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Wind Energy Applications for Sustainable Healthcare: Microgrid and Hybrid Energy System Approaches

P. Nagasekhar Reddy, R. Jegadeesh Kumar
MAHATMA GANDHI INSTITUTE OF TECHNOLOGY,
KARPAGAM COLLEGE OF ENGINEERING

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[1]P. Nagasekhar Reddy, Associate Professor, Department of Electrical and Electronics Engineering, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India. pnsreddy04@gmail.com

[2]R. Jegadeesh Kumar, Assistant Professor, Department of Electrical and Electronics Engineering, Karpagam College of Engineering, Coimbatore, Tamil Nadu, India jegadeeshkumar.eee@gmail.com

Abstract

The growing energy demands of healthcare facilities, combined with the pressing need for climate-resilient and low-carbon infrastructure, have positioned renewable energy integration as a strategic priority in medical operations. This chapter explores the application of wind energy within microgrid and hybrid energy system frameworks to support sustainable and uninterrupted healthcare delivery. In regions where grid access is unreliable or non-existent, hybrid systems combining wind, solar, diesel, and energy storage offer a robust solution to ensure the continuity of critical healthcare services. The discussion emphasizes system architecture, energy storage integration, load prioritization, and automation controls, with a focus on rural and remote health facilities. Technical challenges, economic feasibility, and cybersecurity considerations are analyzed to provide a comprehensive understanding of the deployment and management of autonomous wind-powered systems. Case studies and simulation-based evaluations are used to illustrate lifecycle performance, cost-effectiveness, and reliability. By advancing knowledge in hybrid system design and control strategies tailored to healthcare, this chapter contributes to the global pursuit of resilient, decarbonized medical infrastructure aligned with sustainable development goals.

Keywords: Wind energy, Hybrid energy systems, Healthcare microgrids, Energy resilience, Sustainable healthcare, Renewable integration

Introduction

The demand for uninterrupted and reliable energy in healthcare systems is growing significantly due to increasing technological reliance, rising patient loads, and the expansion of services across geographically dispersed regions [1]. Energy is fundamental for operating life-saving equipment, maintaining sterile environments, powering diagnostic tools, and ensuring the cold chain for sensitive medications [2]. In rural and underserved communities, healthcare infrastructure is often hindered by unreliable grid connections or complete absence of centralized electricity supply [3]. This disparity undermines the ability of health institutions to deliver consistent and quality care, especially during emergencies or public health crises [4]. Consequently, there is a growing

recognition of the need to decentralize energy generation and integrate renewable energy solutions tailored to the unique operational requirements of healthcare environments. Renewable technologies offer the dual advantage of energy security and environmental sustainability, addressing both the continuity of care and the sector's growing carbon footprint [5].

Among renewable options, wind energy holds a distinct advantage due to its scalability, site versatility, and ability to complement other sources like solar photovoltaic systems [6]. When deployed as part of a hybrid energy framework, wind power enhances supply stability by contributing energy during non-daylight hours or low solar generation periods [7]. This is especially beneficial in coastal, high-altitude, or open plain regions where wind resources are plentiful and predictable. Hybrid energy systems combining wind, solar, and backup diesel or battery storage can be configured into microgrids that operate either in tandem with the main grid or in fully autonomous island modes [8]. These configurations are vital in healthcare applications where even brief outages can result in critical service disruptions [9]. By integrating multiple energy streams, hybrid microgrids support consistent load balancing, reduce fuel dependency, and ensure sustainability in healthcare operations across both urban and remote settings [10].