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IoT-Driven Smart Grid Resilience: Real-Time Fault Detection, Adaptive Load Balancing, and Cloud-Edge Automation for Sustainable Energy Distribution

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Abstract: *The rapid evolution of power distribution networks demands innovative solutions to enhance reliability, efficiency, and adaptability. This study presents an IoT-based grid control and feeder management system designed to automate fault detection, load redistribution, and remote monitoring in electrical substations. By integrating Arduino Nano microcontrollers, NodeMCU Wi-Fi modules, and servo-driven actuators, the system enables real-time temperature monitoring of transformers using DHT11 sensors and triggers automated load shifting via relays when thresholds are exceeded. The IoT framework leverages MQTT and HTTP protocols to transmit data to a cloud server, allowing users to monitor grid parameters and manually override operations through a Blynk mobile application. Experimental validation demonstrated a 30% reduction in outage durations by enabling sub-second fault responses and dynamic feeder adjustments. Key innovations include energy-efficient servo mechanisms for precise feeder control, hybrid cloud-edge data processing to minimize latency, and a user-centric interface for seamless remote management. Challenges such as sensor calibration drift and network stability were addressed through adaptive algorithms and redundant communication pathways. Results confirm the system's scalability for smart city deployments, with potential annual cost savings of 18% in maintenance and energy losses. Future extensions could integrate machine learning for predictive fault analytics and blockchain for secure grid data transactions. This work underscores IoT's transformative potential in modernizing power infrastructure, offering a robust blueprint for sustainable, self-healing grids.*

Keywords: Smart grid, IoT, load balancing, fault detection, remote monitoring, servo control