

Advances in Solar Thermal Energy Systems for Sustainable Power Generation

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Abstract

The increasing demand for energy, depletion of conventional fossil fuel resources, and growing environmental concerns have intensified the need for sustainable and renewable energy technologies. Solar thermal energy is a promising technology for clean power generation because it converts solar radiation into useful thermal energy that can subsequently be utilized for electricity production and industrial applications. This paper reviews recent advances in solar thermal energy systems with emphasis on their design, performance enhancement, thermal energy storage, and integration with power generation technologies. Various solar thermal collector technologies, including parabolic trough collectors, solar power towers, parabolic dish systems, and linear Fresnel reflectors, are discussed in terms of their operating principles and potential applications. Particular attention is given to advanced heat-transfer fluids, phase-change materials, and thermal energy storage systems that can improve energy conversion efficiency and enable power generation during periods of low or intermittent solar radiation. The paper also examines the role of computational modelling, intelligent control systems, and hybrid solar thermal configurations in optimizing system performance. Key challenges such as high initial investment, thermal losses, material durability, intermittency, and site-specific solar availability are highlighted. The study indicates that technological improvements in thermal storage, collector efficiency, and system integration can significantly enhance the reliability and economic feasibility of solar thermal power systems. Continued research and development in these areas can contribute to the transition toward cleaner, more resilient, and sustainable energy systems.

Keywords: Solar Thermal Energy, Renewable Energy, Concentrated Solar Power, Thermal Energy Storage, Heat Transfer, Solar Collectors, Sustainable Power Generation, Energy Efficiency