Rescue Grid for Disaster Zones

R Divya
Department of EEE
PSG Institute of Technology and Applied Research
Tamilnadu, India
divya@psgitech.ac.in

A Krishnaprakash
Department of I&CE
PSG Institute of Technology and Applied Research
Tamilnadu, India
krishnaprakash8116@gmail.com

R S Ramprasaath
Department of I&CE
PSG Institute of Technology and Applied Research
Tamilnadu, India
rsramprasaath@gmail.com

P Pradeep
Department of I&CE
PSG Institute of Technology and Applied Research
Tamilnadu, India
pp2075597@gmail.com

S Parthiv
Department of I&CE
PSG Institute of Technology and Applied Research
Tamilnadu, India
sparthiv85@gmail.com

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***Abstract*—Disasters cause widespread power outages, isolating affected communities and hindering essential services. This paper presents a Smart Grid system integrating solar energy, battery storage, real-time IoT monitoring, and a hand-crank generator. By distributing energy to local hotspots with minimal loss, the system ensures reliable power for communication, lighting, and basic appliances in disaster-affected areas. Powered by a 10W solar panel and a portable 12V battery, energy flow is managed by Arduino UNO and ESP32 microcontrollers. Current and voltage are monitored using INA219 sensors, with data transmitted to a custom website. A hand-crank generator supplements power during emergencies. This study discusses the design, implementation, benefits, challenges, and future enhancements of this portable smart grid.**

Keywords: Smart Grid, Disaster Management, Portable Power, IoT, ESP32, Hand-Crank Generator

I. INTRODUCTION

Electricity has emerged as a pillar for societal infrastructure and economic operations in the modern world. Its importance goes beyond mere convenience to include healthcare services, emergency communication, disaster response coordination, and fundamental sustenance requirements like heating, lighting, and water purification. Nevertheless, natural disasters like earthquakes, floods, cyclones, and landslides ravage centralized power infrastructure at will, leaving people in the dark and causing essential services to be interrupted. Such extended power outages can exacerbate the humanitarian emergency, impacting food storage, hospital functions, and communication networks essential for coordinating relief operations.

Ensuring a dependable and rapidly deployable source of power thus becomes not just a logistical imperative but also a moral one in this situation. Traditional energy backup systems, which are usually diesel-fueled generators, have various disadvantages in emergency situations. Their dependency on supply chains for fuel, environmental degradation, maintenance needs, noise levels, and inefficiency in scaling up for numerous distant hotspots restrict their applicability. Moreover, their size makes them inappropriate for territories where access routes can be affected.

This work proposes a Smart Grid solution exclusively designed for disaster-ravaged areas, incorporating renewable energy generated through portable solar panels, battery storage, and a hand-powered hand-crank generator. Combined with real-time monitoring and control facilitated through microcontrollers (Arduino UNO and ESP32), the grid guarantees efficient, flexible, and environmentally friendly power supply to localized hotspots like temporary hospitals, refugee camps, and communication centers.

Its modularity and mobility are the major breakthroughs, as individual modules can be carried, installed, and scaled depending on needs. Its power redirection and real-time load monitoring features reduce wastage and maximize energy efficiency under scarce supply situations. In addition, the presence of a manual generator guarantees essential services are available even in prolonged low-light conditions or when equipment fails.

System architecture is carefully chosen so that simplicity and functionality are both balanced, utilizing commonly available and affordable hardware components such as a 10W solar panel, the INA219 current sensor, a 12 V two-wheeler battery, a 5 V DC motor as load, and regulation circuits employing 7805 voltage regulators and BJT DC547 transistors. The hand-crank power generator, built from a 12 V variable-speed 1400 RPM motor and a hand-pulley, can transform mechanical energy into electricity when sunlight or other typical sources are not present.

Software-wise, the microcontroller programming with Arduino IDE provides ease of access and flexibility for quick modifications, while the IoT features brought in through ESP32 enable real-time, web-based monitoring with an HTML, CSS, and JavaScript dashboard. This enables remote supervision by relief authorities or command centers, enabling active load management choices, hence improving efficiency and reliability of operations.

This document offers a thorough system design analysis, a full examination of hardware requirements, functional flow, operational outputs, and possible enhancements. It places the Smart Grid prototype not only as a technology showcase but as a functional and essential instrument in disaster management protocols, scalable, replicable, and adaptable to various crisis environments. Future upgrades may include AI-driven predictive load balancing, integration with satellite communications for telemetry, and hybrid power feeds from micro wind generators or portable biofuel generators.

The following sections present the literature context summarizing existing research in the area, outline the operational challenges and goals through a problem statement, describe hardware and software architectures,

VII. CONCLUSION AND FUTURE SCOPE

The paper introduced the design, development, and operational testing of a portable Smart Grid system specifically adapted for emergency power distribution in disaster-stricken locations. By its incorporation of solar-powered renewable generation, hand-cranked manual backup, secure battery storage, and smart IoT-based monitoring, the prototype was able to overcome major disadvantages of traditional emergency power solutions. The system proved to be consistently operational in a variety of test scenarios, ensuring its deployability in fast-paced critical situations where mainstream infrastructure is at risk.

The real-time data collection and remote monitoring features of the system through ESP32 and customized web dashboards provided improvement in situational awareness and control agility for relief operators, with optimized energy distribution at minimal human intervention. Prioritization algorithms internal to the Arduino UNO microcontroller effectively dealt with dynamic load scenarios, ensuring vital services were maintained even under limited generation conditions. Additionally, the hand-crank generator was a priceless addition to ensure power continuity in the absence of solar input, further enhancing the system's operational reliability.

Project highlights of note are:

• Efficient integrating renewable and human-powered power sources.

• Real-time IoT-based monitoring of system performance indices.

• Robust load management and emergency load prioritization.

• Compact, modular, and field-deployable hardware assembly.

• Data logging and buffering for operation redundancy.

As part of the system's evolution, enhancing data security was identified as a critical area, particularly due to the reliance on Wi-Fi-based communication in high-stakes, disaster-affected zones. The transmission of sensor and system data from the ESP32 microcontroller to a web dashboard introduces potential vulnerabilities that could compromise operational integrity. Unencrypted communication, lack of authentication, susceptibility to firmware exploits, and man-in-the-middle attacks were highlighted as possible risks.

To mitigate these, a comprehensive set of countermeasures was proposed. TLS/SSL encryption using the WiFiClientSecure library and SSL certification (e.g., Let's Encrypt) ensures end-to-end secure communication. A token-based authentication mechanism allows only verified devices to transmit data, thus avoiding unauthorized data injections. The use of MQTT protocol over TLS with broker-side authentication (via Mosquitto) was also considered, providing a lightweight and secure alternative to HTTP.

Further security measures include implementing secure Over-The-Air (OTA) updates using signed firmware and version control to prevent malicious code uploads. The web dashboard is protected through password authentication, with role-based access control and future provisions for two-factor authentication (2FA).

To maintain data integrity and availability during network outages, the system integrates checksum verification using SHA-256 hashing and supports local data logging via SD card modules. This allows for delayed synchronization once connectivity resumes.

Future enhancements may explore blockchain-based data logging for tamper-proof record-keeping and the application of AI models to detect anomalies in real-time system behaviour. For expanded coverage in rural or dispersed areas, LoRa and mesh networking are under consideration—with full encryption to maintain data confidentiality and reliability.

The effort reported here lays a foundation for community-driven, sustainable, and large-scale disaster management power applications [10]. There are potential avenues on which future research might expand to not only enhance this solution, but apply to different domains of use. First, the current appendix contains substantial room for improvement to include additional renewable power generation modules, such as deployable micro-wind generators and/or micro-biomass power generators. This increased diversity of power inputs will diversify the energy supply chain, allow for constant availability, independent of weather and climate [8].

Second, integrating cloud storage and analytics would also provide capabilities that extend analysis of historical usage data along with predictive maintenance, load forecasting to spatially locate support needs, and some level of anomaly detection employing AI models [9]. The addition of GSM-based SMS alert systems would further enhance communication about outages across a broader landscape where recipients are not on the internet. Execution, further development, and the efficacy of storage subsystems based on integration of lithium-ion batteries designed for higher energy density, reduced-charge / discharge cycle and system integration will increase portability, and produce more efficient systems overall. Enlarging the software platform to accommodate multi-site monitoring and centralized dashboard for greater disaster response networks could also significantly improve coordination and energy resource allocation in large-scale calamities. Subsequent versions can include encrypted communication protocols to ensure better data security in sensitive relief efforts.

In summary, the Smart Grid prototype shows enormous promise as a practical, scalable, and ecologically friendly emergency power system. Its low cost, ease of construction, and flexibility make it a key resource for governments, NGOs, and community disaster resilience efforts globally. With development of the suggested upgrades, shipping versions can become a stand-alone, AI-controlled, multi-source microgrid platform that can revolutionize disaster response energy infrastructure.

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