

Case Study of a Resilient Hospital-Grade Microgrid Control System

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Abstract—Hospitals maintain a zero-tolerance posture toward power interruptions in life safety and critical care environments, while simultaneously requiring strict regulatory compliance, premium power quality, operational visibility, cybersecurity, and lifecycle scalability. This paper presents the design and operational performance of a hospital-grade microgrid control system deployed in a major North American city. The solution, tailored to the unique demands of medical facilities, delivers resilient, reliable, sustainable, and efficient power across critical infrastructure.

The architecture employs real-time utility topology tracking and onsite generation to manage power flow and support seamless grid-to-island and island-to-grid transitions with autosynchronization. Dual power islands segregate emergency and normal systems to preserve the healthcare-mandated separation of critical and noncritical loads. Advanced load management categorizes mission-critical demands and executes priority-based shedding and restoration using onsite spinning reserve, with real-time adjustability to support clinical operations and emergency protocols. Black-start capability enables dead campus recovery under adverse conditions.

Operator visibility and control are provided through a secure human-machine interface with real-time monitoring, alarm management, event logging, and manual override for fail-safe operation. The control system operates on a dedicated, hardened network with virtual local-area networks and HyperText Transfer Protocol Secure to protect data integrity and reduce cyber risk. Sustainability and cost optimization features—including peak shaving and import/export control—enhance grid stability while reducing utility and maintenance costs.

This paper details control strategies, healthcare code compliance, lessons learned from commissioning and operations, and a practical roadmap for scalable, maintainable, and future-ready hospital microgrids.

Keywords—C-HIL, distributed energy resources, generation control system, healthcare, hospital power system, islanding, load shedding, microgrid, power management system, synchronization

I. INTRODUCTION

Reliable, economical, and stable power is essential for mission-critical facilities such as hospitals, where uninterrupted operation is required to support life safety and clinical care. Achieving this level of resilience requires coordinated integration of distributed energy resources (DERs) within a unified system architecture, enabled by a centralized microgrid control system (MCS).

An MCS functions as the core operational layer, ensuring continuity of power in both grid-connected and islanded modes.

It incorporates advanced automated control strategies to prevent, detect, and mitigate power disturbances, including blackouts, while maintaining optimal system performance. By continuously monitoring and managing key electrical assets, the MCS supports efficient energy use, cost optimization, and system reliability.

This paper presents a case study of a well-known North American hospital facility upgraded in 2025 with a state-of-the-art MCS. Acting as the central intelligence of the system, the MCS ensures seamless microgrid operation. The key features include (i) enhancing reliability of the healthcare facility power system, (ii) achieving system performance that exceeds conventional healthcare facility standards by integrating centralized microgrid control with the emergency power supply control system (EPSCS), and (iii) validating control strategies through hardware-in-the-loop (HIL) testing. These contributions establish a scalable framework for next-generation critical care power systems.

II. POWER SYSTEM OVERVIEW

The electrical power system is configured as a medium-voltage microgrid supplied by two independent 26.4 kV utility feeders and multiple onsite generation assets. Power is distributed through 26.4 kV, 13.2 kV, and 0.48 kV switchgears, supporting an estimated campus demand of 8–10 MW. The configuration provides redundancy and operational flexibility to support continuous hospital operation.

Onsite generation includes a 2 MW natural-gas combined heat and power (CHP) unit operating in baseload mode, a 2.5 MW natural-gas peaker generator for peak demand and islanded operation, and two 2.5 MW diesel generators dedicated to emergency service. Two independent utility feeders provide redundancy and enhance reliability for critical healthcare operations.

Emergency generators supply life safety and critical loads through the EPSCS. The electrical system is divided into the normal power system and the emergency power supply system (EPSS). This segregation ensures compliance with healthcare electrical codes and allows independent operation of critical loads. Figure 1 illustrates the simplified single-line diagram of the microgrid, showing utility interconnections, generation assets, and segmentation between the normal and emergency power systems.

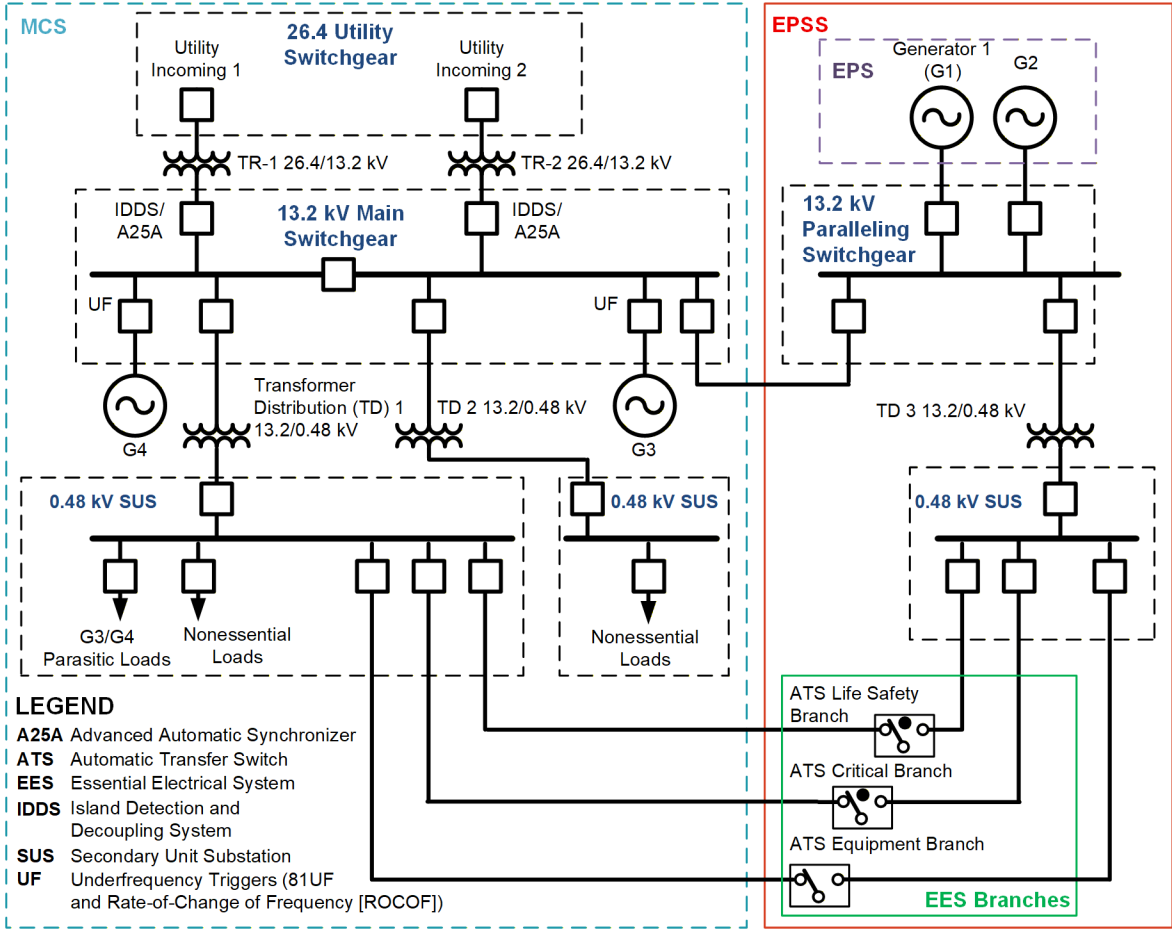


Figure 1. Simplified Single-Line Diagram

III. MICROGRID CONTROL SYSTEM

The MCS is a collection of hardware and software components configured to maintain power system health over a full range of foreseeable operating conditions. The MCS includes custom configured input/output (I/O) modules, front-end processors (FEPs), multifunction protective relays, centralized controllers, and a human-machine interface (HMI) server to provide the MCS functionalities highlighted in Figure 2.

A. MCS Architecture

The MCS is implemented using a layered architecture, as illustrated in Figure 3, providing modularity, scalability, and high system reliability. The architecture is structured into five hierarchical layers (Layer 0 to Layer 4). Lower layers ensure real-time protection and control, while upper layers provide supervisory and operational functions [1].

Layer 0 represents the physical electrical system, including generators, switchgear, circuit breakers, and instrument transformers.

Layer 1 consists of field devices, such as protective relays, meters, remote I/O modules, and generator local controllers, providing measurement, protection, and direct control of

primary equipment. These devices operate independently to ensure system safety under all conditions.

Layer 2 provides communications and data aggregation infrastructure, including the data concentrator, security gateway, and communications networks supporting IEC 61850, Distributed Network Protocol (DNP3), and Modbus. This layer enables reliable data exchange and enforces cybersecurity boundaries between the microgrid and external systems (i.e., the process control system and EPSCS).

Layer 3 hosts centralized control functions, a dedicated load-shedding system, and generation control system controllers. Systemwide control algorithms, such as generation dispatch, load shedding, islanding detection, and synchronization, are executed at this level, requiring coordinated visibility across all assets.

Layer 4 provides supervisory and operator interface functions through HMI servers, engineering tools, and data visualization systems. This layer enables monitoring, diagnostics, and control actions without impacting the real-time operation of the lower layers.

Data flow from field devices (Layer 1) through the communications layer (Layer 2) to centralized controllers (Layer 3), where control decisions are made and issued back to the system, while operator interaction is handled at Layer 4.

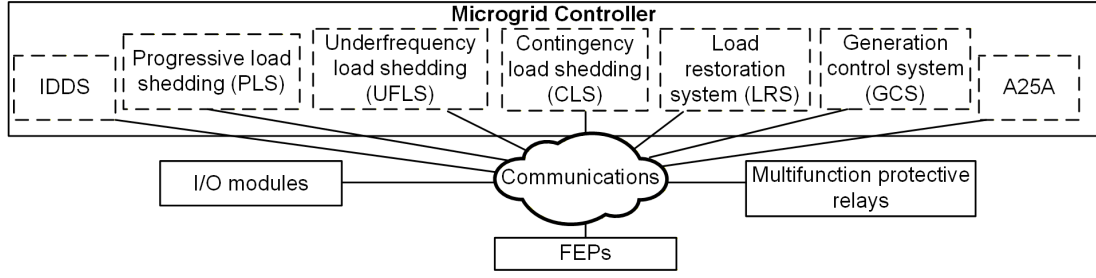


Figure 2. MCS Overview Diagram

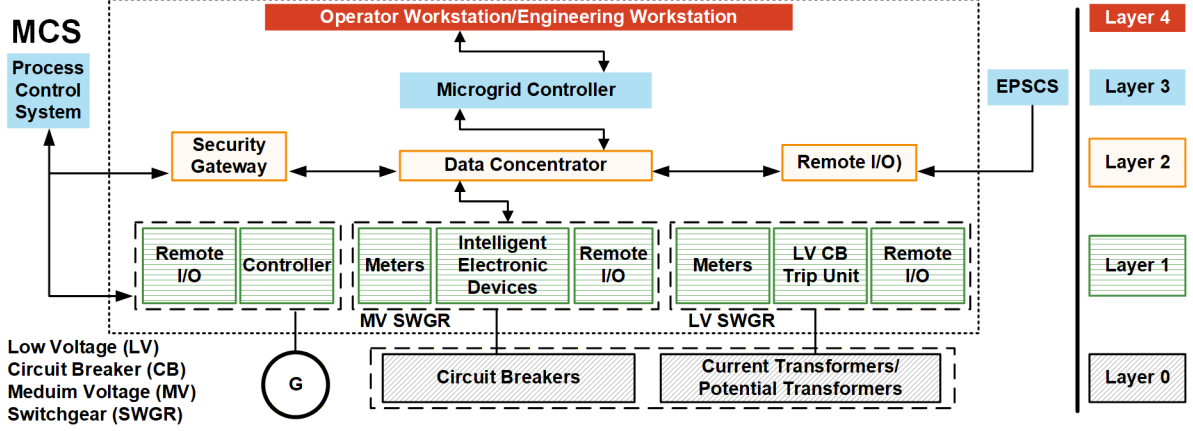


Figure 3. MCS Architecture

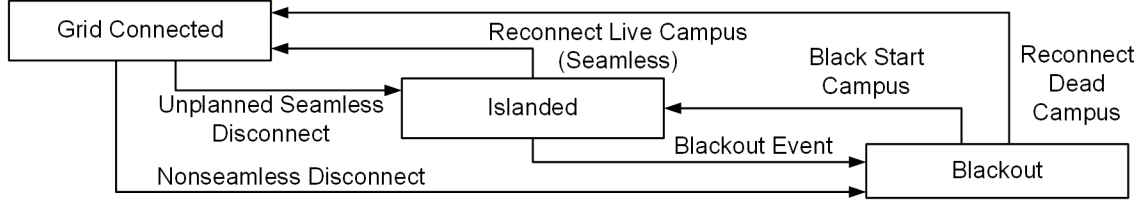


Figure 4. Microgrid Operating Modes and Transitions

B. MCS Control Strategy

The MCS operates as a state-based controller managing grid-connected, islanded, and blackout conditions. Transitions between states are initiated automatically based on system measurements or manually through HMI.

The MCS operates as a state-based control system managing multiple operating modes, as shown in Figure 4.

1) Grid-Connected Operation

The CHP is designed to operate continuously, providing baseload power to the hospital facility. The peaker is designed to operate intermittently in parallel with the utility, to be dispatched during periods of peak power consumption or prolonged utility outage.

Both the CHP and the peaker operate in parallel with the utility in baseload mode. The MCS dispatches both engines using an equal percentage load sharing algorithm up to their maximum capacity, if needed. However, the MCS shall maintain a minimum import limit (i.e., 250 kW) across 13.2 kV utility breakers.

Both the CHP and the peaker, set to power factor (PF) mode, operate at 0.95 lagging PF. If the utility tie-line kilovolt-ampere reactive set-point control is enabled from the HMI, the MCS

sends PF set points to each unit to maintain the user-entered tie-line kilovolt-ampere reactive set points.

2) Islanded Operation

If the point of common coupling (PCC) breaker is open and the facility transitions to the islanded state, the MCS changes the campus state from grid-connected to islanded operation. Accordingly, both CHP and peaker modes switch to isochronous-sharing and voltage-sharing modes to maintain island frequency and voltage at nominal levels.

3) Blackout and Black Start

During a blackout event, loss of utility supply is detected at the PCC, resulting in automatic isolation of the campus electrical system and the separation of normal and emergency power systems. The EPSCS restores the emergency island by initiating diesel generator startup via automatic transfer switch (ATS) signals. Once stabilized, emergency feeders are re-energized and critical loads are restored based on predefined priority classifications in accordance with healthcare power system requirements.

Following stabilization of the emergency island, the MCS coordinates restoration of the normal power system. DERs, including CHP and peaker units, are started against a dead bus, with the first unit establishing the system reference and

subsequent units synchronizing to the system. Generator local control systems manage power sharing using isochronous and voltage control modes, while the MCS performs staged load restoration based on available generation capacity and system conditions. Throughout the process, the MCS maintains transfer inhibit logic to prevent emergency load transfer and ensures coordinated operation between the normal and emergency islands.

4) Reconnection

Following stabilization of the islanded microgrid, reconnection to the utility grid is performed using an automated synchronization scheme coordinated by the MCS. The system continuously monitors voltage magnitude, frequency, and phase angle difference between the microgrid and the utility at the PCC. When synchronization conditions are within predefined limits, the MCS issues control commands to adjust generator set points and eliminate slip and phase mismatch. Upon satisfying synchronization criteria, the utility breaker is closed, enabling seamless transition to grid-connected operation.

C. Load-Shedding System

The load-shedding system (LSS) provides intelligent, automatic load reduction in response to predetermined contingencies. The LSS maintains stability during disturbances by dynamically balancing load and generation. The LSS includes three schemes [2] [3]:

- The contingency load-shedding (CLS) scheme sheds load based on a predicted power deficit when a contingency occurs. A contingency is defined as the opening of a breaker that interrupts system power flow. This scheme reduces the total plant load to less than the available capacity.
- The underfrequency load-shedding (UFLS) scheme sheds load based on underfrequency thresholds and the protective relay ROCOF setting. UFLS only occurs when the electrical system, or part of the electrical system, is islanded from the utility.
- The progressive load-shedding (PLS) scheme monitors overload conditions on generators. If an overload persists for a time, based on an integrating function, small amounts of load are periodically shed until the overload condition is cleared.

After system stabilization following a load shed event, loads are restored in a controlled manner based on priority and available reserve capacity.

D. Generation Control System

The generation control system (GCS) contains various slow-speed control algorithms designed to coordinate generator operation to regulate system frequency, voltage, PF, and power flow. The GCS contains various slow-speed control algorithms designed to correct different power system parameters, such as voltage, frequency, power flows, and PF, which also provide support in system synchronization (i.e., automatic generation control, voltage control system, island control system,

Advanced Automatic Synchronizer [A25A], and generator capability tracking system) [4].

IV. EMERGENCY POWER SUPPLY SYSTEM

Healthcare electrical systems are governed by several key standards, including National Fire Protection Association (NFPA) 70, National Electrical Code; NFPA 99, Health Care Facilities Code; NFPA 101, Life Safety Code; and NFPA 110, Standard for Emergency and Standby Power Systems. These standards define requirements for system reliability, segregation of essential loads, transfer times, and EPSS performance.

NFPA 99 introduces a risk-based classification framework that identifies electrical loads based on their impact on patient safety and defines the structure of the Essential Electrical System (EES) [5]. The EES classification includes life safety, critical, and equipment branches. NFPA 101 ensures that building life safety systems remain powered, particularly during emergency conditions affecting occupant evacuation [6]. NFPA 70 provides installation and wiring requirements to ensure safe and compliant system implementation [7].

NFPA 110 is the primary standard governing the EPSS and defines performance criteria for emergency generation, transfer equipment, and system reliability [8]. The EPSS classification under NFPA 110 is defined using three key parameters:

- **Class:** Specifies the minimum runtime capability of the system at rated load without refueling or recharge. Typical values range from minutes to several hours, depending on fuel storage and operational requirements.
- **Type:** Defines the maximum allowable time between loss of normal power and restoration of supply. Hospital systems are required to meet Type 10, which mandates restoration within 10 s.
- **Level:** Defines the criticality of the system based on consequences of failure. This standard specifies that hospital systems must be designed as Level 1 EPSS, where system failure could result in loss of life or serious injury.

The EPSCS is designed to exceed these requirements by providing coordinated control, monitoring, and automation of emergency system components. The EPSCS operates independently to ensure continuous supply to life safety and critical loads. Key functions include (i) automatic diesel generator startup triggered by ATS in accordance with NFPA-required transfer times, (ii) generator synchronization and paralleling for enhanced reliability and capacity, (iii) priority-based load restoration aligned with EES classifications, and (iv) independent islanded operation to maintain continuity of critical loads.

When integrated with the centralized MCS, the EPSCS benefits from enhanced coordination and systemwide visibility. This allows optimized interaction between emergency and normal systems, improving operational flexibility and system response beyond minimum code requirements.

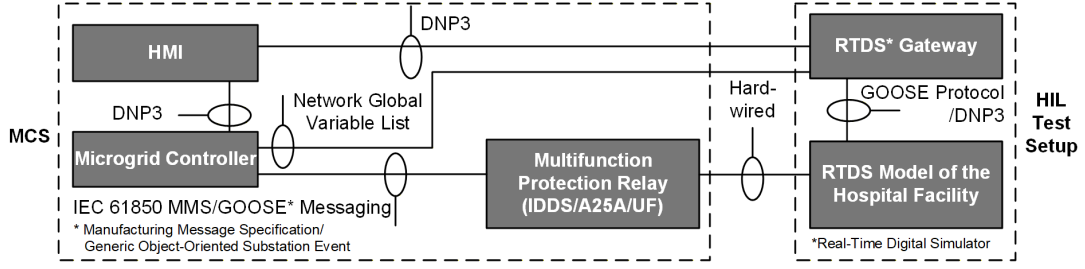


Figure 5. Simplified C-HIL Architecture

V. TESTING SCENARIO

Real-time closed-loop modeling of microgrid power systems is essential in determining the efficiency of MCS protection and control schemes [9]. Factory acceptance testing validated control strategies prior to site deployment with controller HIL (C-HIL) simulation [10] (see Figure 5).

A. Test Description

For this scenario, unplanned loss of utility supply during grid-connected operation was evaluated. The system detected the disturbance, isolated from the utility, transitioned generators to islanded control modes, and executed contingency-based load shedding. Figure 6 illustrates the frequency and voltage response during this event. (For a more detailed view, see Figure 7.)

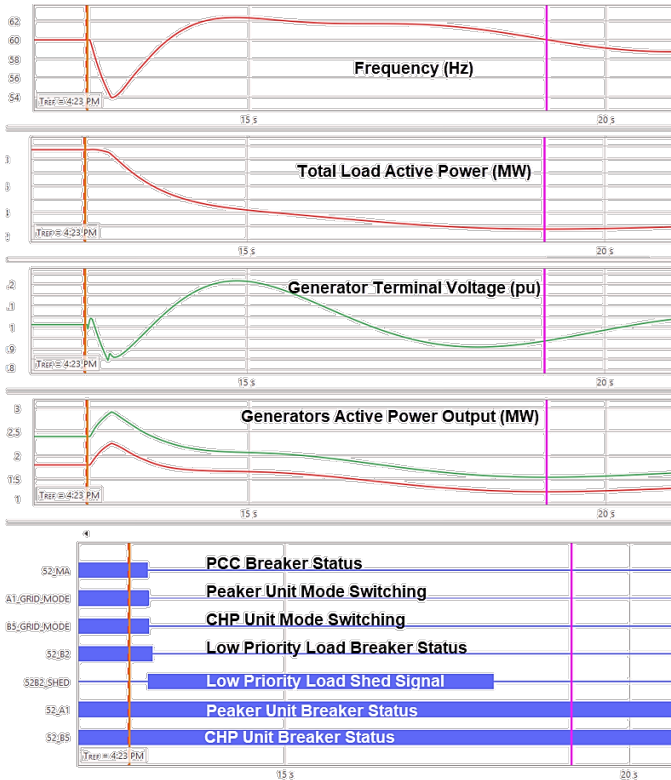


Figure 6. Frequency and Voltage Response During Unplanned Islanding

During the test, the system operated in a grid-connected mode, importing approximately 4.55 MW from the utility. The total system load was 8.75 MW, with the remaining 4.2 MW supplied by online onsite generation comprising CHP and peaker units operating in parallel.

A disturbance was introduced on the utility source to initiate the island detection and decoupling scheme at the PCC protective relay. Upon detection of abnormal utility conditions, the decoupling logic isolated the microgrid from the grid by opening the PCC breaker. The MCS detected the transition to islanded operation and automatically reconfigured system control modes. The online CHP and peaker units transitioned to support islanded frequency and voltage regulation and maintained system stability through coordinated control action.

To reestablish generation-load balance following loss of utility import, the LSS executed selective shedding of lower-priority loads in accordance with operator-defined priority settings. This action ensured that total generation capacity matched the reduced load demand.

Following load adjustment, the system rapidly achieved a stable operating condition, with frequency and voltage maintained within acceptable operational limits. No disruption to critical loads was observed during the transition, demonstrating effective coordination between island detection, generation control, and hierarchical load-management functions under islanded conditions. The total response time from detection of utility loss to execution of load shedding was approximately 70 ms, including approximately 50 ms (three cycles) of breaker operating time. The calculated ROCOF (df/dt), approximately 25 Hz/s based on system inertia, explains the observed frequency dip to 54 Hz before system recovery.

While the 70 ms response time represents the interval from utility disconnection to load shedding, the total duration of an unplanned islanding event is significantly longer due to island detection and decoupling processing, PCC breaker interrupting time, frequency decline to the trip threshold, and governor-driven frequency recovery and stabilization. Therefore, the reported 70 ms interval is intended only to highlight the MCS communication latency (~ 20 ms) and not the complete islanding-to-stabilization timeline.

B. Test Observations

Several test observations were made, including minimized frequency deviation through precalculated load shedding, stable coordination among generators, the achievement of seamless transition between operating modes, and the necessity for onsite tuning of governor settings to prevent a frequency drop exceeding ten percent and the unintentional triggering of generator protection. The protection settings should be carefully coordinated to prevent unnecessary asset protection trips and should be evaluated and validated using C-HIL results, which are beyond the scope of this paper.

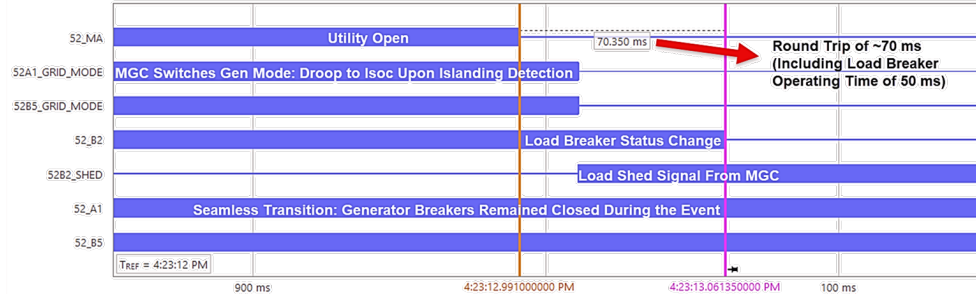


Figure 7. Zoomed-In Plot Showcasing Timing Diagram for the Unplanned Islanding Event

VI. FINDINGS AND OBSERVATIONS

System validation results confirm that a centralized MCS provides stable operation and coordinated control of DERs under a range of disturbance scenarios. The system performance evaluation highlights several key technical observations related to control system responsiveness, load management effectiveness, protection coordination, and system integration. These findings reflect the successful implementation of a control architecture designed to enhance the stability, survivability, and resilience of the hospital power system.

- Standards and regulations compliance: The combined EPSCS/MCS implementation complies with NFPA standards, enhancing system performance, providing greater reliability and resilience than conventional EPSS designs.
- System integration performance: The mature MCS control algorithms demonstrated a stable, reliable interaction with the EPSCS, enabling coordinated operation of both normal and emergency islands. This integration ensured consistent system performance across all operating modes, including blackout and islanded conditions.
- Protection coordination validation: Successful transitions from grid-connected to islanded operation require careful coordination of generator protection settings and MCS control actions. Detailed analysis confirmed that system transitions were achieved without violating protection thresholds or compromising equipment safety.
- Importance of real-time validation: HIL testing is essential for systems of this complexity. It provides a realistic platform for validating control strategies, verifying system dynamics, and ensuring that implemented MCS functions perform as intended across a wide range of operating scenarios.

VII. CONCLUSION

This paper demonstrates that an MCS is essential for ensuring reliable and resilient power in hospital environments. However, beyond system design and advanced control capabilities, rigorous testing plays a decisive role in successful deployment, particularly for functions such as grid transitions, load shedding, and black-start operations.

For critical infrastructure like hospitals, where power interruptions are unacceptable, thorough validation under real-world and fault conditions is fundamental. Such testing ensures operational reliability and safety while reducing risk, strengthening compliance, and building confidence in system performance under all scenarios.

REFERENCES

- [1] Manson S, Ravikumar KG, Raghupathula SK. Microgrid Systems: Design, Control Functions, Modeling, and Field Experience. Paper presented at: *XIII Simposio Iberoamericano Sobre Proteccion de Sistemas Electricos de Potencia*; February 19–24, 2017; Monterrey, Mexico.
- [2] Allen W, Lee T. Flexible High-Speed Load Shedding Using a Crosspoint Switch. Paper presented at *32nd Annual Western Protective Relay Conference*; October 25–27, 2005; Spokane, Washington.
- [3] Akhtar GMA, Ahmed MW, Allen W, Dasgupta S, Zhang P, Jensen K. Fast and Reliable Load-Shedding Scheme for Wastewater Treatment Plant—A Case Study. Paper presented at the *2022 IEEE Electrical Power and Energy Conference (EPEC)*; December 5–7, 2022; Victoria, British Columbia, Canada.
- [4] Akhtar GMA, Allen W, Shoaib H, Zhang P, Jensen K. Distributed Energy Resource (DER) Management for Wastewater Treatment Plant Using Redundant Centralised Control Scheme—A Case Study. Paper presented at the *2025 CIGRE International Symposium*; September 29–October 2, 2025; Montreal, Quebec, Canada.
- [5] NFPA 99: *Health Care Facilities Code*. Quincy (MA): NFPA; 2021.
- [6] NFPA 101: *Life Safety Code*. Quincy (MA): NFPA; 2021.
- [7] NFPA 70: *National Electrical Code*. Quincy (MA): NFPA; 2023.
- [8] NFPA 110: *Standard for Emergency and Standby Power Systems*. Quincy (MA): NFPA; 2022.
- [9] Manson S, Khatib AR, Cai N, Rajan SS. Advantages of real-time closed-loop simulation. Paper presented at: *68th Annual Petroleum and Chemical Industry Technical Conference*; September 13–16, 2021; San Antonio, Texas.
- [10] Limpaecher E, Salcedo R, Corbett E, Manson S, Nayak B, Allen W. Lessons Learned from Hardware-in-the-Loop Testing of Microgrid Control Systems. Paper presented at: *Grid of the Future Symposium*; October 22–25, 2017; Cleveland, Ohio.