, and education initiatives can help alleviate fears and build trust in the technology.
- **Interference with Biological Processes:** Microwave radiation from WPT systems can potentially interfere with biological processes in living organisms. Studies have suggested that exposure to microwave radiation may affect cellular functions, DNA integrity, and reproductive health in animals and humans. Research into the biological effects of microwave radiation is ongoing, and precautions should be taken to minimize exposure, especially in sensitive populations such as pregnant women and children.
- **Effects on Wildlife:** WPT systems may also have impacts on wildlife, particularly birds and insects. Microwave radiation can disrupt navigation, communication, and foraging behaviors in birds and insects, leading to potential habitat disturbance and population declines. Careful siting of WPT facilities and environmental assessments are necessary to minimize these risks and protect biodiversity.
- **Electromagnetic Sensitivity:** Some individuals claim to experience symptoms such as headaches, fatigue, and cognitive impairments in the presence of electromagnetic fields, including those generated by WPT systems. While scientific evidence supporting the existence of electromagnetic sensitivity is limited, it's important to consider public concerns and address them through rigorous safety measures and communication efforts.

Conclusion

long-range Microwave Power Transmission (MPT) holds significant promise as a solution for remotely powering satellites, drones, and mobile facilities, thereby eliminating the need for a wired power network. While challenges such as overall efficiency, robustness, and directional radiation persist, ongoing research is addressing these obstacles. This paper has provided a comprehensive overview of the current state of MPT technology, focusing on transmitter, directional radiation, and receiver design, as well as highlighting its significance in daily life applications.

Moreover, the concept of Solar Power Satellites (SPS) offers a compelling solution to global environmental and energy challenges by harnessing solar energy in space and transmitting it to Earth. Despite technological hurdles, progress is being made in the development of microwave power transmission technologies, paving the way for the commercial utilization of SPS technology.

The roadmap outlined in this paper emphasizes the importance of continued research and development, collaboration, regulatory frameworks, and public awareness in advancing the commercialization of space-based solar power. Furthermore, the safety issues and biological impacts associated with MPT systems underscore the importance of implementing rigorous safety measures and conducting thorough environmental assessments.

Overall, space-based solar power technology represents a transformative opportunity for clean, sustainable energy generation, with the potential to address pressing global energy needs while mitigating environmental impacts. By addressing key challenges and leveraging technological advancements, stakeholders can work together to realize the full potential of space-based solar power for the benefit of humanity.

References

[1] Ralph H. N (1996). Wireless Power Transmission. Solar Space Industries The Key to Solar Power Satellites: IEEE AES Systems Magazine, pp 33.

[2] S. Mihara, T. Saito, Y. Fuse, K. Ijichi, K. Namura, Y. Honma, T. Sasaki, Y. Ozawa, E. Fujiwara, and T. Fujiwara, ‘‘Microwave wireless power transmission demonstration on ground for SSPS,’’ presented at the 62nd Int. Astronaut. Congr., Cape Town, South Africa, Oct. 2011, IAC-11-C3.2.4.

[3] Q. Hui, K. Jin and X. Zhu, "Design of an RF power generator for microwave power transmission system," 2019 IEEE Applied Power Electronics Conference and Exposition (APEC), Anaheim, CA, USA, 2019, pp. 846-850.

[4] Akhil, N. (2012). Use of Geosynchronous Satellites for Production and Wireless Transfer of Solar Power. Available online at: http://seekdl.org/nm.php .pp81-84. Accessed (11/09/13).

[5] V. B. Tarate, T. H. Nagawade, V. M. Shitole, M. R. Kambale, R. R. Pawar, " Transforming Institutes into Energy –Efficient Hubs through Automation , International Journal of Scientific Research in Science, Engineering and Technology(IJSRSET), Print ISSN : 2395-1990, Online ISSN : 2394-4099, Volume 10, Issue 3, pp.245-248, May-June-2023