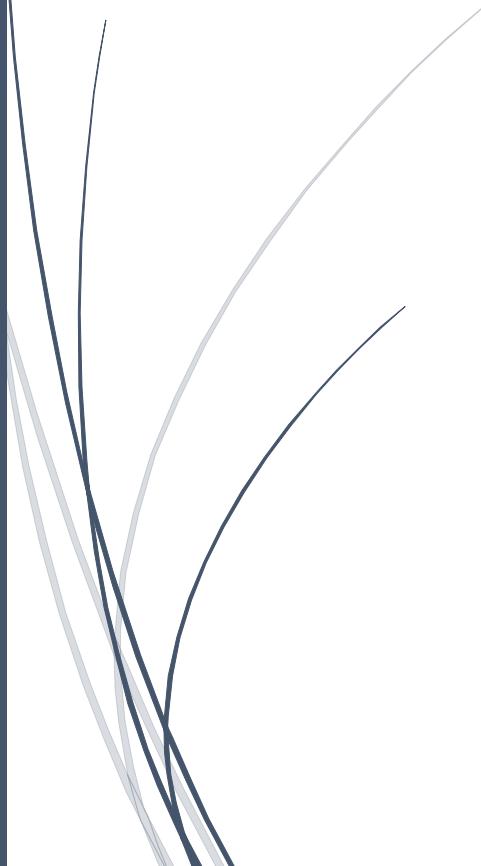


AI and ML for Solar Energy Forecasting and Optimization



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Abstract

The rapid adoption of solar energy as a sustainable power source necessitates the development of advanced forecasting and optimization strategies to address its inherent intermittency and variability. This chapter explores the integration of Artificial Intelligence (AI) and Machine Learning (ML) in enhancing solar energy forecasting and optimizing system performance. With a focus on cutting-edge techniques, such as ensemble methods, Random Forests, and neural architecture search, the chapter highlights how AI-driven models can improve the accuracy of solar power generation predictions across diverse geographical locations and weather conditions. Additionally, the role of AI in optimizing energy storage systems, ensuring efficient utilization of stored solar energy, and enhancing grid stability is critically examined. The challenges of explainability and trust in AI-based solar energy systems are also addressed, emphasizing the need for transparent and interpretable models to foster greater stakeholder confidence. Through a detailed discussion of data preprocessing, feature engineering, and the synergy between forecasting and optimization, this chapter provides a comprehensive overview of the transformative potential of AI and ML in solar energy systems. By bridging the gap between theoretical advancements and practical applications, the chapter aims to contribute to the continued evolution of solar energy technologies, ensuring a more reliable, efficient, and sustainable energy future.

Keywords: Solar Energy Forecasting, Machine Learning, AI Optimization, Energy Storage, Ensemble Methods, Neural Architecture Search.

Introduction

The transition towards renewable energy sources is imperative to address the growing concerns of climate change and the depletion of fossil fuels [1]. Among the various renewable energy sources, solar power stands out due to its abundance and sustainability [2]. As solar energy adoption accelerates globally, it becomes increasingly important to address the inherent challenges associated with its integration into existing power grids. The intermittent nature of solar power, influenced by fluctuating weather patterns, time of day, and seasonal variations, poses significant challenges to grid stability, energy storage, and overall system efficiency [3]. Accurate solar energy forecasting and system optimization are vital to ensuring a smooth and reliable integration of solar power into the broader energy mix [4]. Artificial Intelligence (AI) and Machine Learning (ML) have emerged as transformative tools to address these challenges, offering solutions that

enhance forecasting accuracy, optimize energy storage, and improve overall system performance [5].

Solar energy forecasting involves predicting the amount of solar energy that can be generated over a specific period, ranging from short-term (hours to days) to long-term (seasonal or yearly) forecasts [6]. Accurate forecasting is crucial for effective grid management, as it enables utilities to anticipate fluctuations in solar power generation and make necessary adjustments to ensure a balanced and reliable energy supply [7]. Traditional forecasting methods, often based on physical models, have limitations in accounting for the inherent variability of solar irradiance due to changing weather conditions [8]. AI and ML, with their ability to learn complex patterns from large datasets, have revolutionized solar forecasting by providing more precise and adaptive predictions [9]. By utilizing real-time meteorological data, satellite imagery, and historical solar generation data, AI-based models can significantly improve the accuracy of solar energy predictions, facilitating better decision-making for grid operators and energy managers [10].

The role of AI and ML extends beyond forecasting to the optimization of solar energy systems, particularly in the management of energy storage [11]. Solar energy generation does not always align with energy consumption patterns, with excess energy often produced during peak sunlight hours and demand peaking at night or during cloudy days [12]. To address this mismatch, energy storage systems, such as batteries, play a vital role in storing excess energy for later use [13]. AI-driven optimization techniques enable more efficient operation of these storage systems by predicting energy demand, optimizing charging and discharging cycles, and extending the operational life of storage units [14]. By continuously adjusting to real-time conditions, AI algorithms ensure that energy storage systems are utilized effectively, maximizing the use of solar energy while minimizing reliance on fossil fuels and grid imports. This optimization is crucial in ensuring that solar energy remains a reliable and flexible source of power, capable of supporting both residential and commercial energy needs [15].