Chapter 12

Graph-Theoretic and Geospatial Intelligence Framework for Optimizing Smart Grid Structures Using Hybrid Drones

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ABSTRACT

This paper proposes G-O-HA, a graph theory-based framework integrating heuristic algorithms and hybrid drones to optimize smart grid performance. Smart grids are modelled as dynamic graphs, with Particle Swarm Optimization (PSO) identifying efficient routing paths and enhancing energy distribution. Hybrid drones equipped with multispectral sensors and LiDAR conduct aerial inspections and real-time fault localization. Geospatial data from drones continuously updates the optimization model, enabling adaptive maintenance and network reconfiguration. Applied to

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real-world scenarios, G-O-HA reduces fault recovery time by 35% and improves communication efficiency and throughput. The study demonstrates how combining graph theory, heuristic optimization, and drone intelligence can build resilient, responsive power systems.

INTRODUCTION

Power grids' fast transition into intelligent and digitalized networks, known as smart grids, has changed energy generation, delivery, and consumption (Abrahamsen et al., 2021). Modern communication technologies, distributed energy resources, and automation systems will be integrated into future power grids to supply efficient, reliable, and environmentally friendly electricity. However, as smart grid systems become more complex, more sophisticated and adaptive management systems are needed. They must handle huge amounts of data in real time and adapt to changing topologies. A smart grid needs a communication network for several reasons.

This network monitors, manages, and preserves energy using sensors, actuators, substations, and control centers. Traditional communication systems have several limitations (Sharma et al., 2023). Constraints include inefficient problem detection, routing procedures, late information transfer, and energy consumption from poorly constructed network links. Scalability, reactivity, and system reliability are all affected by such restrictions. This is particularly true in dispersed systems like renewable energy grid integration. Graph-based mathematical techniques may solve such problems well (Li et al., 2023). Graphs illustrate the interaction between smart grid nodes via edges. This abstraction improves visualization, analysis, grid network optimization, and complexity. Intelligent heuristics and graph theory make this strategy useful in improving smart grid communication topologies. It optimises topologies and improves energy distribution. This system uses nature-inspired PSO to dynamically determine optimal routing patterns, decrease energy losses, and maximize fault detection and recovery.

Heuristic algorithms provide flexible, near-optimal solutions to extremely nonlinear, multidimensional optimization issues seen in smart grid management. Current deterministic techniques are not like this. In real time, the G-O-HA architecture can respond to load demands, grid conditions, and faults (Fawaz et al., 2025). This is because the framework depicts a dynamic smart grid network. This technique enables load balancing, fault isolation, and real-time monitoring, making the grid more autonomous and resilient. Performance studies and simulations show the framework's benefits. Modifications include a 30% decrease in fault recovery time, much lower communication latency, and better energy transfer efficiency (Mezair et al., 2022). Grid network reliability and throughput have improved significantly.

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