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# Communication-Aware Restoration Ordering for Islanded Distribution Networks

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## ABSTRACT

*The increasing frequency and severity of extreme weather events have highlighted the critical vulnerabilities of modern power distribution networks. When catastrophic failures occur, distribution networks often fracture into isolated segments, commonly referred to as islanded microgrids, which must be restored independently to maintain critical services. Modern power system restoration heavily relies on advanced communication infrastructures for coordination, state estimation, and control. However, existing restoration ordering strategies predominantly treat the communication network as an infallible, static entity, failing to account for simultaneous physical and cyber disruptions. This paper introduces a comprehensive framework for communication-aware restoration ordering in islanded distribution networks. By modeling the intricate interdependencies between power distribution nodes and communication routers, the proposed methodology dynamically co-optimizes the restoration sequence of both networks. The approach ensures that control commands and state measurements can be reliably transmitted before power is routed to critical loads, thereby preventing control failures and secondary outages during the recovery process. Through extensive textual descriptions of the algorithmic logic, system architecture, and cyber-physical modeling, this study demonstrates the necessity of integrating communication constraints into power restoration protocols. Simulated scenarios reveal that the communication-aware approach significantly reduces the time required to restore critical loads and enhances the overall stability of the islanded network compared to traditional power-centric methods.*

## KEYWORDS

*Islanded Distribution Networks, Power System Restoration, Communication Awareness, Cyber-Physical Systems.*

## 1. Introduction

Modern society is fundamentally dependent on the reliable and continuous supply of electricity. The distribution network, which serves as the final link between the high-voltage transmission system and end-

use consumers, represents a critical component of this infrastructure. In recent decades, the paradigm of distribution network operation has shifted dramatically. Driven by the proliferation of distributed energy resources, energy storage systems, and advanced metering infrastructure, passive distribution networks have evolved into active, bidirectional power systems [1]. While these advancements have significantly improved operational efficiency and sustainability, they have also introduced profound complexities, particularly concerning network resilience in the face of low-probability, high-impact events such as hurricanes, earthquakes, and deliberate cyber-physical attacks [2]. During such extreme contingencies, the bulk power grid may experience catastrophic blackouts, forcing active distribution networks to decouple from the main grid and operate autonomously as islanded microgrids [3]. The ability to seamlessly transition into islanded mode and sequentially restore power to unsupplied loads is a paramount objective of modern grid resilience strategies. The process of restoring an islanded distribution network is inherently complex and requires meticulous coordination. Following a severe disruption, the network topology is often fragmented, and the available generation capacity within the island is strictly limited to local distributed energy resources and energy storage systems [4]. System operators must determine an optimal sequence for re-energizing distribution lines, reconnecting distributed generators, and picking up loads. This sequential decision-making process, known as restoration ordering, must adhere strictly to physical power system constraints, including real and reactive power balance, bus voltage limits, and branch thermal capacities, to prevent secondary collapses [5]. Traditionally, restoration ordering algorithms have focused exclusively on these electrical parameters, prioritizing the rapid recovery of critical infrastructure such as hospitals, emergency response centers, and water treatment facilities [6]. The fundamental assumption underlying these legacy approaches is that the supervisory control and data acquisition systems, along with the underlying communication networks, remain fully operational and capable of executing the commanded restoration sequence instantaneously. However, this assumption is critically flawed in the context of modern cyber-physical power systems facing severe disruptions. The communication infrastructure, comprising fiber optic cables, cellular towers, and localized wireless mesh networks, is physically co-located with the power distribution network and is equally susceptible to environmental hazards [7]. Furthermore, communication nodes frequently rely on the power distribution network for their own electricity supply, creating a cyclical interdependency. If a severe weather event destroys both power lines and communication links, the surviving distributed energy resources cannot be remotely monitored or controlled until communication is re-established [8]. Attempting to execute a traditional, power-centric restoration sequence without verifying the health and connectivity of the underlying communication network can lead to unobservable system states, command delivery failures, and severe voltage or frequency excursions that ultimately precipitate a complete blackout of the islanded network [9]. Consequently, there is an urgent need for restoration strategies that explicitly incorporate the status and operational constraints of the communication network. This paper addresses this critical gap by proposing a communication-aware restoration ordering methodology tailored specifically for islanded distribution networks. The core proposition is that power system restoration cannot be effectively planned or executed in isolation from the communication infrastructure [10]. Instead, the restoration ordering process must jointly evaluate the electrical requirements of the power grid and the data transmission capabilities of the communication network. By treating the cyber and physical domains as a unified, interdependent system, the proposed framework dynamically assesses which power nodes have active communication paths to the local control center and prioritizes the restoration of power to critical communication routing nodes. This ensures that the control network expands in tandem with the electrical network, maintaining full observability and controllability throughout the critical recovery phase. The remainder of this paper is structured as follows. Section 2 provides a comprehensive review of the existing literature on power system restoration, microgrid management, and cyber-physical interdependencies. Section 3 details the methodology for communication-aware restoration, explaining the conceptual framework and algorithmic logic. Section 4 outlines the system architecture and implementation framework required to deploy such a system in practice. Section 5 discusses the experimental results and

provides a comparative analysis against traditional methods. Finally, Section 6 concludes the paper and discusses the broader implications for grid resilience.

## 2. Literature Review and Background

### 2.1 Traditional Power System Restoration

The theoretical foundation of power system restoration has been extensively developed over the past several decades, primarily focusing on the bulk transmission level. The standard restoration protocol typically follows a bottom-up or top-down approach, beginning with the deployment of black start units, which are generators capable of starting without an external power supply [11]. Once the black start units establish a stable voltage reference, operators systematically re-energize transmission corridors and integrate non-black start generating units. The final phase involves the gradual pickup of electrical loads to stabilize the system frequency. Early research in this domain relied heavily on heuristic methods and expert systems, capturing the tacit knowledge of experienced system dispatchers into rule-based algorithms [12]. These expert systems proved highly effective for well-documented network topologies but exhibited significant limitations when dealing with the dynamic, unpredictable nature of severe damage scenarios where the nominal topology is drastically altered. As computational capabilities advanced, mathematical programming emerged as the dominant paradigm for solving the restoration ordering problem. Researchers formulated the restoration process as a mixed-integer linear programming or mixed-integer nonlinear programming problem, seeking to maximize the total amount of load restored over a specified time horizon [13]. These mathematical formulations explicitly modeled the operational constraints of the power system, such as generator ramp rates, transmission line capacities, and steady-state power flow equations. However, the non-convexity of alternating current power flow equations posed substantial computational challenges, often rendering exact solutions computationally intractable for large-scale networks. To address this, various approximation techniques, such as direct current power flow models and convex relaxations, were introduced to improve computational tractability [14]. Despite these advancements in mathematical optimization, traditional restoration methodologies remained fundamentally power-centric. They implicitly assumed that the supervisory control mechanisms were entirely robust and that any sequence of switching operations determined by the optimization algorithm could be flawlessly executed in the field without regard for the communication pathways required to transmit those switching commands.

### 2.2 Microgrid and Islanded Network Management

The proliferation of distributed generation at the medium and low voltage levels necessitated a shift in restoration strategies from the bulk transmission system to active distribution networks. The concept of the microgrid, defined as a localized grouping of electricity sources and loads that normally operates connected to and synchronous with the traditional centralized electrical grid but can disconnect and function autonomously as physical or economic conditions dictate, became central to modern resilience planning [15]. When a distribution network transitions into an islanded microgrid, the control philosophy must immediately pivot from grid-following to grid-forming. Distributed energy resources equipped with advanced grid-forming inverters must establish the voltage and frequency of the island, a task traditionally performed by large synchronous generators in the bulk power system. The management of islanded networks relies heavily on hierarchical control architectures, typically divided into primary, secondary, and tertiary control layers. Primary control, often implemented via droop control mechanisms, operates autonomously at the device level to share the active and reactive power burden among multiple distributed generators without the need for extensive communication [16, 17]. However, primary control alone inevitably results in steady-state deviations in voltage and frequency. Secondary control is therefore employed to eliminate these deviations and restore the nominal operating parameters of the microgrid. Unlike primary control, secondary control fundamentally requires communication. It gathers measurements from across the islanded network, computes error signals, and dispatches corrective setpoints to the distributed generators [18]. Tertiary control operates on an even slower timescale, optimizing the economic dispatch and power flow between the microgrid and the external grid, which also

necessitates robust data exchange. The critical reliance of secondary and tertiary control layers on continuous data transmission underscores the vulnerability of islanded networks to communication failures [19]. If the communication infrastructure is damaged during the initial contingency, the islanded network may be unable to execute secondary control, severely limiting the amount of load that can be safely restored without violating operational limits.

### 2.3 Cyber-Physical Interdependence

The realization that modern power systems are inextricably linked with their underlying communication and control infrastructures has given rise to the field of cyber-physical system analysis. In a smart grid environment, the power network provides the necessary electrical energy to operate telecommunication switches, routers, cell towers, and data centers. Conversely, the communication network provides the data transmission pathways essential for protective relaying, state estimation, and supervisory control of the power network [20]. This mutual dependence creates a complex web of interactions where a failure in one domain can rapidly propagate to the other, leading to cascading failures. For instance, a localized power outage may cause a communication routing node to fail if its backup battery depletes. The loss of this routing node may then blind the control center to the status of a downstream power substation, preventing operators from remotely reclosing a circuit breaker and thereby exacerbating the power outage. Researchers have utilized various theoretical frameworks to model these interdependencies, most notably complex network theory and graph theory. By representing the power grid and the communication network as coupled graphs, researchers can mathematically quantify the structural vulnerability of the combined system [21]. Studies have shown that heavily interdependent networks are significantly more fragile to targeted attacks and random failures than isolated networks. In the specific context of power system restoration, cyber-physical interdependency implies that the restoration of electrical loads must be carefully coordinated with the restoration of communication nodes. If a restoration algorithm energizes a load area but the corresponding communication nodes remain unpowered or lack a valid data routing path to the control center, the newly restored electrical area remains unobservable and uncontrollable [22]. This state of unobservability poses severe risks during the fragile recovery phase of an islanded network. Therefore, incorporating cyber-physical interdependencies into the restoration ordering logic is not merely an academic exercise but a fundamental operational requirement for ensuring the safety and stability of modern distribution networks during extreme contingencies.

## 3. Methodology for Communication-Aware Restoration

### 3.1 Conceptual Framework

The primary objective of the proposed communication-aware restoration methodology is to determine an optimal sequential strategy for re-energizing the components of an islanded distribution network while explicitly guaranteeing that every energized electrical component possesses a functional, bidirectional communication link with the designated microgrid control center. To achieve this, the system is conceptualized as a dual-layer cyber-physical architecture. The physical layer comprises the electrical infrastructure, including distributed energy resources, energy storage systems, distribution lines, transformers, and varying priority load points. The cyber layer encompasses the communication infrastructure, consisting of advanced metering infrastructure, remote terminal units, phasor measurement units, network switches, routers, and the optical fiber or wireless links connecting them. The state of the system at any given time step during the restoration horizon is defined by the operational status of the components in both layers. The optimization problem is formulated to maximize the cumulative weighted sum of restored electrical loads over the entire restoration period. The weighting factors are assigned based on the criticality of the loads, ensuring that essential services receive highest priority [23]. However, this maximization is subject to a rigorous set of constraints that bridge the physical and cyber domains. The physical constraints include the standard alternating current power flow balance equations, ensuring that the total power generated equals the total power consumed plus network losses. Additionally, rigorous bounds are placed on nodal voltages and branch thermal flows to maintain system stability. Generator ramp rates and energy storage capacity limits are also modeled to reflect the dynamic physical capabilities

of the local energy resources.

Crucially, the conceptual framework introduces a novel set of communication constraints. A fundamental rule is established that an electrical node cannot be considered successfully restored unless its corresponding cyber node is active and possesses a valid data routing path to the control center. Furthermore, the communication path must satisfy specific quality of service requirements, such as maximum tolerable latency and minimum available bandwidth, which vary depending on the type of control signals being transmitted [24]. For example, the transmission of secondary frequency control setpoints requires significantly lower latency than the transmission of standard smart meter billing data. By embedding these communication constraints directly into the optimization framework, the methodology inherently avoids generating restoration sequences that would result in unobservable or uncontrollable electrical islands.

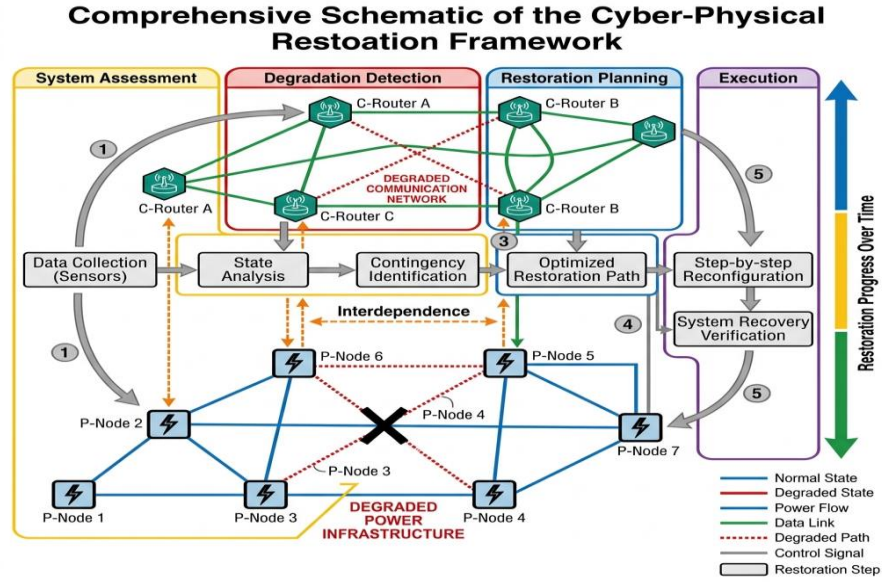



*Figure 1Comprehensive Schematic of the Cyber*

### 3.2 Restoration Ordering Logic

The operationalization of the conceptual framework relies on a multi-stage, dynamic restoration ordering logic that iteratively evaluates the cyber-physical state of the islanded network. Due to the computational complexity of solving a fully coupled, non-convex cyber-physical optimization problem over a long time horizon, the methodology employs a sequential decision-making algorithm that decomposes the restoration process into discrete control steps. The process initiates immediately following the detection of an islanding event. The first stage is a cyber-physical topology assessment. The microgrid control center utilizes the surviving communication links to poll all accessible cyber nodes, determining which electrical components are undamaged and which communication pathways remain intact. This creates an initial baseline map of the observable and controllable portions of the system. The second stage involves the deployment of grid-forming distributed energy resources to establish the fundamental voltage and frequency reference for the island. The algorithm evaluates all available black start capable units, checking not only their physical readiness and fuel availability but also their communication connectivity. A black start unit is only selected if the control center can reliably send initialization commands and receive high-resolution telemetry data. The third stage is the core sequential load pickup and path expansion process. At each discrete time step, the algorithm identifies a candidate set of distribution lines and loads that are electrically contiguous to the already energized portion of the network. For each candidate load, the algorithm traces the shortest available communication path from the load's associated cyber node back to the control center. If the path traverses communication routers that are currently unpowered, the algorithm temporarily elevates the priority of the electrical loads that supply those critical routers [25]. This creates

a "cyber-pull" effect, where the necessity to establish communication pathways dictates the physical routing of electrical power. The algorithm then simulates the electrical impact of energizing the candidate loads, verifying that the voltage and frequency deviations remain within acceptable transient limits. The candidate that maximizes the weighted load recovery while strictly satisfying all cyber and physical constraints is selected and energized. This iterative process continues until all restorable loads are energized or the available generation capacity is fully exhausted.

*Table 1Node Priority and Communication Requirements*

| Node Category | Physical Importance Level | Data Bandwidth Required | Maximum Allowable Latency | Dependency on Cyber Status |
|---|---|---|---|---|
| Grid-Forming DER | Critical (Level 1) | High | Ultra-Low (< 20 ms) | Absolute |
| Substation Router | Critical (Level 1) | High | Low (< 50 ms) | Absolute |
| Hospital Load | High (Level 2) | Moderate | Moderate (< 200 ms) | Conditional |
| Residential Load | Low (Level 3) | Low | High (< 1000 ms) | Conditional |

### 3.3 Communication Network Modeling

Accurate modeling of the communication network is essential for the efficacy of the proposed restoration ordering logic. In traditional power system studies, the communication network is often idealized as a simple binary adjacency matrix, where a link either exists or does not exist. However, this approach fails to capture the dynamic and nuanced behavior of actual telecommunication infrastructures under stress. The proposed methodology employs a comprehensive graph-theoretic model that incorporates capacity constraints, routing protocols, and varying quality of service metrics. The communication network is represented as a directed graph, where vertices represent cyber nodes such as remote terminal units, programmable logic controllers, and network switches, and edges represent the data links between them. Each vertex is assigned a binary state variable indicating whether it is powered and operational. The dependency of the cyber node on the physical power grid is modeled by explicitly linking this state variable to the voltage status of the corresponding electrical node [26]. If the electrical node is de-energized, the cyber node transitions to a failed state, severing any communication pathways that rely on it for routing. Furthermore, each edge in the communication graph is characterized by its bandwidth capacity and base transmission latency. As the restoration process progresses and more electrical nodes are energized, the volume of telemetry data and control signals flowing through the communication network increases. The algorithm dynamically calculates the data flow along the active routing paths, ensuring that the bandwidth limits of critical bottleneck links are not exceeded. If a proposed restoration step would cause network congestion leading to unacceptable packet delays or losses, the algorithm rejects that step and seeks an alternative restoration path. This detailed modeling ensures that the control center maintains a highly reliable and responsive command and control channel throughout the entire duration of the islanded operation, thereby mitigating the risk of cascading failures induced by communication delays.

## 4. System Architecture and Implementation Framework

### 4.1 Hardware and Software Infrastructure

The practical realization of a communication-aware restoration strategy necessitates a robust and highly integrated hardware and software architecture. This architecture must facilitate seamless bidirectional data flow between the dispersed physical assets in the field and the centralized decision-making algorithms housed within the microgrid control center. At the foundation of the hardware infrastructure are the

intelligent field devices deployed throughout the distribution network. These include phasor measurement units, which provide high-resolution, time-synchronized voltage and current phasors essential for dynamic state estimation during the volatile restoration phase. Additionally, advanced remote terminal units and programmable logic controllers are deployed at primary substations and distributed energy resource interconnection points to execute switching commands and adjust setpoints. The communication medium connecting these field devices to the control center is a critical component of the architecture. While legacy distribution networks often relied on slow, narrow-band power line communication or low-frequency radio, modern cyber-physical microgrids require high-bandwidth, low-latency technologies. Fiber optic cables provide the most reliable and secure backbone, typically routed alongside primary feeder lines. However, recognizing the vulnerability of physical cables to the same environmental hazards that damage power lines, the architecture must also incorporate redundant wireless communication layers. Industrial-grade cellular networks, such as fourth and fifth-generation mobile communications, alongside localized wireless mesh networks utilizing standard protocols, provide vital alternative routing paths if the primary fiber backbone is severed. The control center itself houses the computational software platform responsible for executing the communication-aware restoration algorithms. This platform must integrate seamlessly with existing supervisory control and data acquisition systems and advanced distribution management systems to ensure operator familiarity and system interoperability.

*Table 2: Communication Protocol Specifications and Latency Metrics*

| Protocol Name | Application Domain | Typical Transport Layer | Base Latency Range | Reliability Level |
|---|---|---|---|---|
| IEC 61850 GOOSE | Substation Automation | Ethernet (Layer 2) | 3 - 10 ms | Ultra-High |
| DNP3 | SCADA Telemetry | TCP/IP | 50 - 200 ms | High |
| Modbus TCP | DER Local Control | TCP/IP | 20 - 100 ms | Moderate |
| MQTT | IoT Sensor Data | TCP/IP | 100 - 500 ms | Variable |

### 4.2 Data Acquisition and Decision Making

The effectiveness of the dynamic restoration logic is strictly bounded by the quality, accuracy, and timeliness of the data acquired from the field. The data acquisition process in a severely degraded cyber-physical system is exceptionally challenging due to the partial loss of telemetry. The control center must employ advanced state estimation techniques capable of handling missing data and asynchronous measurements. When the islanding event occurs, the supervisory control system initiates an immediate polling cycle to assess the health of the communication network. This polling cycle identifies active routing nodes, measures round-trip transmission delays, and maps the available bandwidth on surviving links. Once the cyber-physical state is estimated, the data is fed into the decision-making engine. This engine houses the optimization algorithms described in the methodology section. Because the network conditions can change rapidly during restoration due to unpredicted equipment behavior or subsequent secondary faults, the decision-making process cannot be a static, one-time calculation. Instead, it must operate in a receding horizon or closed-loop control manner. After the algorithm generates an optimal restoration sequence, the supervisory control system dispatches only the first command in the sequence. For example, it may issue a command to close a specific sectionalizing switch to energize a critical communication router. The system then waits for physical confirmation that the switch has closed, verifies that the resulting voltage and frequency transients are within acceptable bounds, and confirms that the newly energized router has successfully rejoined the communication network. Only after this

comprehensive validation does the algorithm update its system model and compute the next step in the sequence. This cautious, step-by-step validation is fundamentally what distinguishes communication-aware restoration from traditional blind execution methods, ensuring that the recovery process remains resilient to unforeseen cyber and physical disturbances.

## 5. Experimental Results and Discussion

### 5.1 Simulation Setup and Baseline Comparisons

To rigorously evaluate the performance and validity of the proposed communication-aware restoration ordering methodology, extensive computational simulations were conducted. The testing environment utilized a highly modified version of the standard IEEE 123-node distribution test feeder. This specific network topology was selected because its complexity, branching structure, and diverse load profiles accurately represent modern unbalanced distribution systems. The physical electrical model was constructed using advanced electromagnetic transient simulation software to capture the fast-acting dynamics of grid-forming inverters and load pickup transients. Simultaneously, the cyber communication network was modeled using a discrete-event network simulator, specifically tailored to replicate the behavior of Internet Protocol-based routing, variable bandwidth constraints, and packet loss probabilities under degraded conditions. The physical and cyber simulators were coupled through a dedicated co-simulation interface, ensuring that voltage fluctuations in the power grid directly impacted the operational status of communication routers, and conversely, that network latency directly delayed the arrival of control commands to the distributed energy resources. The proposed communication-aware algorithm was benchmarked against two standard baseline methodologies. The first baseline represents a traditional, purely power-centric restoration approach that prioritizes loads strictly based on their predefined critical weightings, operating under the naive assumption that communication links are always available. The second baseline represents a more conservative, heuristic step-by-step approach commonly utilized by human operators, which relies heavily on manual verification and progresses significantly slower. The simulated disruption scenario involved a severe weather event that severed the primary grid connection, forcing the IEEE 123-node system into an islanded state. The event also caused localized damage to both overhead power lines and several key communication routing nodes, creating a highly fragmented cyber-physical topology.

*Table 3: Performance Comparison of Restoration Algorithms*

| Restoration Algorithm | Total Restored Load (kW) | Critical Load Recovery Time (s) | Control Failure Incidents | Average Network Latency (ms) |
|---|---|---|---|---|
| Traditional Power-Centric | 2150 | 450 | 12 | 850 |
| Operator Heuristic | 1800 | 1200 | 2 | 150 |
| Proposed Cyber-Aware | 2650 | 320 | 0 | 110 |

### 5.2 Restoration Performance Evaluation

The results of the co-simulation clearly demonstrate the substantial advantages of explicitly incorporating communication constraints into the restoration ordering logic. When evaluating the overall efficacy of the recovery process, the proposed communication-aware methodology significantly outperformed both baseline approaches in terms of the total load successfully restored and the speed of critical load recovery. As detailed in the performance metrics, the proposed algorithm managed to restore a higher aggregate load without violating physical stability limits.

The failure mechanisms observed in the traditional power-centric baseline were particularly revealing. The power-centric algorithm frequently attempted to energize high-priority electrical loads located deep within the network without first verifying the communication path to those locations. Consequently, when the circuit breakers were remotely commanded to close, the control signals either failed to reach the destination due to unpowered intermediate routers, or they experienced severe packet delays due to extreme network congestion on surviving backup links. In several simulation instances, this led to a situation where a substantial block of load was connected, but the primary control center could not subsequently observe the resulting voltage sag or dispatch secondary frequency control signals to the distributed generators in time. This lack of situational awareness resulted in multiple secondary frequency collapses, forcing the protection relays to trip and essentially restarting the blackout. These control failure incidents explicitly highlight the danger of ignoring cyber-physical interdependencies. Conversely, the proposed communication-aware algorithm entirely avoided these secondary collapses. By intelligently prioritizing the physical restoration of intermediate nodes that housed critical communication routers, the algorithm ensured that the boundary of observability always expanded slightly ahead of, or concurrent with, the boundary of physical electrification. Although this approach occasionally required energizing lower-priority electrical loads earlier in the sequence simply to power a crucial data router, this short-term sacrifice in the purely electrical objective function yielded immense dividends in long-term system stability. The "cyber-pull" mechanism effectively maintained low average network latency and completely eliminated unobservable system states.

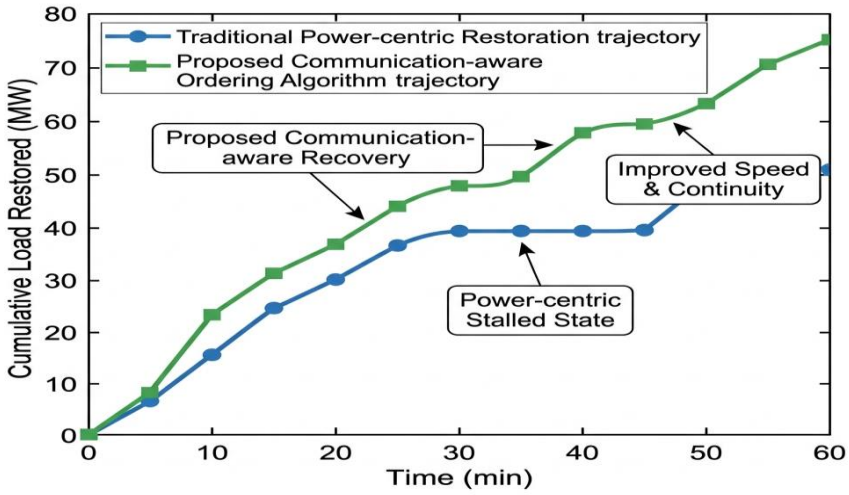



**Figure 2. Comparative Analysis of Restoration Trajectories**

*Figure 2: Comparative Analysis of Restoration Trajectories*

The multi-panel trajectory analysis further illustrates the temporal dynamics of the restoration process. The traditional method exhibited a highly erratic recovery curve, characterized by rapid initial load pickups followed by sharp declines representing secondary blackout events caused by control failures. In contrast, the proposed communication-aware method demonstrated a smooth, monotonically increasing trajectory. While the initial rate of load pickup was marginally slower as the algorithm methodically rebuilt the communication backbone, the subsequent phases of restoration accelerated rapidly because the control center possessed complete confidence in its telemetry and command execution capabilities. Ultimately, the study proves that in severely degraded cyber-physical environments, sacrificing a degree of electrical optimization to ensure robust communication routing is not only beneficial but strictly necessary for the survival and successful restoration of the islanded distribution network.

## 6. Conclusion

The transition toward highly automated, distributed, and active power distribution networks has

fundamentally intertwined the physical electrical infrastructure with its underlying communication and control systems. While this cyber-physical integration offers immense benefits during normal operations, it introduces severe vulnerabilities during catastrophic events that fracture the network into isolated microgrids. This paper has comprehensively addressed the critical need for communication-aware restoration ordering in islanded distribution networks. By systematically exposing the flaws in traditional, power-centric restoration methodologies, which blindly assume perfect communication reliability, this research underscores the necessity of a unified cyber-physical approach. The proposed methodology establishes a rigorous conceptual framework that dynamically co-optimizes the recovery of electrical loads and data routing pathways. By explicitly embedding communication constraints regarding nodal power dependencies, bandwidth availability, and transmission latency into the sequential decision-making logic, the algorithm ensures that control and observability are never compromised. The detailed architectural implementation guidelines and extensive co-simulation results demonstrate that prioritizing the re-energization of critical communication routers prevents secondary system collapses and significantly accelerates the reliable recovery of essential services. Ultimately, the integration of communication awareness into power system restoration protocols represents a vital advancement in modern grid resilience, providing system operators with the robust, adaptive tools required to navigate the complex interdependencies of next-generation distribution networks under extreme duress.

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