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Implementation of Intentional Islanding Algorithm for Distributed Energy Resources in Disaster Management Using Arduino Uno

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Abstract: *Power system stability is vital during disasters, especially in regions that rely heavily on Distributed Energy Resources (DERs). This study focuses on creating a practical solution by introducing an Intentional Islanding Algorithm. The algorithm is designed to ensure a steady energy supply when the main grid experiences faults or disruptions. At the heart of the system is an Arduino controller, which detects grid issues and switches seamlessly to an islanded mode. During this mode, renewable energy sources like solar power and battery backups are utilized to keep the power flowing, with priority given to critical loads to ensure their uninterrupted operation. The system was thoroughly tested in different fault scenarios, and the results demonstrate its capability to respond effectively, maintain energy flow, and adapt to changing conditions without requiring manual intervention. This research provides a straightforward and reliable approach to building disaster-resilient energy systems. By combining affordability with efficiency, the solution aims to inspire future advancements in making energy systems more robust and dependable, even under challenging circumstances.*

Key Words: *Distributed Energy Resources, Renewable Energy System, Solar Photo Voltaic (PV), LVDC, Intentional Islanding, Arduino Uno.*
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1. INTRODUCTION:

Power outages caused by natural disasters or technical failures can severely disrupt daily life, halting critical services and affecting the well-being of entire communities. These disruptions highlight the importance of having resilient power systems that can adapt and sustain energy delivery during emergencies. Traditional grids, often centralized and rigid, are especially vulnerable to faults that may lead to widespread blackouts. To address this issue, Distributed Energy Resources (DERs) such as solar panels, wind turbines, and battery storage have become essential components of modern energy systems, offering not only sustainability but also a means to improve grid flexibility and reliability. One of the most effective strategies for leveraging DERs in emergencies is intentional islanding. This concept involves isolating a segment of the grid, known as a microgrid, from the primary power network when faults occur. In this state, the microgrid operates independently, ensuring a stable power supply to critical loads such as hospitals, emergency services, and communication networks. Intentional islanding has emerged as a critical tool for enhancing disaster preparedness and maintaining energy continuity in vulnerable regions.

This research focuses on developing and implementing an Intentional Islanding Algorithm designed to ensure a reliable energy supply during grid failures. The system uses a cost-effective setup comprising an Arduino controller, voltage sensors, and relays to detect grid faults and initiate islanding. Once isolated, the system seamlessly manages the distribution of energy from DERs to sustain essential loads. By prioritizing critical energy demands, the solution effectively mitigates the impact of outages on vital services. The proposed system is particularly valuable for areas with limited resources, as it offers a low-cost, practical approach to improving energy resilience. Rigorous testing under different fault scenarios has demonstrated the system's ability to maintain energy stability during emergencies, validating its potential for real-world deployment. By integrating DERs into disaster response frameworks, this study addresses both immediate energy needs during emergencies and the broader goal of sustainable energy solutions. The findings contribute to the growing body of knowledge on how intentional islanding can play a key role in building resilient power systems capable of adapting to and overcoming challenges posed by disasters.

2. LITERATURE REVIEW:

The concept of intentional islanding is crucial for ensuring power continuity during grid disturbances, such as natural disasters, by isolating specific parts of the grid. Many researchers have examined this strategy, looking into different algorithms, monitoring systems, and how renewable energy can play a role in making these systems more resilient in emergencies.

In their work, Yezhou Wang, Chen Chen, Jianhui Wang, and Ross Baldick [1**]** tackled the issue of power grid disruptions during extreme weather events. They highlighted the importance of proactive measures, such as planning ahead of storms and quickly restoring power once the disruption is over. Their research showed how enhancing these methods could improve grid reliability, but they also pointed out the need for better frameworks that integrate distributed energy sources (like solar and wind power) to support disaster response efforts.

Another group of researchers, Giuseppe Barone, Giovanni Brusco, Alessandro Burgio, Daniele Menniti, Anna Pinnarelli, and Nicola Sorrentino [2]**,** focused on DC microgrids and how islanding could be implemented using DC bus voltages to detect and manage disconnections from the grid. While their approach proved successful in DC systems, the transferability of these techniques to AC microgrids (which are more common in larger power grids) still remains an open question.

M. Ankush Kumar and A. Jaya Laxmi [3] explored islanding algorithms in distributed energy systems. Their work, from 2016, emphasized the importance of these algorithms for grid stability during emergencies. However, they didn't delve deeply into the communication technologies needed for managing distributed energy resources (DERs) during crises. Later, in 2021, they developed a more comprehensive framework for implementing islanding algorithms in real-time systems, but they also pointed out the rising concern of cybersecurity risks in energy systems that are becoming more connected and digitally managed.

3. OBJECTIVES:

This thesis aims to create a practical and efficient energy management system that brings together solar power, grid electricity, and battery storage to ensure reliable energy availability. Using an intentional islanding algorithm, the system is designed to keep power flowing even during disasters when the main grid may not be operational.

Here are the key objectives of the project:

1. **Bringing Energy Sources Together:** The system integrates solar panels, batteries, and grid electricity into a single platform, providing a dependable and sustainable power supply.
2. **Ensuring Smooth Transitions:** It facilitates seamless switching between energy sources, so the power supply remains uninterrupted no matter the circumstances.
3. **Real-Time Monitoring Made Easy:** A simple, user-friendly interface lets users monitor energy generation, usage, and load distribution in real time, making the system easy to manage.
4. **Flexible Control Options:** The system offers both manual control through buttons and remote operation via Bluetooth, giving users the flexibility to manage loads conveniently.

Through these objectives, the thesis aims to demonstrate how combining renewable energy with smart controls can provide reliable, cost-effective, and sustainable solutions for energy management. The use of Arduino Uno makes the system accessible, affordable, and adaptable for real-world applications.

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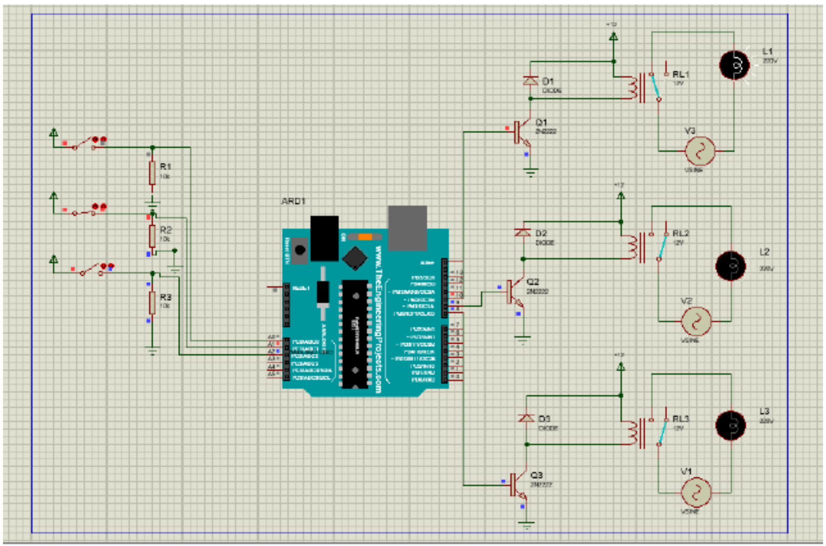

Fig. 3.1 Software Design of Prototype Module

4. RESEARCH METHODOLOGY:

This paper focuses on the implementation of an Intentional Islanding Algorithm designed to enhance the reliability and efficiency of Distributed Energy Resources (DERs) during disaster scenarios. The system prioritizes energy sources and ensures continuous power supply by utilizing Arduino UNO as the central controller. The following methodology outlines the hardware and software integration used to develop a cost-effective and reliable energy management system.

System Design and Components:

The proposed system integrates various components to manage power distribution effectively during grid outages:

1. **Arduino UNO**: Serves as the core controller, managing power source selection and load prioritization.
2. **Voltage Sensors**: Monitor the availability of solar, grid, and battery power by detecting voltage levels.
3. **Relays**: Enable the seamless switching of power sources and control load connections.
4. **LCD Module**: Displays real-time information about the active power source and load status.
5. **12V Battery and Inverter**: Act as backup energy sources during grid failures.
6. **Manual Control Buttons**: Allow testing of specific conditions, such as simulating peak hours or low battery levels.

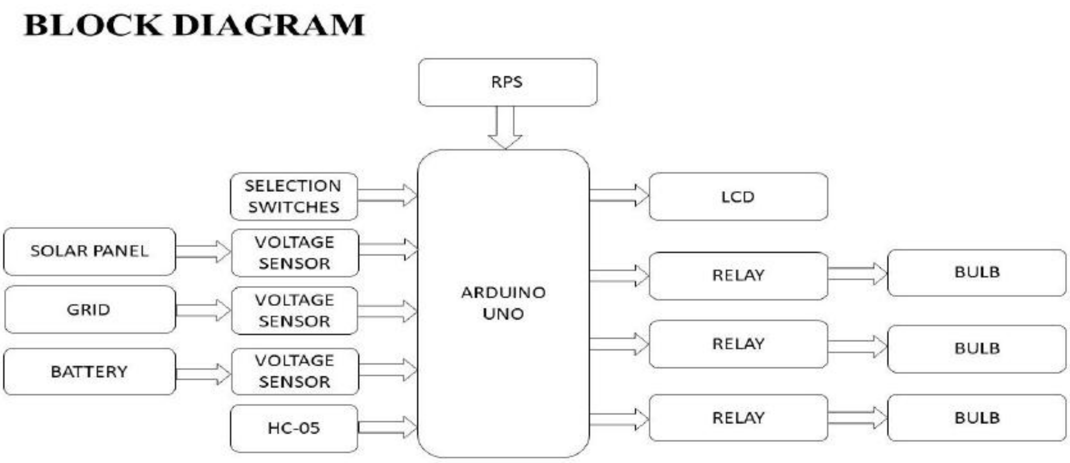

Fig. 4.1 Block Diagram for the Proposed Intentional Islanding Algorithm

Operational Framework:

The system uses a stepwise approach to prioritize energy sources and manage loads efficiently during various scenarios:

1. **Energy Source Prioritization**:
   - **Primary Source: Solar Power**
     Solar energy is utilized as the first preference. When available, it powers all loads, including high-priority, normal-priority, and low-priority loads.
   - **Secondary Source: Grid Power**
     If solar energy is unavailable, the grid becomes the default source. During peak hours, only high-priority and normal-priority loads are powered, while low-priority loads are disconnected. If it is not peak hours, all loads are supplied from the grid.
   - **Tertiary Source: Battery Backup**
     When both solar and grid power are unavailable, the battery is used. Load operation depends on the battery's charge level:
     - **Battery > 40%**: high-priority and normal-priority loads..
     - **Battery ≤ 40%**: Only high-priority loads are powered.

2. **Load Categorization and Control**:
   - **High-Priority Load**: Essential systems that require uninterrupted power.
   - **Normal-Priority Load**: Moderate systems that function under normal conditions.
   - **Low-Priority Load**: Non-essential systems that can be disconnected during emergencies.
3. **Automatic Switching**:
   The relays enable automatic switching between power sources based on availability, ensuring an uninterrupted supply to critical loads.

Hardware Configuration:

The system's hardware setup is designed for efficient operation:

- Voltage sensors track the availability and condition of solar, grid, and battery power.
- Relays manage the switching of power sources and load connection/disconnection.
- The Arduino UNO executes the algorithm and communicates the system status through the LCD display.
- Manual buttons simulate real-world scenarios, such as peak hours or low battery levels, to test the system effectively.

Implementation Process:

1. **Component Setup and Calibration**:
   Hardware components are connected and calibrated to ensure accurate voltage monitoring and reliable operation.
2. **Algorithm Development**:
   The intentional islanding algorithm is written and uploaded to the Arduino UNO using the Arduino IDE. The algorithm controls source prioritization and load management.
3. **Scenario Testing**:
   The system is tested under various scenarios, such as solar power availability, grid peak hours, and low battery conditions, to evaluate its performance.
4. **Validation and Analysis**:
   The performance of the system is analyzed under different conditions to ensure energy continuity and reliability.

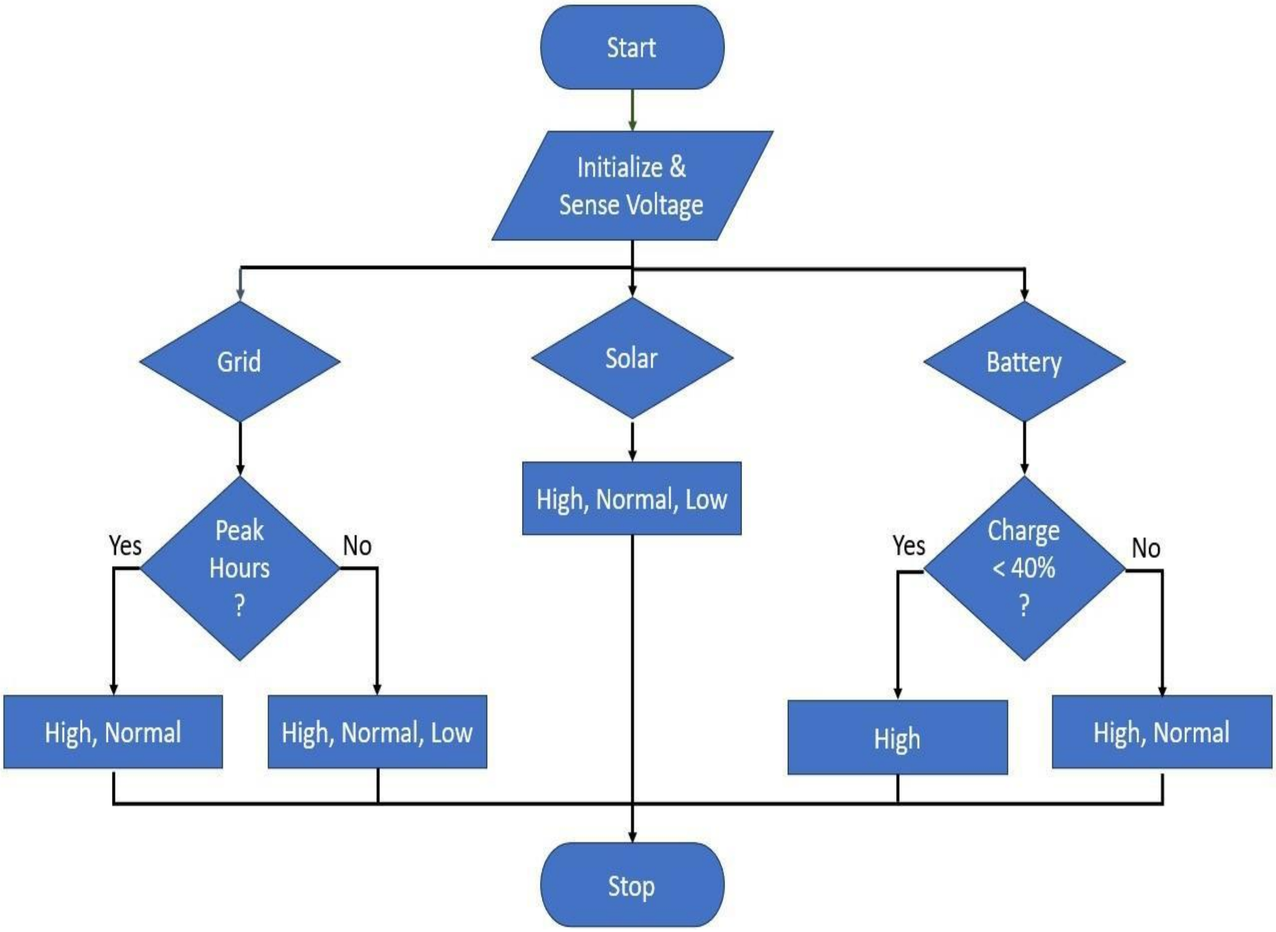

Fig. 4.2 Flowchart for the Proposed Intentional Islanding Algorithm

Key Benefits of the Proposed System:

This approach provides a cost-effective and practical solution for managing power during disasters. By effectively utilizing DERs, the system ensures reliable energy distribution and strengthens resilience in disaster management frameworks.

5. RESULTS:

The prototype demonstrated reliable performance across all test conditions:

- **Fault Detection**: The system identified faults swiftly and isolated the grid within milliseconds.
- **Power Continuity**: The intentional islanding mechanism ensured uninterrupted supply to critical loads.
- **Scalability**: The modular nature of the design supports future integration with additional DERs.
- **Efficiency**: Minimal energy losses were observed during transitions between grid-connected and islanded modes.

A sample prototype with 230 volts and 50 Hertz is developed. The voltage is then decreased to 12 volts by means of a step down transformer and the bridge rectifier is used to convert the lower voltage into direct current from alternating current. Regulator LM7805 is used for regulating the voltage from 12V to 5V. The converter and the inverter both utilize it to create an ON/OFF pulse from time to time. The functioning of the controller is simplified by the allocation of buffers. Different types of switches like MOSFETs, capacitors, and inductors are used

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Case 1: Load Status During Solar-Powered Operation

Table 5.1 Load Status During Solar-Powered Operation

Load Category	Load Priority	Status
High-Priority Load	High	ON
Normal-Priority Load	Medium	ON
Low-Priority Load	Low	ON

Case 2: Load Status During Grid-Powered Operation

Case 2.1: Load Status During Grid Operation in Non-Peak Hours

Table 5.2: Load Status During Grid Operation in Non-Peak Hours

Case	Load Category	Power Source	Load Status
Grid Operation (Non-Peak Hours)	High-Priority Load	Grid Power	ON
	Normal-Priority Load	Grid Power	ON
	Low-Priority Load	Grid Power	ON

Case 2.2: Load Status During Grid Operation with Peak Hours

Table 5.3: Load Status During Grid Operation with Peak Hours

Case	Load Category	Power Source	Load Status
Grid Operation (Peak Hours)	High-Priority Load	Grid Power	ON
	Normal-Priority Load	Grid Power	ON
	Low-Priority Load	Grid Power	OFF

Case 3: Load Status During Battery-Powered Operation

Case 3.1: Load Status During Battery Operation with Charge Above 40%

Table 5.4: Load Status During Battery Operation with Charge Above 40%

Case	Load Category	Power Source	Load Status
Battery Operation (Charge > 40%)	High-Priority Load	Battery Power	ON
	Normal-Priority Load	Battery Power	ON
	Low-Priority Load	Battery Power	OFF

Case 3.2: Load Status During Battery Operation with Charge Below 40%

Table 5.5: Load Status During Battery Operation with Charge Below 40%

Case	Load Category	Power Source	Load Status
Battery Operation (Charge < 40%)	High-Priority Load	Battery Power	ON
	Normal-Priority Load	Battery Power	OFF
	Low-Priority Load	Battery Power	OFF

6. CONCLUSION:

This paper presents the successful implementation of an Arduino-based Intentional Islanding Algorithm tailored for Distributed Energy Resources (DERs) to efficiently manage and prioritize electrical loads across varying energy source conditions. The system seamlessly transitions between solar, grid, and battery power, ensuring uninterrupted energy delivery based on availability and pre-established scenarios.

When utilizing solar energy, all load categories high, normal, and low priority remain active. Under grid operation, the system adapts to peak and non-peak hours, supplying only high and normal priority loads during peak hours while powering all loads during non-peak times. In battery mode, the system is programmed to prioritize essential loads: when the battery charge exceeds 40%, both high and normal priority loads are powered, whereas only the high-priority load is supplied when the charge drops below 40%.

The integration of a Bluetooth module for remote monitoring and control enhances the system's user accessibility, providing a cost-effective and versatile solution for energy management. This work highlights the algorithm's adaptability, making it an ideal approach for areas with intermittent energy sources and specific load prioritization requirements. Future advancements could explore greater automation, enhanced system scalability, and the inclusion of more sophisticated energy networks to expand the scope of its applications.

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