ARTIFICIAL INTELLIGENCE (AI) BASED RECOVERY TECHNOLOGY (AIRT) FOR POWER DISTRIBUTION NETWORK USING µ-GRID RESOURCES DURING NATURAL DISASTERS - A LITERATURE REVIEW

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ABSTRACT:- Natural Disasters may cause many kinds of activating events, including particularly significant blackoutsPower outages caused by natural disasters have a big effect on an electrical network that distributes electricity. In electrical distribution networks, natural catastrophes cause widespread disruptions and a loss of service for end users. Grid recovery may need several weeks or even months to complete the restoration process. Power must be provided throughout this time, if not for necessities. Integratedµ-grid resources play a vital role in meeting this requirement.Creating µ-grids is a viable way to improve distribution networks' resilience. This paper discusses many typical techniques for segregating a distribution network into manyµ-grids, utilizing SCADA,Fault Diagnosis and Restoration Control Program (FDARC), Mixed Linear Integer Programming (MILP), and Heuristic rule-based algorithm.Future research directions as well as the benefits and drawbacks of these methods are discussed.This paper reviews the Artificial Intelligence (AI) Based Recovery Technologies (AIRT) for Power Distribution Networks by employing µ-grid resources in the event of a natural disaster.

Keywords: Natural Disasters, blackouts, Distribution Network, µ-grid resources, SCADA, Fault Diagnosis and Restoration Control Program (FDARC),Mixed Linear Integer Programming (MILP), Artificial Intelligence.

I. INTRODUCTION

Since many essential services (such as gas, water, and communications) depend on electricity's continuous availability to function, electricity is the most crucial resource in modern civilization.It may be used in many different contexts in daily life. Figure 1 shows many of the possible outcomes.

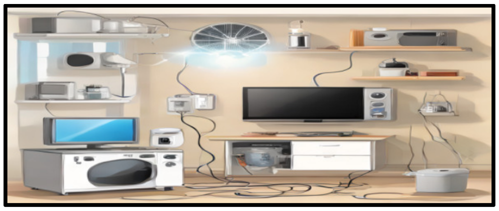

Figure 1.Uses of Electricity

The electric distribution network is the last step in delivering electrical energy from the transmission network to consumers to provide an uninterrupted power supply [1]. Figure 2 shows the power distribution network.

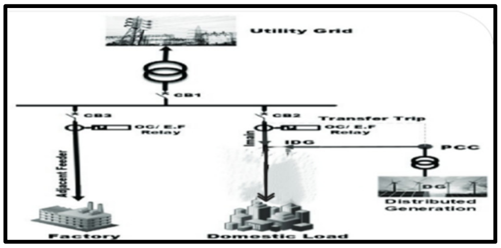

Figure 2. Simple layout of power distribution network

Enhancing power system’s resistance to severe events is a crucial component of their operation and design [2]. Major incidents might include cyber attacks or natural disasters, which can have significant financial losses in addition to limiting the amount of power available to a large number of customers [3].Widespread power outages can result from natural disasters including hurricanes, earthquakes, floods, and wildfires damaging electrical conductors, transformers, and other essential components [6].This can disrupt the supply of electricity to homes, businesses, and essential services, causing inconvenience, economic losses, and potential safety hazards as shown in Figure 3.

Figure 3. Impacts of disasters on the power distribution network

Following a natural disaster getting electricity back to the affected areas becomes the highest priority.To lessen the effects of natural catastropheson power distribution networks, utilities may invest in resilient infrastructure, implement better disaster preparedness plans, and explore alternative energy sources. Furthermore, advancements in technology, such as smart grid systems [4],Predictive analytics, and µ-grids can enhance the ability of electricity distribution networks to withstand and react to natural disasters. µ-grids are localized power systems that are tiny in size and may function either independently or in tandem with the main electrical grid. [5]. They consist of distributed energy sources, including solar panels, wind turbines, fuel cells, and storage systems, along with a control system to manage the flow of electricity illustrated in Figures 4 & 5.

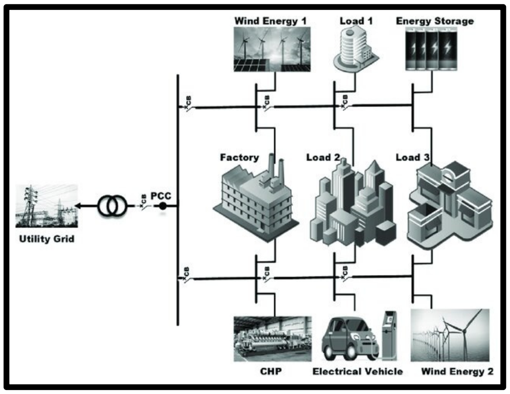

Figure 4. Single-line diagram of a µ-grid connected to the grid

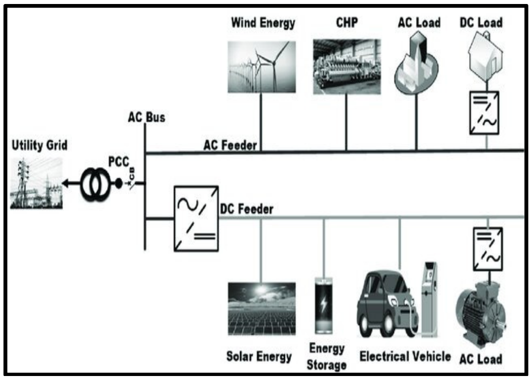

Figure 5. µ-grid with AC and DC systems

The main purpose of this research is to give an overview of the literature on computerized techniques that are now accessible for enhancing and restoring power distribution networks while utilizing µ-grid resources. [7]. this paper has five sections: Section 2 shows several computerized methods for system restoration. Section 3 highlights µ-grid resources for power distribution network restoration, Section 4 suggests thoughts on Artificial Intelligence (AI) Based Recovery Technology (AIBRT) for Power Distribution Networks, and Section 5 concludes.

II. VARIOUS CONVENTIONAL METHODS FOR RESTORATION

A.SCADA

Restoring the power distribution network during disasters using μ-grid resources with a SCADA (Supervisory Control and Data Acquisition) system involves a coordinated approach to leverage the capabilities of the grid within the broader context of the SCADA-controlled power distribution network [8]. The first step is to assess the available resources within the μ-grid, including Energy preservation technologies, environmentally friendly power sources, and versatile loads. This assessment provides the basis for understanding the capabilities and limitations of the μ-grid resources [9].

The μ-grid resources are integrated into the SCADA system, permitting the distributed energy resources to be commanded and tracked in real-time.This integration enables the SCADA system to remotely monitor the status of μ-grid components and manage their operation as part of the broader power distribution network.Simultaneously, the degree to which the bigger electricity distribution network has been destroyedis assessed. This includes identifying areas without power, damaged infrastructure, and critical loads that need to be restored.

The SCADA system, in coordination with advanced control algorithms, optimally allocates the μ-grid resources to support the restoration efforts. This includes decisions about when and how to deploy renewable energy, how to manage energy storage, and how to prioritize critical loads within the μ-grid and the larger network.

The SCADA system, with input from the μ-grid resources, can optimize the reconfiguration of the μ-grid to support the restoration of the larger distribution network. This may involve islanding certain sections of the μ-grid, reconfiguring the network topology, and managing the electricity transfer between the main distribution network and the μ-grid.

The SCADA system provides real-time monitoring of the μ-grid resources, including renewable energy generation, energy storage levels, and load demand. This allows operators to make informed decisions and adjust the operation of μ-grid resources as needed to support the restoration efforts. The SCADA system facilitates coordination and communication between the μ-grid and the broader power distribution network, making certain that μ-grid resource operation is in line with the overall restoration strategy [10].

The results of the SCADA-monitored μ-grid operation provide a detailed plan for leveraging μ-grid resources to support the restoration efforts. This plan is then implemented by controlling the operation of μ-grid resources in coordination with the larger network restoration activities.

Implementing μ-grid resources with a SCADA system for power distribution network restoration during disasters requires seamless integration of the μ-grid into the SCADA infrastructure, advanced control algorithms, real-time monitoring capabilities, and well-defined coordination protocols. The simple structure of the SCADA system for the restoration of the power distribution network is depicted in Figure 6.

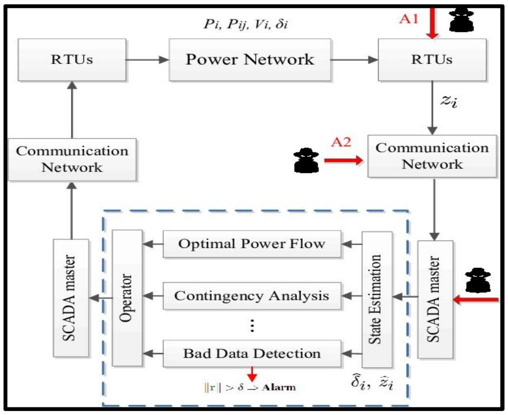

Figure 6.The simple layout of SCADA

Certainly, while SCADA systems offer numerous advantages for managing and restoring power distribution systems during disasters, they also come with their own set of challenges and disadvantages. They are cyber security measures, interoperability standards, physical infrastructure protection, cost-effective solutions, training programs, and effective data management strategies [11]. Despite these challenges, SCADA systems remain a critical tool for managing and restoring power distribution systems during disasters when properly implemented and managed.

B. Fault Diagnosis and Restoration Control Program (FDARC)

Using the Fault Diagnosis and Restoration Control Program (FDARC) to restore the power distribution network during catastrophes is a methodical process of fault identification, isolation of damaged regions, and power restoration to minimize interruption. The FDARC system keeps an eye out for defects, such as equipment failures, line outages, or other interruptions, in the power distribution network. The location and kind of the malfunction are promptly determined by utilizing real-time data from sensors and monitoring equipment.

The FDARC system examines the data once a defect is found to determine the particular kind of malfunction. This can entail determining the kind of equipment failure, the location of a line outage, or any other problems that the network is experiencing. The FDARC system assists in isolating the impacted regions of the power distribution network by using the data obtained from fault diagnosis. To stop the issue from spreading to other areas of the network, this might entail turning on switches or circuit breakers.Following the isolation of the damaged regions, the FDARC system helps in the creation of a restoration strategy.

It assists in setting priorities for the restoration process, organizing the dispatch of repair teams, and overseeing the network's safe and regulated re-energization. In response to evolving circumstances or fresh data, the FDARC system may additionally include algorithms for adaptive decision-making that allow the restoration strategy to be modified. This adaptability may be essential in circumstances of sudden situations. FDARC helps teams participating in the restoration process communicate and coordinate with each other so that information is shared efficiently and everyone is working toward the same objective of restoring the power distribution network [12].

Well-defined restoration procedures, a real-time communication infrastructure, and strong data collecting and analysis capabilities are necessary for FDARC implementation for power distribution network restoration during catastrophes. The schematic flow chart of FDARC is given in Figure 7.

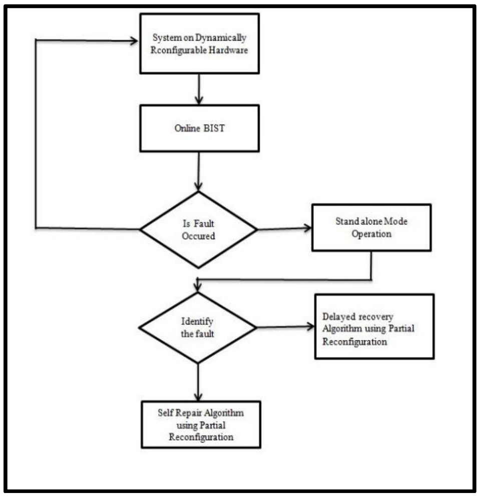

Figure 7. Flow chart of FDARC

Undoubtedly, the Fault Diagnosis and Restoration Control Program (FDARC) has several benefits for recovering the power distribution network in the event of a disaster, but it also has drawbacks and difficulties. These include complexity, data reliability and accuracy, cybersecurity risks associated with integration with legacy systems, cost-effectiveness, training and expertise, and adaptability to changing circumstances. FDARC systems, when properly designed and maintained, continue to be an essential tool for controlling and restoring power distribution networks during catastrophes, despite these challenges.

C. Mixed Linear Integer Programming (MILP)

To facilitate the restoration of the broader distribution network, a complex method called Mixed Linear Integer Programming (MILP) is used to optimize the utilization of dispersed energy resources inside the μ-grid [13]. Evaluating the μ-grid's resources, such as controlled loads, energy storage devices, and renewable energy sources, is the initial stage. This evaluation provides the foundation for comprehending the capabilities and constraints of the μ-grid resources. At the same time, the degree of harm to the wider power distribution network is evaluated. This entails locating blacked-out locations, compromised infrastructure, and vital loads that require restoration.To maximize the utilization of μ-grid resources to help the power distribution network restoration, a MILP model is developed.

This involves choosing when and how to use renewable energy, controlling energy storage, and setting priorities for important loads both inside the μ-grid and across the wider network [14].To facilitate the restoration of the larger distribution network, MILP may also be utilized to optimize the reconfiguration of the μ-grid. This might entail controlling the electrical energy transfer between the main distribution network and the μ-grid, rearranging the network architecture, and islanding certain μ-grid parts.TheMILP model takes into account several constraints, including the criticality of loads, operational limits, and the capacity of off-grid resources.

The MILP model incorporates various constraints, such as the capacity ofμ-grid resources, operational limits, and the criticality of loads, as well as objectives, such as minimizing downtime, maximizing the use of renewable energy, or optimizing the support provided to the larger network [15]. Certainly, while Mixed Linear Integer Programming (MILP) offers significant advantages for optimizing the use of μ-grid resources to restore the power distribution system during disasters, it also comes with its own set of challenges and disadvantages. [16], [17].

Addressing these challenges requires a comprehensive approach that includes advanced modeling techniques, real-time data acquisition and processing capabilities, robust communication infrastructure, and well-defined protocols for integrating MILP-based optimization into the broader disaster response framework. Despite these challenges, MILP remains a powerful tool for optimizing the use of µ-grid resources in power distribution network restoration when effectively implemented and managed.

D. Heuristic Rule-Based Algorithm

Leveraging established rules and heuristics to make judgments regarding the operation and coordination of µ-grid resources is a key component of employing heuristic rule-based algorithms to restore the power distribution network after disasters. The µ-grid resources functioning is guided by established rules and heuristics by the heuristic rule-based algorithm while the restoration process is underway.

These principles are predicated on operational best practices, specialist knowledge, and particular protocols for µ-grid management during an outage [18].Using specified rules and heuristics, the algorithm calculates the best way to allocate µ-grid resources. This involves choosing which vital loads to prioritize inside the µ-grid and the wider power distribution network, when to implement renewable energy sources, and how to manage energy storage systems.

The algorithm keeps an eye on the changing circumstances of the power distribution network as well as the state of the µ-grid resources. The algorithm modifies the process of making decisions using this information in real-time to guarantee that the µ-grid resources efficiently assist with the restoration activities**.**The heuristic rule-based algorithm makes sure that the µ-grid resources operate under the power distribution network's larger restoration plan.

This coordination entails taking the network's stability, resource availability, and essential load requirements into account [19]. The judgments made by the algorithm are put into practice by managing the µ-grid resources' operations in tandem with the more extensive network repair initiatives. This might entail controlling energy storage devices, modifying the output of renewable energy sources, and using heuristic methods to prioritize vital loads**.** Implementing a heuristic rule-based algorithm for power distribution network restoration using µ-grid resources requires a deep understanding of the operational characteristics of the µ-grid the specific challenges posed by the disaster, and the predefined rules and heuristics that guide the algorithm's decision-making process [20]. It also requires real-time monitoring capabilities and effective coordination with the broader restoration efforts. The µ-grid building flowchart utilizing the heuristic approachis given below in Figure 8.

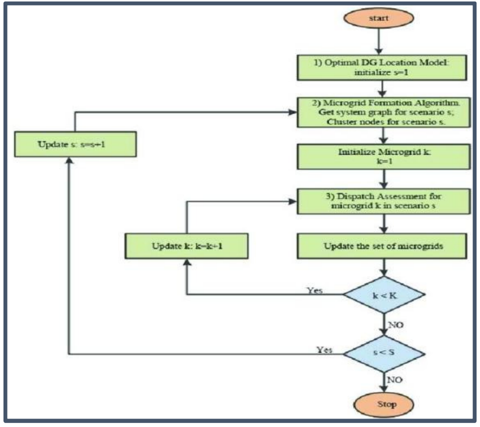

Figure 8: The µ-grid building flowchart using the heuristic approach

III. µ-GRID RESOURCES

µ-grids are localized, small-scale power grids that may function separately from the main electrical grid. They consist of a combination of distributed Renewable energies including battery storage, windmills, and photovoltaic cells, as well as sophisticated control systems for efficient allocation of resources. The µ-grid is vital in emergencies because it supplies dependable energy to critical facilities including nursing homes, emergency response centres, and wireless networks for communication. [21]. Figure 9 illustrates the µ-grid's single-line layout.

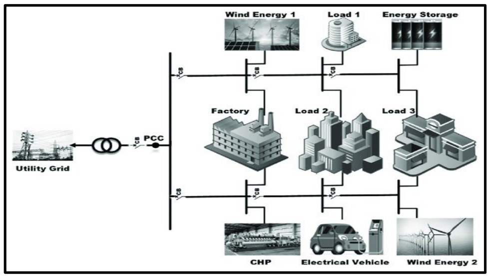

Figure 9. Single line diagram of a µ-grid connected to the grid.

When disasters strike, whether it's a severe storm, a blackout, or even a cyber-attack, power outages can leave communities vulnerable and paralyzed. This is where µ-grids come to the rescue. µ-grids can quickly detect power outages and automatically switch to island mode, keeping essential services running [22]. By reducing dependency on the main grid, µ-grids decrease the overall vulnerability of communities during emergencies. Residential µ-grids can keep households powered, maintaining comfort, safety, and the ability to communicate.µ-grids provide an opportunity for communities to reduce their reliance on centralized power systems and embrace energy independence. By generating power locally from renewable sources,µ-grids offer a sustainable and resilient energy solution for disaster-prone areas [23]. The hybrid µ-grid is illustrated in Figure10.

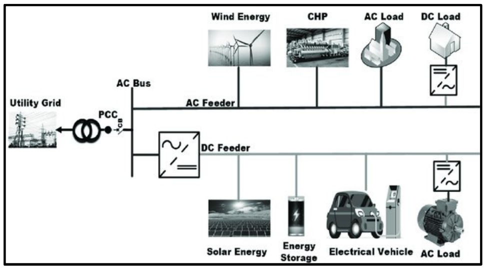

Figure 10.A hybrid µ-grid

After a disaster, restoring power quickly is critical for recovery efforts. Their flexibility enables faster recovery, ensuring that communities can bounce back swiftly. µ-grids can be built in modular, scalable formats, allowing for quick replacement or expansion as needed. The flexibility of µ-grids allows for innovative solutions such as mobile µ-grids, deployable in post-disaster scenarios or remote locations. By incorporating renewable energy sources, µ-grids systems offer several advantages [24]. However, there are several advantages to integrating renewable energy sources with µ-grid systems, it also comes with its own set of challenges. Integrating renewable energy sources into µ-grids systems requires careful planning and consideration of several key factors such as Feasibility Assessment, Energy Management Systems, Storage Technology, Collaboration, and Partnerships [25]**.**

Power outages caused by natural disasters can have disastrous consequences. In emergencies, timely access to electricity is crucial for maintaining vital services and saving lives. Efficient power distribution during emergencies ensures that essential facilities have uninterrupted access to electricity, enabling them to function at maximum capacity when they are needed the most [26].

Efficient power distribution is vital in emergencies to ensure the continuity of essential services.

IV. ARTIFICIAL INTELLIGENCE (AI) BASED RECOVERY TECHNOLOGY (AIRT)

This research study proposes Artificial Intelligence (AI) tools for the restoration ofpower distribution Networks (AIRT) including AI-powered monitoring systems, which offer improved reliability and the ability to detect and predict power disruptions. The block diagram of the proposed AIRT is illustrated in Fig 11.

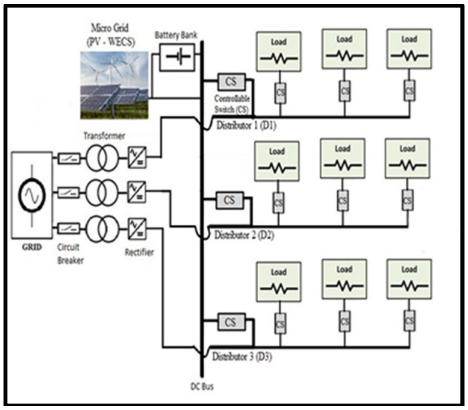

Figure 11. Block diagram of the proposed AIRT for Distribution Network.

AIRT tools can also optimize resource allocation during disasters, analyze historical and real-time data to generate optimal restoration plans and minimize downtime. Furthermore, the use of AI in conjunction with µ-grid resources holds promise for enhancing the restoration of power distribution networks during disaster conditions. AIRT can identify anomalies and notify operators so they may take corrective action and reduce downtime by continually monitoring and analysing real-time data.

To minimize outages, optimize maintenance schedules, and improve overall operational efficiency, power companies may benefit from important insights that the AIRT can give by analysing patterns and trends in energy usage, weather, and infrastructure problems. AIRT-powered analytics provide several cutting-edge capabilities, such as Data Integration, in terms of power outage prediction. Machine learning algorithms, Real-time Monitoring and Alerts, Predictive Analytics, and Geographic Mapping.

V. CONCLUSION

This paper reviewed the literature survey of many typical techniques for segregating a distribution network into many µ-grids, utilizing SCADA, Fault Diagnosis and Restoration Control Program (FDARC), Mixed Linear Integer Programming (MILP), Heuristic rule-based algorithm. This review paper proposes Artificial Intelligence (AI) based Recovery Technologies (AIRT) for Power Distribution Networks by employing µ-grid resources in the event of a natural disaster.

Power distribution network management and monitoring are being completely transformed by AIRT technology. Power network operators may identify abnormalities, forecast breakdowns, and enhance network performance instantly by utilizing machine learning and data analytics. AIRT monitoring systems offer cost savings, increased efficiency, greater dependability, and data-driven decision-making. Adopting AIRT technology is essential for the future of power network operations as the demand for electricity rises.

FUTURE RESEARCH DIRECTIONS

Develop AI algorithms to predict natural disasters with higher accuracy, allowing utilities to proactively deploy µ-grid resources. Integrate real-time weather data, satellite imagery, and historical disaster patterns for more precise predictions. Design AI-driven optimization models to allocate µ-grid resources efficiently during disasters, considering factors like demand, resource capacity, and critical infrastructure priorities. Explore multi-objective optimization techniques to balance energy restoration, cost-effectiveness, and resilience.

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