A REVIEW PAPER ON CURRENT TREND ON SOLAR PHOTOVOLTAIC TECHNOLOGY

Dharmraj Vanraj Dodiya
Department of Mechanical Engineering
Government polytechnic Himmatnagar

Abstract

In 2021 the solar photovoltaic (PV) sector passed several historic milestones: annual installations approached 170 GW, and cumulative global capacity neared 1 TW. Utility-scale PV became the least-cost source of new electricity in most regions, with a global weighted-average levelised cost of electricity (LCOE) of USD 0.048 /kWh—13 % lower than in 2020. Simultaneously, pandemic-related supply-chain shocks drove polysilicon prices to quadruple and temporarily reversed a decade-long decline in module prices. This paper reviews 2021 from a mechanical-engineering standpoint: global deployment and economics, the dominant and emerging cell architectures, manufacturing and materials challenges, system-integration advances, and key R&D directions.

1. INTRODUCTION

Mechanical engineers underpin every stage of the PV value chain—from crystallising ultrapure polysilicon to designing giga-watt-scale tracker arrays that withstand hurricane-force winds. The year 2021 was unique: demand surged even as COVID-19 disruptions and commodity inflation tested the resilience of manufacturing systems and logistics. Understanding the technical successes and bottlenecks of 2021 provides a baseline for future cost-reduction and performance-improvement strategies.

2. GLOBAL DEPLOYMENT AND ECONOMICS

Annual PV installations in 2021 reached around 167–182 GW, bringing the global cumulative capacity to approximately 940 GW. China led the market with 54.9 GW, followed by the USA and India. Solar became the largest source of new power capacity, and the global weighted-average LCOE fell to USD 0.048 /kWh, despite material and logistics price spikes.

3. CELL AND MODULE TECHNOLOGY STATUS IN 2021

Monocrystalline silicon dominated production, with p-type PERC leading but starting to give way to TOPCon and HJT due to higher efficiencies. The first certified perovskite-silicon tandem cell hit 28.2 % efficiency. Engineering trends focused on stress management, improved encapsulants, and bifacial module integration.

4. MANUFACTURING AND SUPPLY-CHAIN DYNAMICS

A polysilicon shortage sent prices up 4× versus 2020. Mechanical solutions included improved Czochralski furnaces and smarter slicing equipment. Efforts were made globally to diversify manufacturing locations and reduce reliance on China. Silver paste shortages triggered interest in copper-based alternatives.

5. SYSTEM INTEGRATION ADVANCES

Wider adoption of 1500 V systems, smarter single-axis trackers, and hybrid PV-storage plants occurred. These developments required coordinated mechanical and electrical engineering—e.g., foundation sharing, heat dissipation in storage cabinets, and vibration damping in large tracker arrays.

6. KEY TECHNICAL CHALLENGES OBSERVED IN 2021

Major challenges included: supply chain volatility, module reliability (e.g., delamination and chalking), increased demand for hail- and wind-resistant modules, and labor shortages that accelerated the need for modularization and robotic deployment.

7. RESEARCH & DEVELOPMENT OUTLOOK POST-2021

Future efforts include scaling tandem cells to GW levels, developing Ag-free contacts, integrating thermal and photovoltaic outputs, and designing for end-of-life recovery. AI-driven control systems for grid integration will continue gaining momentum.

8. CONCLUSION

2021 proved that solar PV can scale under pressure. Innovations in mechanical design, materials engineering, and manufacturing resilience were critical. Lessons from 2021 will be key to reaching terawatt-scale annual deployment and achieving solar-driven global decarbonization.

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