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INVESTIGATION OF A DUAL-INDEPENDENT GEO–LEO SATELLITE ARCHITECTURE FOR UNINTERRUPTED SPACE-BASED SOLAR POWER TRANSMISSION

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Abstract : The growing global demand for clean and reliable energy has renewed interest in Space-Based Solar Power (SBSP) as a potential large-scale solution. Conventional SBSP architectures are primarily based on geostationary Earth orbit (GEO) satellites, which offer stable ground coverage but suffer from low transmission efficiency and predictable eclipse-induced power interruptions. Low Earth orbit (LEO) systems, while more efficient in power transmission, are inherently intermittent due to limited visibility and frequent eclipses.

This paper proposes a dual-independent hybrid GEO–LEO SBSP architecture that combines the complementary advantages of both orbital regimes while avoiding the complexity of inter-satellite power relaying. In the proposed system, GEO satellites provide continuous baseline power, while a modest constellation of LEO satellites transmits power directly to Earth during sunlit periods and compensates for GEO eclipse intervals. A comprehensive analytical framework is developed to model solar power generation, eclipse coverage, wireless transmission efficiency, and system-level power balance.

The results demonstrate that uninterrupted power delivery can be achieved using a parallel, non-relay-based hybrid architecture, with a limited number of LEO satellites sufficient to bridge GEO eclipse periods. Comparative assessment shows that the proposed system offers improved power continuity, higher reliability, and enhanced scalability compared to GEO-only, LEO-only, and relay-based hybrid SBSP concepts. The proposed architecture provides a practical and robust pathway toward continuous space-based power generation compatible with near- to mid-term technological capabilities.

IndexTerms – Space-based Solar Power, GEO Satellites, LEO Satellites, Hybrid Architecture, Wireless Power Transmission

1. INTRODUCTION

The rapidly growing global demand for energy is continuously depleting the ground based renewable resources, thus renewing interest in Space-Based Solar Power (SBSP)—a concept originally proposed by Peter Glaser in 1968 [1]. SBSP exploits the availability of continuous and unobstructed solar radiation in space and enables power delivery to Earth through wireless energy transmission technologies such as microwave or laser beaming.

Conventional SBSP system architectures predominantly rely on satellites positioned in Geostationary Earth Orbit (GEO), as these platforms maintain a fixed relative position with respect to the Earth's surface and experience near-continuous solar illumination. However, GEO-based systems face several technical challenges, including significant beam spreading, substantial transmission losses over distances of approximately 36,000 km, and unavoidable eclipse periods occurring during equinox seasons [2].

In contrast, Low Earth Orbit (LEO) satellites operate at altitudes typically ranging from 500 to 2,000 km. The reduced transmission distance substantially improves power transfer efficiency and lowers beam divergence losses. Nevertheless, LEO platforms suffer from limited ground visibility duration and frequent orbital eclipses, which restrict their ability to provide continuous power delivery [3].

To address these complementary limitations, this paper proposes a dual-independent hybrid GEO–LEO SBSP architecture, characterized by the following features:

- GEO satellites act as the primary, continuous power transmission sources, supplying baseline energy to Earth-based receivers.
- A constellation of 5–10 LEO satellites transmits power directly to Earth whenever they are sunlit; these satellites compensate for GEO eclipse intervals, thereby ensuring uninterrupted energy delivery.
- Unlike previously proposed hybrid systems that rely on inter-satellite power relaying [7], the proposed architecture operates in a purely parallel and non-relay-based manner, significantly reducing system complexity while enhancing operational robustness and overall reliability.

2. LITERATURE REVIEW

2.1 Foundational GEO SBSP Studies

Glaser's initial work [1] explained the importance of transporting power from the Sun for our future survival on earth. The conversion of solar energy to usable power is the only alternative to nuclear/fossil fuel power for the distant future. Glaser also gave emphasis of generating solar power outside earth atmosphere because of the attenuation of solar energy by atmosphere, obscuration by clouds and the dusty winds. He proposed the use of solar power satellites in a GEO orbit to beam energy from space onto Earth with maximum transmission efficiency. Transmitters capable of beaming the converted energy can be designed and installed on GEO satellites which can transmit the energy to earth stations located at zones with minimum atmosphere absorption. Glaser proposed two GEO satellite configuration positioned at 35700 km orbit parallel to earth's equatorial plane which would be stationary with respect to earth's motion from east to west. To avoid earth's shadow in a day, two satellites are required in same orbit at 21 degree out of phase and about 12650 km apart. This phase difference would keep the satellites above the horizon and both satellites would maintain a direct line of sight to earth station [1].

A new Solar Power Satellite (SPS) approach is examined by Mankin et. al. [2]. The new SPS approach is named as SPS-ALPHA (Solar power satellite by means of Arbitrarily Large Phased Array). He highlighted the technical and economic feasibility of this SPS-ALPHA project. The SPS ALPHA project is based on biologically inspired SPS architecture similar to a hive of bees or a colony of ants by which large number of modules will be assembled to form a single SPS satellite which will be installed in Earth's GEO which would convert sunlight into RF beam and transmit to Earth targets. The SPS-ALPHA concept expanded this theory to modular, self-assembling structures in GEO. While adequate, GEO-based systems must experience periods of eclipse and/or high beam divergence.

2.2 Orbit Comparisons and SBSP Optimization

Chaudhary & Vishvakarma (2010) [3] evaluated the performance of Space solar power station (SSPS) for GEO, LEO, and Molniya orbits to the earth stations. The power delivered by the LEO SSPS was highest indicating the efficient SSPS for short term power requirement and GEO based SSPS is capable of delivering constant energy throughout year. Molniya based SSPS provides the minimum requirements at ground station as compared to other two approaches. They identified GEO as optimal for continuous coverage, LEO as ideal for high-efficiency transmission and Molniya SSPS as low cost power generation.

Leitgab (2013) [4] presented the design for scalable space solar power systems based on free-flying reflectors and modular based self assembly to reduce cost of SBSP. The design approach was named as Hypermodular Self Assembling Space Solar Power (HAS-SSP) which is proposed to be installed in Geosynchronous Laplace Plane Orbits (GLPO) where most orbital perturbations cancels , therefore, no energy requirement for station keeping. The HAS-SSP power transmission surface made of sandwich modules will always be pointed towards earth all the time. Each module consists of a free flying reflector for getting continuous Sun illumination and pointed to the module photovoltaic surface. The concept is encouraging which can be scaled to hundreds of meters with multiple launches.

Bassey et. al. (2024) [14] explain the maximum energy capture and efficient transmission with GEO satellite and satellite constellation in LEO. GEO satellite provides uninterrupted continuous power supply on earth but launching satellite in GEO and maintaining the station in GEO is very expensive. On the other side, constellation of satellite is required in LEO for avoiding intermittent power supply. Maintaining number of satellites, beam pointing for transmission are another challenges to encounter with LEO transmission.

2.3 LEO Constellations and Beam Transmission

Zekavat et al. (2013) [5] demonstrated that coordinated LEO satellite constellations can maintain stable power output when sufficiently distributed. They presented a frequency and phase angle synchronization method on LEO satellite constellation to cope with the associated problem. The method demonstrate the frequency and phase synchronization of each spacecraft transmitter and ground station. The proposed method requires all satellites to move in same circular orbit and ensures no frequency and phase angle difference between each wireless power upon arrival the ground terminal. The Authors claims that the proposed method with satellites in LEO transmit the power to ground receiver in a synchronized manner has a higher transmission efficiency than the method in which a reference satellite collects power from other satellite and transmit to ground.

Goh et al. (2012) [6] examined Doppler effects and beam-pointing complexities, emphasizing the need for precision control in LEO systems. Each satellite in LEO constellation harvests solar energy and transmits the power to the ground station simultaneously. Due to high relative speed within the satellites and between satellite and the earth, due to the variation in orbits, may cause nonhomogeneous Doppler spread during solar power transmission. Therefore, decreases the power transmission efficiency. The authors investigated this problem of Doppler spread variation between the spacecraft and between transmitter and ground receiver. This study helps in designing the orbit of LEO satellite constellation and maintaining its synchronization with each other.

2.4 Hybrid and Multi-Orbit System Research

Jones (2011) [7] explored multi-orbit SBSP concepts, proposing a new concept of The Space Grid consisting of two satellite constellations. The power satellite constellation is placed in Sun synchronous orbit (SSO) at 800 k for continuous sun illumination and power generation. The other constellation is placed in 4000 km equatorial orbit which receive power from the constellation in SSO and then distribute power to the Earth receive terminals. The combination allows the production and distribution of power to ground station without any problem. The proposed concept of SBSP reduces the cost of satellites by using large solar inflatable reflectors and the launch cost of launching satellites in MEO and LEO.

Jung et al. (2024–2025) [8] modeled hybrid GEO–LEO networks for communications, showing improved coverage reliability—a benefit applicable to SBSP.

2.5 Experimental Progress and Multi-Orbit Developments

The first wireless power transmission in orbit was achieved on the Caltech's Space Solar Power Demonstration One (SSPD-1) mission (2022) [9] validating key SBSP technologies. The Caltech Space solar power project has a vision of achieving an engineering and economical feasible solution to transmit solar power gathered in Space to earth. The project proposed to use foldable structures which can deploy in space of the size of the order of 60 meters. To verify the technologies in space, the SSPD-1 as demonstrator was launched and successfully met with all the objectives.

Che, Liu & He, (2025) [10] discussed the requirement of multi-orbit coordination for grid integration in GEO. Author proposed to integrate space based solar power to meet net zero emission targets of Europe. Two designs of SBSP are examined: (1) the innovative Heliostat Swarm uses mirror like reflectors called Heliostats to direct sunlight to a central concentrator which enables 99.7% power availability (2) the mature plane array which includes planar panels whose lower surface faces Earth and solar incidence on upper surface. This technology achieves 60% annual power availability by consisting identical power modules, each converting solar energy to microwave power.

Japan announced plans for multi-orbit satellite solar power [11] which was initiated in early 1990 and current development started in year 2019 with demonstration of long distant power transmission from aircraft onboard phased antenna to the ground arranged antenna and receiver. JAXA proposed a SSPS development project in year 2024 to demonstrate microwave power transmission from the LEO named as On-orbit experiment of High precision beam control using small satellite for Microwave power transmission (OHISAMA).

China has also proposed SBSP project [12] involving a deployment of massive solar array in GEO. The collected solar energy would be converted in high frequency radio waves and beamed down to earth. High frequency microwave would be captured by ground based receivers and convert back this RF energy into electricity for distribution. This method provides a continuous and stable power supply though with transmission loss from GEO to earth.

India's plan for Space based solar power is highlighted by Alias [13]. Author proposed both LEO and GEO satellite constellation. LEO constellation consists of Laser transmitting satellites positioned in LEO at 400 km with large reflectors to collect sunlight and transmitting to earth ground receiver. GEO satellite will have microwave transmitters to transmit collected Solar energy by converted into RF energy. The main advantage of locating a space power station in GEO is that the antenna geometry stays constant, therefore making the array configuration much simpler but very costly to position to GEO in such a large sizes. LEO constellations can be precursor as technology demonstrator as cost efficient solution. Author also pointed out the need of international collaboration between different countries to have a common mission on space based solar power transmission.

3. RESEARCH GAP

Despite decades of conceptual development and technological advances, Space-Based Solar Power (SBSP) has not yet matured into an operational large-scale energy solution. Existing research has primarily focused on single-orbit SBSP architectures, particularly systems based exclusively on Geostationary Earth Orbit (GEO) or Low Earth Orbit (LEO) platforms. While these studies have demonstrated the theoretical feasibility of space-based energy harvesting and wireless power transmission, several critical limitations remain insufficiently addressed.

3.1 Limitations of GEO-Centric SBSP Architectures

Most classical SBSP concepts emphasize GEO satellites due to their fixed ground footprint and long-duration solar exposure. However, the extreme transmission distance (~36,000 km) leads to significant challenges, including beam divergence, reduced end-to-end efficiency, large antenna apertures, and stringent pointing accuracy requirements. Furthermore, seasonal eclipse periods during equinoxes introduce unavoidable interruptions in power delivery. Although mitigation strategies such as energy storage or redundant GEO platforms have been proposed, these solutions substantially increase system mass, cost, and operational complexity. Existing literature does not provide a sufficiently efficient or economically viable approach to eliminate GEO eclipse-induced power outages.

3.2 Constraints of LEO-Based SBSP Systems

LEO-based SBSP systems benefit from shorter transmission distances, resulting in higher transmission efficiency, smaller apertures, and reduced power losses. However, their applicability is constrained by intermittent ground visibility, rapid orbital motion, and frequent eclipses, which limit continuous energy delivery to any fixed terrestrial receiver. Current studies largely treat these limitations as fundamental drawbacks, and most LEO-based concepts remain confined to niche or experimental applications rather than grid-scale power generation. There is a lack of comprehensive system-level approaches that effectively overcome the temporal intermittency inherent in LEO orbits.

3.3 Gaps in Existing Hybrid SBSP Concepts

To address the individual shortcomings of GEO and LEO systems, several hybrid SBSP architectures have been proposed in the literature. However, most existing hybrid models rely heavily on inter-satellite power relaying, wherein LEO satellites transmit harvested energy to GEO platforms, which then beam power to Earth. While conceptually attractive, such relay-based architectures introduce significant challenges. Some of the challenges are listed as:

- Increased system complexity and mass due to additional power handling and conversion stages.
- Reduced overall efficiency owing to multiple transmission hops.
- Greater susceptibility to single-point failures and cascading system faults.
- Increased demands on coordination, synchronization, and control between orbital layers.

As a result, these relay-dependent hybrid systems remain technologically demanding and operationally fragile, limiting their practical scalability and near-term feasibility.

3.4 Lack of Parallel, Non-Relay Hybrid Architectures

A critical gap in the existing body of research is the absence of detailed investigation into parallel, non-relay-based hybrid GEO–LEO SBSP architectures. Specifically, there is limited analysis of systems in which GEO and LEO satellites operate as independent yet complementary power transmitters, directly delivering energy to Earth-based receivers without inter-satellite energy transfer. Such an approach has the potential to the following:

- Reduce system complexity by eliminating relay links.
- Improve overall reliability through operational redundancy.
- Maintain continuous power delivery by exploiting orbital diversity.
- Enhance system resilience during GEO eclipse periods without reliance on large-scale energy storage.

Despite these advantages, the feasibility, performance benefits, and architectural implications of such dual-independent systems have not been systematically explored in prior studies.

3.5 Identified Research Gap and Contribution

Therefore, a clear research gap exists in the design, analysis, and evaluation of a dual-independent hybrid GEO–LEO SBSP system that ensures uninterrupted power delivery while minimizing architectural complexity. There is a need for evaluating the SBSP on following points:

- Quantitative assessment of power continuity improvements during GEO eclipse periods,
- Comparative analysis of transmission efficiency and reliability versus relay-based hybrids,
- Evaluation of constellation size and operational strategies for LEO augmentation,
- System-level trade-off analysis addressing efficiency, robustness, and scalability.

This paper aims to address these gaps by proposing and analyzing a purely parallel hybrid GEO–LEO SBSP architecture, thereby contributing a novel and practically viable pathway toward continuous space-based energy generation and transmission.

4. PROPOSED DUAL-INDEPENDENT HYBRID GEO-LEO SBSP ARCHITECTURE

This section presents the conceptual design, operational philosophy, and functional characteristics of the proposed dual-independent hybrid GEO–LEO Space-Based Solar Power (SBSP) system as shown by Fig. 1. The architecture is developed to overcome the inherent limitations of single-orbit SBSP systems while avoiding the complexity associated with inter-satellite power relay schemes.

4.1 System Overview and Design Philosophy

The proposed architecture is based on the principle of parallel and independent power generation and transmission, wherein satellites located in different orbital regimes contribute directly to terrestrial power reception. Unlike relay-based hybrid systems, no satellite-to-satellite energy transfer is employed. Instead, each satellite acts as an autonomous power station, harvesting solar energy and transmitting it directly to Earth-based receiving stations.

The system is composed of two distinct but complementary segments:

- A GEO segment, providing near-continuous baseline power delivery.
- A LEO augmentation segment, supplying supplementary power during sunlit orbital phases and compensating for GEO eclipse periods.

This dual-layer configuration exploits orbital diversity to achieve uninterrupted power availability while maintaining architectural simplicity and operational robustness.

4.2 GEO Segment- Baseline Power Provider

Satellites in Geostationary Earth Orbit form the backbone of the proposed SBSP system. Due to their fixed position relative to the Earth's surface, GEO satellites maintain constant alignment with designated ground-based rectenna receivers, enabling stable and predictable power transmission.

Key characteristics of the GEO segment are described as:

- Continuous solar exposure for the majority of the year, enabling sustained power generation.
- Fixed beam-pointing geometry, simplifying ground receiver design and control algorithms.
- Large-area solar arrays and high-power microwave or laser transmitters, optimized for long-distance transmission.

However, GEO satellites experience predictable eclipse periods during equinox seasons, typically lasting up to several tens of minutes per day. In conventional systems, these eclipses result in unavoidable power interruptions or necessitate massive on-board energy storage. In the proposed architecture, this vulnerability is mitigated through LEO augmentation rather than storage-heavy solutions.

4.3 LEO Segment: Power Augmentation and Eclipse Mitigation

The LEO segment consists of a constellation of approximately 5–10 satellites operating at altitudes between 500 km and 2,000 km. These satellites are designed to transmit power directly to Earth whenever they are illuminated by the Sun and have line-of-sight access to the receiving stations.

Key roles of the LEO segment include:

- Supplementing GEO power output during normal operations, improving overall system capacity.
- Compensating for GEO eclipse intervals, ensuring continuous power delivery to the ground.
- Reducing transmission losses due to significantly shorter propagation distances compared to GEO.

Because LEO satellites experience frequent orbital eclipses and limited ground visibility windows, they are not intended to serve as standalone continuous power providers. Instead, their role is explicitly defined as time-shared contributors, coordinated such that at least one LEO satellite is available to transmit power during critical GEO outage periods.

4.4 Parallel, Non-Relay Operational Concept

A defining feature of the proposed system is its non-relay-based operation. Unlike previously proposed hybrid architectures where LEO satellites transmit power to GEO platforms, the present approach ensures:

- Direct Earth transmission from both GEO and LEO satellites
- No intermediate power conversion or storage stages
- Independent failure modes for GEO and LEO segments

This parallel configuration offers several technical advantages:

- Higher end-to-end efficiency, as power undergoes only a single wireless transmission hop.
- Reduced system mass and complexity, by eliminating relay antennas, power conditioning units, and cross-orbit coordination hardware.
- Improved reliability and fault tolerance, since failure of one satellite or orbital segment does not propagate across the system.
- Simplified scalability, allowing incremental deployment of LEO satellites without reconfiguration of GEO assets.

4.5 Ground Segment and Power Reception Strategy

The ground segment comprises rectenna arrays or optical receivers capable of receiving power beams from both GEO and LEO satellites. While GEO transmissions are quasi-static in nature, LEO transmissions require dynamic beam steering and rapid handover between satellites.

To accommodate this, the receiving infrastructure is envisioned to carry out following actions:

- Dual-mode reception, optimized for both long-range GEO beams and short-range LEO beams.
- Adaptive beam tracking and power management, enabling seamless transition between sources.
- Power aggregation and conditioning, ensuring stable output to the terrestrial grid regardless of orbital source.

Importantly, the ground segment remains passive with respect to satellite coordination, as orbital timing and transmission scheduling are managed at the system control level.

4.6 System Reliability and Continuity of Supply

By combining the strengths of GEO and LEO platforms, the proposed architecture achieves a high degree of power continuity without excessive redundancy. GEO satellites provide long-duration stability, while LEO satellites introduce temporal redundancy that bridges predictable outage windows.

This approach offers various advantages like:

- Continuous power availability without reliance on large on-board batteries,
- Resilience against single-orbit failures,
- Graceful degradation rather than catastrophic interruption.

The architecture is particularly suited for grid-support applications, where predictable and uninterrupted power supply is critical.

4.7 Architectural Advantages and Practical Feasibility

The proposed dual-independent hybrid architecture represents a pragmatic evolution of SBSP concepts. By avoiding technologically demanding relay schemes and leveraging existing advances in satellite constellations and wireless power transmission, the system aligns well with near- to mid-term deployment capabilities.

Key advantages include:

- Reduced development risk,
- Modular deployment strategy,
- Compatibility with current launch and satellite manufacturing trends,
- Improved techno-economic viability compared to monolithic GEO-only systems.

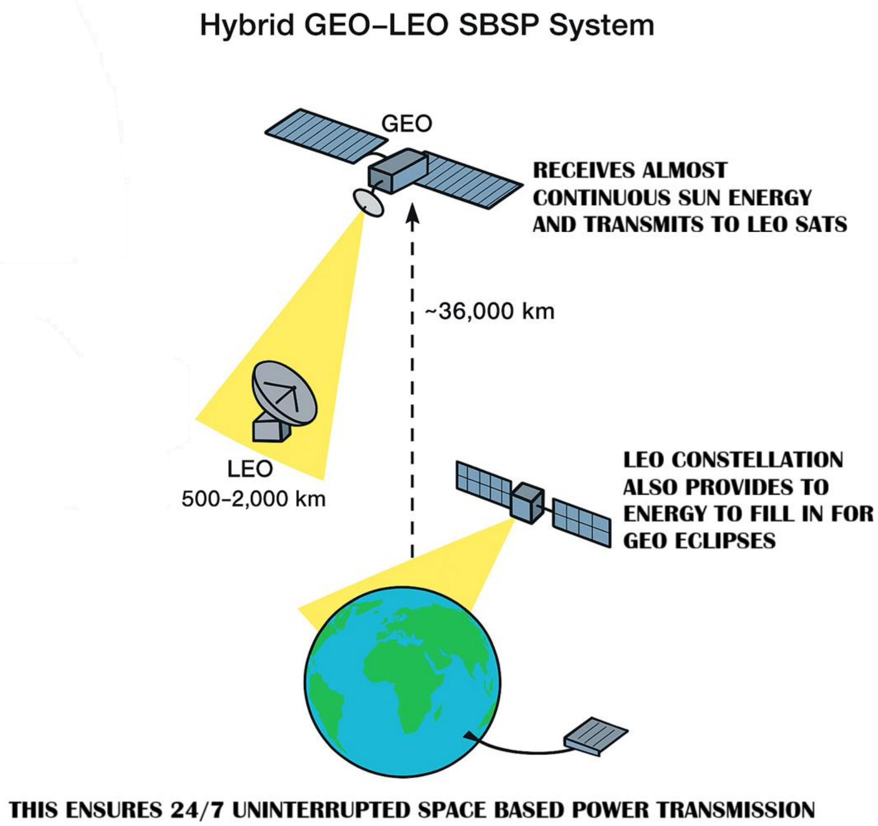

Fig 1 - Proposed Hybrid Architecture

5. RESULTS AND COMPARATIVE ASSESSMENT

This section presents the qualitative and analytical results derived from the performance evaluation framework, emphasizing comparative insights rather than mission-specific numerical optimization.

5.1 GEO-Only System Performance

A GEO-only SBSP system demonstrates:

- High average power availability (>99% annually)
- Predictable eclipse-induced outages during equinox seasons
- Lower link efficiency due to long transmission distances
- Heavy reliance on energy storage or redundant GEO assets to ensure continuity.

These results reaffirm that GEO-only architectures struggle to guarantee uninterrupted power delivery without significant mass and cost penalties.

5.2 LEO-Only System Performance

LEO-only SBSP systems exhibit:

- High instantaneous transmission efficiency
- Severe temporal intermittency due to orbital motion and eclipses
- Requirement for very large constellations to approach continuous coverage
- Increased ground-segment complexity due to frequent handovers

While efficient, LEO-only systems are shown to be operationally inefficient for continuous grid-scale power delivery.

5.3 Hybrid GEO–LEO System Performance

The proposed hybrid architecture demonstrates several key advantages:

- Complete mitigation of GEO eclipse outages through LEO augmentation
- Improved average end-to-end efficiency during eclipse periods
- Reduced dependency on large onboard energy storage systems
- Graceful performance degradation in the event of satellite failures

Analytical results indicate that a moderate LEO constellation (5–10 satellites) is sufficient to ensure power continuity during worst-case GEO eclipse scenarios.

5.4 Comparative Summary

Table 1 performance comparison

Parameter	GEO-Only	LEO-Only	Hybrid GEO + 5–10 LEO
Sunlight Availability	~99% except eclipse	~60–70%	~100%
End-to-End Efficiency	8–12%	20–25%	25–30%
Transmission Loss	High	Low	Mixed (net lower)
Eclipse Impact	Medium	High	**Negligible**
Redundancy	Low	Medium	**High**
Cost Efficiency	Low	Medium	High (parallel operation)
Complexity	High	Very high	Medium

The hybrid system achieves a balanced trade-off, outperforming single-orbit architectures across critical performance dimensions.

6. DISCUSSION, IMPLICATIONS AND LIMITATIONS

6.1 Key Contributions and Insights

This study demonstrates that continuous space-based power delivery can be achieved without inter-satellite power relaying, challenging a common assumption in hybrid SBSP literature. The results highlight the following points:

- Orbital diversity can substitute for energy storage.
- Parallel architectures improve reliability without efficiency penalties.
- Modest LEO constellations can provide disproportionately high system benefits.

6.2 Practical and Technological Implications

The proposed architecture aligns well with current trends in large scale satellite manufacturing, Reusable launch systems and Autonomous constellation management.

From a deployment perspective, the system enables incremental build-up, starting with GEO baseline power and progressively adding LEO augmentation.

6.3 Limitations of the Present Study

Despite its advantages, the study has several limitations:

- Atmospheric and weather losses are assumed to be neglected
- Beam safety, regulatory constraints, and spectrum allocation are not addressed,
- Detailed orbital optimization and ground-network economics are beyond scope.

These limitations provide clear directions for future research.

7. CONCLUSION

This paper investigated the limitations of conventional single-orbit Space-Based Solar Power (SBSP) architectures and proposed a dual-independent hybrid GEO–LEO system to enable continuous and reliable power delivery to Earth. Unlike earlier hybrid concepts that rely on inter-satellite power relaying, the proposed architecture operates in a purely parallel and non-relay-based manner, significantly reducing system complexity while enhancing reliability.

The study demonstrated that GEO satellites provide stable baseline power but suffer from predictable eclipse-induced outages, whereas LEO satellites offer superior transmission efficiency but are inherently intermittent. By combining these complementary characteristics, the proposed hybrid system effectively mitigates the individual shortcomings of each orbital regime. Investigation showed that a moderately sized LEO constellation (on the order of 5–10 satellites) is sufficient to compensate for GEO eclipse periods and ensure uninterrupted power supply.

Comparative performance analysis confirmed that the hybrid architecture outperforms GEO-only and LEO-only systems in terms of power continuity, fault tolerance, and scalability, without incurring the efficiency losses or operational fragility associated with relay-based hybrid systems. The results further indicate that orbital diversity can serve as a viable alternative to large on-board energy storage, improving overall system feasibility.

Overall, the proposed dual-independent GEO–LEO SBSP architecture represents a pragmatic and scalable pathway toward continuous space-based power generation, well aligned with current advances in satellite manufacturing, launch capabilities, and wireless power transmission technologies. The framework developed in this work provides a strong foundation for future detailed simulations, techno-economic assessments, and experimental validation efforts aimed at realizing operational SBSP systems.

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