

Role of Internet of Things (IoT) and AI in Smart Grid Optimization for Solar Energy

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Abstract

The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) has become a transformative force in the optimization of solar energy systems, offering innovative solutions to the inherent challenges of renewable energy management. This book chapter explores the synergistic role of IoT and AI in enhancing solar energy generation, storage, distribution, and consumption within smart grids. IoT devices, through continuous real-time data collection, enable precise monitoring of solar power generation, environmental conditions, and consumer demand. AI algorithms then leverage this data to optimize energy production, predict demand fluctuations, and enhance the efficiency of energy storage and distribution systems. The chapter highlights key advancements in AI-driven predictive analytics, anomaly detection, and demand-side management, demonstrating how these technologies can enable dynamic balancing of solar power supply with consumer demand. The integration of IoT with weather forecasting data and smart grid architectures is examined as a critical strategy for ensuring grid stability and sustainability in the face of fluctuating renewable energy production. The application of these technologies promises significant advancements in the efficiency, reliability, and scalability of solar power systems, supporting the transition towards a more sustainable and resilient energy future.

Keywords: Internet of Things (IoT), Artificial Intelligence (AI), Solar Energy Optimization, Smart Grids, Predictive Analytics, Demand-Side Management.

Introduction

The rapid advancement of renewable energy technologies has brought solar power to the forefront of sustainable energy solutions [1]. The integration of solar energy into the existing energy grid presents several challenges, primarily due to its intermittent nature and dependency on environmental factors [2]. Solar energy production is heavily influenced by weather conditions, time of day, and geographic location, resulting in fluctuations in power generation [3]. To address these issues, the incorporation of the Internet of Things (IoT) and Artificial Intelligence (AI) offers promising solutions [4]. These technologies provide a more efficient and reliable means of managing solar energy generation, distribution, and consumption by enabling real-time monitoring and data-driven decision-making [5]. The integration of IoT and AI allows for precise adjustments to solar energy systems, optimizing their performance and facilitating seamless integration into the broader energy grid [6].

IoT plays a crucial role in solar energy systems by providing real-time data collection from a vast array of sensors installed across solar panels, inverters, energy storage systems, and other grid components [7]. This data includes information on solar irradiance, temperature, energy production, battery levels, and even weather conditions, which is continuously transmitted to central processing systems [8]. The volume and complexity of this data make manual monitoring and decision-making impractical [8]. When paired with AI technologies, this data can be analyzed and used to make autonomous decisions, such as adjusting energy production rates or rerouting power to areas with higher demand [9]. This real-time feedback loop ensures that solar energy systems are always operating at their highest efficiency, minimizing waste and optimizing power delivery [10].

AI algorithms play a vital role in predictive analytics, one of the most critical aspects of solar energy optimization [11]. Through machine learning techniques, AI systems can analyze historical data and real-time inputs to predict solar energy generation based on environmental factors such as cloud cover, temperature, and sunlight hours [12]. These predictive capabilities enable grid operators and consumers to forecast energy availability more accurately, allowing for better planning and more efficient use of available resources [13]. In the context of demand-side management, AI can also predict when energy consumption is likely to peak, allowing for better scheduling of energy use or the shifting of demand to times when solar power generation is at its peak [14]. This reduces the need for backup power from conventional fossil fuel-based sources, contributing to a more sustainable energy system [15].

Integrating IoT and AI into solar energy systems, challenges remain in achieving seamless coordination between various technologies [16]. One of the primary challenges is ensuring the interoperability of IoT devices and AI models with existing infrastructure [17]. Solar power systems are often deployed in diverse geographical locations, and each installation may have different system requirements and configurations [18]. The challenge lies in adapting AI algorithms and IoT technologies to operate across such diverse systems while maintaining high levels of accuracy and reliability [19]. As the volume of data generated by IoT devices increases, ensuring robust data security and privacy becomes increasingly important. These issues must be addressed to fully leverage the potential of IoT and AI in solar energy optimization [20].