



REVOLUTIONIZING ENERGY GENERATION: ADVANCES IN SOLAR TECHNOLOGY

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Abstract

Energy resources can be broadly categorized into renewable and non-renewable sources. Due to adverse environmental effects like air pollution, climate change, and depletion of natural resources, there is a growing emphasis on utilizing renewable energy resources for power generation. Among these, solar energy stands out as a widely discussed and promising renewable source. With the continuous increase in the global population and corresponding rise in energy demand, it has become imperative to advance technologies in the field of solar energy. This is not only to meet the escalating global energy needs but also to enhance energy efficiency. A notable drawback of traditional solar cells is their inability to generate electricity during nighttime. This study primarily centers on solar energy, exploring innovations, improvements, and the future prospects of solar energy technologies. Addressing the limitations, such as the nocturnal energy production challenge, is crucial for the continued development and widespread adoption of solar energy.

Keywords – solar cell, Innovations, retina, tandem solar cell.

1 Introduction

The imperative for global attention to renewable energy resources arises from the constraints and environmental impacts associated with non-renewable energy sources. Issues like global warming, greenhouse gas emissions, fluctuating oil prices, and increasing electricity demand in developing nations necessitate the exploration of alternative solutions. Renewable energy, particularly solar energy, plays a crucial role in the current energy landscape and the trajectory of energy development. Solar energy has seen widespread development and applications at a large scale, overcoming limitations in energy transmission. In comparison to fossil-based coal and oil, solar energy offers numerous advantages, including reduced carbon emissions, improved air quality, and the ability to regenerate within our lifetimes. The escalating global electricity consumption has driven researchers to focus on enhancing solar energy technologies, aiming for high efficiency with minimal investment costs and reduced environmental pollution. However, challenges persist in the intermittent and fluctuating nature of solar energy, limiting its utilization and efficiency. In remote areas, such as rural and mountainous regions distant from large power grids, solar hybrid power systems are commonly employed. The randomness and fluctuations in solar power pose challenges in providing continuous and stable active power output. Additionally, solar power's adaptability is hindered by the dependence on the natural resource distribution, which varies based on the cultural context of individual communities. When compared to fossil-based electricity generation systems like thermal oil power plants and coal power plants, solar power faces limitations in achieving maximum power output, partly due to its high initial costs. To meet the growing global energy demand, researchers are compelled to introduce innovations in the solar energy field to address these disadvantages and challenges. The increasing global primary energy consumption, projected to reach 240,318 million MWh in 2040, underscores the urgency for sustainable energy solutions. The rising share of renewable energy-based electricity generation, expected to reach 31% in 2035, aligns with the sustainable future scenario outlined by the International Energy Agency. Long-term planning and forecasts are essential to achieving the target of 57% of world electricity supply from renewable energy resources by 2025. The



expanding role of solar energy in electricity production globally is evident, driven by concerns over negative externalities and irreversibility's associated with conventional energy production. Considerable investments and technological advancements have made solar energy production more cost-effective in recent years. Innovation in the solar energy field is vital for achieving high efficiency with minimal environmental impact. Researchers are exploring new materials, such as organic compounds, to reduce the cost of extracting and manufacturing solar cells. The environmental friendliness and lower production costs of organic materials offer potential benefits for solar photovoltaic cells. Notably, future advancements may include the concept of anti-solar cells, enabling electricity generation at night without sunlight. This review paper delves into these innovations and discusses the future trajectory of solar energy technology.

2 The weakness of the solar energy technologies

In contemporary times, the predominant material for manufacturing solar cells is silicon. The conventional fabrication process of crystalline silicon (C-Si) solar cells involves several key steps:

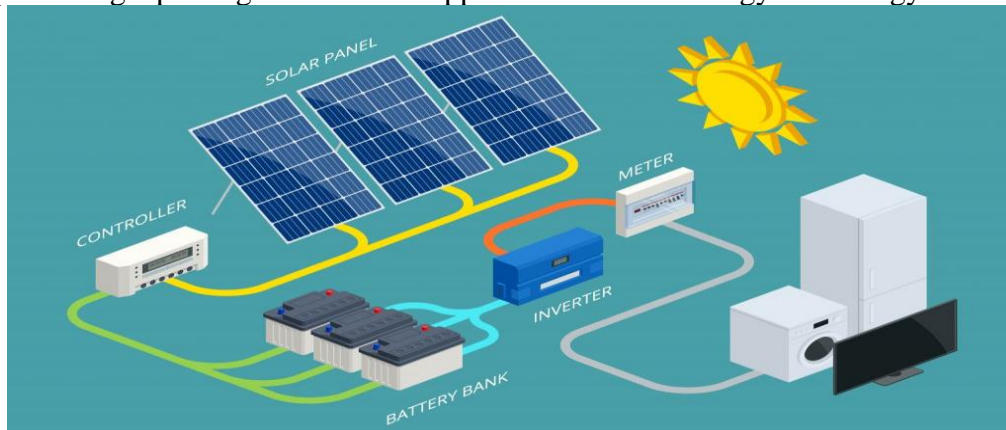
- Wafer cleaning and saw damage removal
- Surface texturing
- Doping of textured wafer for junction formation
- Antireflection coating and front surface passivation
- Metallization
- Edge isolation

High-purity silicon ingots, derived from silica, serve as the starting material for solar cell production. However, a notable limitation of solar energy is its availability only during daylight hours. Consequently, photovoltaic panels and collectors can only convert sunlight into energy when there is sufficient daylight. To ensure an uninterrupted power supply, an additional energy storage system is required, contributing to the overall cost and making solar systems more expensive. In traditional silicon solar cells, not all parts of the solar spectrum are absorbed; some wavelengths are wasted. This results in a relatively low conversion efficiency, typically around 20%. For larger-scale applications, a substantial number of photovoltaic cells are necessary to capture enough energy. The efficiency of photovoltaic panels drops significantly due to overheating, necessitating a considerable quantity of solar panels. The space requirement for solar collectors poses a challenging task, especially when considering alternative uses of space. Efficient harnessing of solar energy is contingent upon sunny conditions, making regions with unpredictable weather or adverse climates less reliable for solar energy. Additionally, the efficacy of solar cells is influenced by air pollution levels, with exhaust fumes and aerosols diminishing the current of silicon solar cells by 10% and 7%, respectively. These factors contribute to the ongoing challenges and considerations in the development and widespread adoption of solar energy technologies.

3 The innovations of solar energy technology

In contrast to traditional solar cells that cease electricity generation after sunset, the concept of anti-solar cells proposes the generation of electricity at night using solar cells. This innovative approach considers the Earth as a heat source and leverages radiative photovoltaic concepts derived from advancements in the field of radioactive cooling. The underlying physical principles of thermo-radiative cells closely resemble those of conventional photovoltaic cells. In the absence of sunlight, during thermal equilibrium of a p–n junction with its surroundings, the random absorption of photons by the cell equals the random emission from the cell, keeping the Fermi level constant through the semiconductor. When the p–n junction is at a higher temperature than its surroundings, the emission from the device predominates over absorption as the device attempts to cool. Connecting the cell to a thermal reservoir maintains a constant cell temperature. In this scenario, enhanced emission reduces the carrier concentration below its equilibrium value, creating a reverse bias voltage across the junction by splitting the hole and electron Fermi levels in opposite directions. Recombination of a hole and an

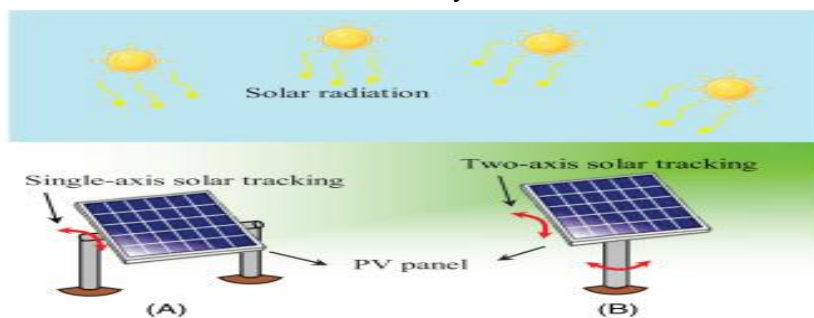
electron, unbalanced by photon absorption, leads to the insertion of an additional electron and hole via the contacts to compensate for the lost pair. When the cell is connected to a load, this situation results in the flow of current. The primary distinctions between a thermo-radioactive PV cell and a conventional PV cell lie in the direction of current flow and the reversal of the generated voltage's sign. In essence, the innovative thermo-radioactive PV cell enables the generation of electricity during the night, presenting a paradigm shift in the application of solar energy technology.



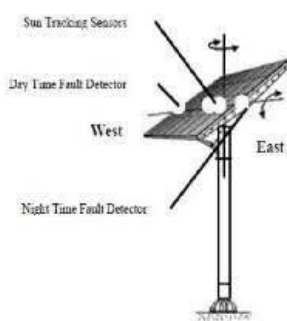
As an alternative to traditional semiconductor photovoltaic's, the optical rectenna concept has been introduced. A rectenna functions as a high-frequency rectifier system, comprising an antenna for receiving electromagnetic radiation and a diode that converts it into DC power. The primary applications of rectennas lie in infrared sensing and detection. Utilizing optical frequency rectennas for solar energy harvesting offers a potentially cost-effective pathway to achieve high-efficiency photovoltaics. The materials used are inexpensive and readily available, and the fabrication process is well-suited for roll-to-roll manufacturing. In contrast to semiconductor solar cells, which are fundamentally limited by the minimum frequency of harvestable radiation proportional to the band gap, a rectenna's frequency response depends primarily on the design of the antenna and its impedance match with the diode. Under the rectenna concept, it is possible to achieve efficiencies up to 100% under monochromatic illumination. Concentrated photovoltaic technology (CPV) represents a novel approach in solar power technology, employing mirrors and lenses to focus sunlight on solar cells for electricity generation. CPV offers advantages over non-concentrated photovoltaics, with one notable benefit being the reduced number of solar cells required for the same power output. However, the performance of solar cells is significantly influenced by sunlight intensity and temperature. High temperatures can lead to a 50% reduction in the performance of a solar cell under concentrated solar radiation, with the temperature rising from 46°C to 84°C, as demonstrated in a previous case study. To ensure maximum efficiency and prevent cell degradation and damage, an efficient cooling system becomes essential. Photovoltaic solar panels can be cooled through active or passive methods. In the active mode, an external power source is required to cool the system, whereas in the passive approach, no additional power source is needed. Table 1 provides a summary of the performance of active cooling systems for solar panels under various concentration techniques. The proposal of a micro-heat-pipe arrays system for solar panel cooling aims to address issues related to low energy output efficiency and thermal failure caused by elevated solar cell temperatures. Solar energy's widespread use is attributed to its limitless reserves, universality, cleanliness, and numerous advantages. Enhancing solar power efficiency is crucial, and several key approaches are suggested.

Improving the conversion efficiency of solar panels: Scientists are actively researching and inventing new solar panels, with Nano solar panels showcasing recent advancements in solar panel technology.

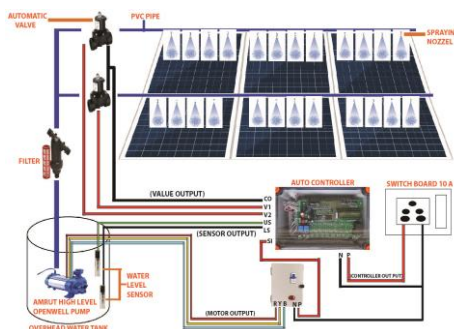
Automatic tracking system: Implementing an automatic tracking system that adjusts the orientation of solar panels with the changing perspective of sunlight can enhance the generating capacity. A simple automatic tracking solar system model is illustrated in Fig. 2.



Separating collection and transformation: Dividing the collection and transformation processes into two independent devices—one for collecting and strengthening solar energy (the collector) and the other for converting light energy into electrical energy (the converter)—can significantly increase generating capacity. Mirrors are utilized to construct the collector, and the converter enhances efficiency, surpassing traditional solar panels by a thousand times. The cleanliness and particle-free condition of solar panel surfaces are crucial for optimal efficiency. Dust-free panels, devoid of any particles obstructing photon flow, operate at maximum efficiency. To maintain cleanliness, an automated cleaning system is preferable to manual methods. Fig. 3 illustrates a cost-effective automation system for highly optimized solar panel array cleaning.



In solar cell generation, thin-film technology represents the second generation. Materials like Cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) are utilized in these flexible and efficient thin-film solar cells. Multi-junction solar cells, a type of thin-film solar cell, consist of two or more sub-cells combined to enhance overall cell efficiency by converting a broader spectrum of sunlight into electricity.



The innovative concept of a solar tree addresses the challenge of limited space for solar panel installation. Unlike traditional systems requiring vast land, the solar tree efficiently utilizes minimal space. The artificial tree, with photovoltaic cells arranged in a Fibonacci series manner in place of leaves, symbolizes a sustainable energy source that mirrors the functionality of natural trees. Fig. 4 depicts the artificial solar tree.



A solar unit tree, designed for the environmental conditions of Medellin in Colombia, stands at approximately 3.5 meters in height, with four leaves made of acrylic featuring solar panels on top. This tree has an energy storage capacity of about 180 Amp and includes six USB ports for connecting mobile devices, along with two 110v–200W electrical outlets. Solar energy holds great promise for meeting future energy demands. Researchers have made significant strides by studying the flow of solar energy within photosynthetic organisms, paving the way for higher-efficiency solar energy technology. A device designed with tungsten and alumina layers can absorb the sun's broad-spectrum radiation and convert it to electricity. Additionally, a dye-sensitized solar cell was fabricated using a green polymer derived from bio-waste.

4 Discussions

Conventional energy sources, relying on oil, natural gas, and coal, have historically been robust drivers of economic growth. Global primary energy consumption experienced a 1.8% growth in 2012, highlighting the rapid depletion of conventional sources and the escalating demand for energy. Recognizing the need for more efficient and environmentally friendly power plants, various organizations have advocated intensive research and the application of advanced technology. Solar energy technology, while promising, faces a challenge in its lower efficiency compared to non-renewable technologies in electricity generation. Nuclear and fossil-based power plants can generate a higher electricity capacity than solar power plants. To address this challenge, achieve maximum efficiency, and meet future energy demands, innovation and research in the solar energy sector are imperative. Despite the high initial costs and the need for advanced technology, such endeavors hold the potential to transform our planet into a better place by mitigating environmental impacts associated with non-renewable technologies. Solar power technology is evolving into its second and third generations, with a significant focus on nonmaterial's in research. Traditional silicon-based solar panels can only extract specific parts of the solar spectrum. However, the utilization of multi-junction solar cells enables the extraction of the entire solar spectrum, improving solar cell efficiency. Hybrid solar power technologies, such as solar-wind systems and solar-biomass technology, contribute to electricity generation during cloudy days and nighttime. Innovations in solar technology offer various benefits:

- Maximized Efficiency:
 - Extracting multiple parts of the solar spectrum results in maximum efficiency.
- Reduced Initial Cost:
 - Ongoing research and innovation can lead to cost reductions in solar technology.
- Flexible Solar Cells with Fewer Environmental Impacts:
 - Advancements in technology enable the development of flexible solar cells with minimized environmental impacts.
- Continuous Daytime Electricity Generation:
 - Solar technology enhancements facilitate efficient electricity generation during daylight hours.
- Optimized Efficiency in High-Temperature Regions:



- Concentrated solar technology proves more efficient in high-temperature regions compared to traditional solar technology.

Through persistent innovation, solar energy holds the potential to not only address its current limitations but also emerge as a sustainable and efficient solution for meeting global energy needs while minimizing environmental consequences. As we approach a potential global catastrophe resulting from a confluence of interconnected incidents, unprecedented in human social history, the imperative to shift away from our reliance on fossil fuels becomes evident. Despite this urgency, solar energy sources, while promising, are not without drawbacks. Presently, solar energy technologies face challenges in meeting the progressively growing global energy demands while simultaneously mitigating health and environmental impacts. To navigate these challenges, innovations and improvements are essential to enhance the efficiency of solar energy technologies, striving for parity with nonrenewable counterparts like nuclear power and fossil-based power. This paper aims to delve into the current weaknesses of solar energy technologies, shedding light on the limitations that impede their ability to adequately meet the escalating global energy needs while maintaining a minimal impact on health and the environment. Furthermore, the discussion extends to innovations and future trends in solar power, providing insights into the evolving landscape of the solar energy field. By understanding these challenges and advancements, we gain valuable insights into the future trajectory and direction of solar energy, crucial for addressing the pressing energy and environmental concerns of our time.

5 Conclusions

The conventional approach to power generation using solar energy is often deemed unsustainable in the long run due to inherent limitations and low power efficiency. Consequently, there is a global surge in the introduction of innovations to address these challenges. Among the critical innovative options, the ability to generate electricity at night stands out. Presently, solar energy technologies face limitations in providing sufficient energy to meet the growing global demand when compared to nonrenewable technologies. Therefore, innovations play a pivotal role in the solar energy sector, serving as a crucial factor for its development with optimal efficiency. This paper aims to present novel ideas and future perspectives on solar energy technology. In conclusion, innovation emerges as the remedy for advancing solar energy technology to effectively meet the rising energy demands of the future.

References

- [1] O. Peter, C. Mbohwa, Renewable energy technologies in brief, Renewable energy technologies in brief International Journal of Scientific and Technology Research, Vol.8, 1283-1289, 2019.
- [2] Thomas B. McKee, Nolan J. Doesken and John Kleist, Analysis of Standardized Precipitation Index (SPI) data for drought assessment, Water (Switzerland), Vol.26, 1-72, 1993.
- [3] H. Soonmin, S. Wagh, A. Kadier, I. A. Gondal, N. Putra Bin Abdul Azim, M. K. Mishra, Renewable energy technologies, Sustainable Innovation and Impact, 237 – 250, 2018.
- [4] J. Mohtasham, Review Article-Renewable Energies, Energy Procedia, Vol. 74, 1289-1297, 2015.
- [5] Thomas T.D. Tran, Amanda D. Smith, Evaluation of renewable energy technologies and their potential for technical integration and cost-effective use within the U.S. energy sector, Renewable and Sustainable Energy Reviews, Vol.80, 1372-1388, 2017.
- [6] M. A. Islam, M. Hasanuzzaman, N. A. Rahim, A. Nahar, and M. Hosenuzzaman, Global renewable energy-based electricity



- generation and smart grid system for energy security, *Scientific World Journal*, Vol.2014, 2014.
- [7] D. NchelatebeNkwetta, M. Smyth, A. Zacharopoulos, Trevor Hyde, Optical evaluation and analysis of an internal lowconcentrated evacuated tube heat pipe solar collector for powering solar air-conditioning systems, *Renewable Energy*, Vol.39, 65-70, 2012.
- [8] F.R. Pazheri , M.F. Othman , N.H. Malik, A review on global renewable electricity scenario, *Renewable and Sustainable Energy Reviews*, Vol.31, 835-845, 2014.
- [9] S. Abolhosseini, A. Heshmati, J. Altmann, A review of renewable energy supply and energy efficiency technologies, *IZA Discussion Paper Series*, 1-36, 2014.
- [10] Ronald-J.-Parise,-G.-F.-Jones,-Energy-from-deep-space-the-Nighttime-Solar-Cell™-electrical-energy-production, 35th Intersociety Energy Conversion Engineering Conference and Exhibit, 139-147, 2000.
- [11] S. Mughal, Y. Raj Sood, R.K Jarial, A Review on Solar Photovoltaic Technology and Future Trends,(NCRACIT) *International Journal of Scientific Research in Computer Science, Engineering and Information Technology* © 2018 *IJSRCSEIT*, Vol.1, 227-235, 2008.
- [12] F. M. Guangul, Girma T. Chala, Solar energy as renewable energy source: SWOT analysis, 2019 4th MEC International Conference on Big Data and Smart City, ICBDS 2019, 2019.
- [13] K.A. Moharram , M.S. Abd-Elhady , H.A. Kandil , H. El-Sherif, Enhancing the performance of photovoltaic panels by water cooling, *Ain Shams Engineering Journal*, Vol.4, 869-877,2013.
- [14] E. Kabir, P. Kumar, S. Kumar, Adedeji A. Adelodun, Ki-Hyun Kim,Solar energy: Potential and future prospects, *Renewable and Sustainable Energy Reviews*, Vol.82, 894-900, 2018.
- [15]T.E. Girish, Nighttime operation of photovoltaic systems in planetary bodies, *Solar Energy Materials and Solar Cells*, Vol.90, 825-831, 2006.
- [16] T. Deppe, and Jeremy N Munday, Nighttime Photovoltaic Cells: Electrical Power Generation by Optically Coupling with Deep Space, *ACS Photonics*, Vol.7, 1-9,2020.
- [17] Sachit Grover, Saumil Joshi and Garret Moddel, Quantum theory of operation for rectenna solar cells, *Journal of Physics D: Applied Physics*, Vol.46, 2013.
- [18] Saumil Joshi, Sachit Grover, and Garret Moddel, Efficiency limits of rectenna solar cells: Theory of broadband photonassisted tunneling, *Applied Physics Letters*, Vol.102, 2013.
- [19] Rizwan Arshad, Salman Tariq, Muhammad UmairNiaz, Mohsin Jamil, Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling, 2014 International Conference on Robotics and Emerging Allied Technologies in Engineering, iCREATE 2014 – Proceedings, 292-295, 2014.
- [20] BanchaSreewirote, AkeratanaNoppakant, and ChaichanPothisarn, Increasing efficiency of an electricity production system from solar energy with a method of reducing solar panel temperature, *Proceedings of the 2017 IEEE International Conference on Applied System Innovation: Applied System Innovation for Modern Technology, ICASI 2017*, 1308-1311,2017.