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IoT-Enabled Energy Monitoring and Predictive Maintenance for Renewable-Powered Healthcare System

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Abstract

The increasing integration of renewable energy sources within healthcare infrastructure has brought forward critical opportunities for sustainability, energy resilience, and operational efficiency, the dynamic nature of renewable energy systems demands intelligent oversight and predictive control to ensure uninterrupted power supply in clinical environments where reliability is non-negotiable. This book chapter explores the role of IoT-enabled energy monitoring and predictive maintenance architectures tailored for renewable-powered healthcare facilities. It presents a comprehensive examination of system design, communication protocols, sensor deployment, and real-time analytics that underpin proactive energy management. Special attention is given to the interoperability of monitoring platforms with hospital infrastructure, the implementation of secure data storage and redundancy mechanisms, and the strategic application of machine learning models for equipment health diagnostics, the chapter addresses risk mitigation through advanced cybersecurity frameworks, aligned with international compliance standards, to protect critical energy assets against digital threats. Case studies and emerging technologies are also analyzed to provide insights into real-world applications and advancements in the field. By bridging the disciplines of healthcare operations, renewable energy systems, and digital technologies, this work contributes to the evolution of intelligent, sustainable, and resilient hospital energy ecosystems.

Keywords: IoT monitoring, predictive maintenance, renewable energy, healthcare infrastructure, cybersecurity, smart energy systems

Introduction

Healthcare facilities are increasingly transitioning toward renewable energy integration to enhance sustainability, reduce carbon emissions, and achieve operational independence from conventional power grids [1]. This shift is driven not only by environmental considerations but also by the growing demand for energy security, especially in mission-critical environments like hospitals where continuous power is vital [2]. As decentralized energy resources such as solar photovoltaic systems, wind turbines, and energy storage units become part of healthcare [3]. The infrastructure, maintaining real-time visibility into their performance becomes essential [4]. Without robust monitoring and predictive capabilities, the benefits of renewable energy may be

compromised by unforeseen failures or inefficiencies, particularly in settings that require uninterrupted electrical supply for life-supporting equipment and digital healthcare systems [5].

The incorporation of Internet of Things (IoT) technologies has emerged as a transformative solution to this challenge [6]. IoT-based energy monitoring systems offer real-time data acquisition, fault detection, system diagnostics, and automated control features that optimize the performance of renewable energy components [7]. These systems are designed to gather granular data from a network of intelligent sensors deployed across energy generation, storage, and distribution subsystems [8]. When supported by machine learning algorithms and cloud analytics platforms, these data streams provide actionable insights into energy usage patterns, equipment degradation trends, and load forecasting [9]. In healthcare environments, such insights are critical for ensuring power reliability across intensive care units, operating theaters, diagnostic labs, and other sensitive medical zones [10].