

Development of an Integrated Blackout Recovery and Fault Diagnosis Framework for Offshore Vessels: A System-Level Approach for Electrical Resilience and Automation Reliability

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Abstract : Coordinated control of electrical, automation and auxiliary systems is needed to successfully recover from vessel blackout while offshore. Current techniques depend on specific hardware to be able to diagnose and plan fault recovery, which reduces the possibility of utilizing a single diagnosis to service multiple hardware platforms. This research develops an Integrated Blackout Recovery and Fault Diagnosis Framework (IBRF) that incorporates assessment of generators, verification of PMS, evaluation of automation, analysis of electrical distribution, and structured recovery sequencing. The framework is assessed through representative blackout scenarios and quantitative coverage assessment. The scenario assessment checks whether the framework covers the failure sources and recovery steps defined by the author; it does not measure operational recovery performance. The framework offers a structured basis for blackout diagnosis and recovery planning. The framework provides a basis for enhancing electrical resilience and offers a foundation for future operational validation.

Keywords: *Blackout recovery, Offshore vessels, Fault diagnosis, Power management system, Automation reliability, Electrical resilience, Recovery framework, Scenario-based evaluation*

I. Introduction

Research Background: Offshore Vessel Electrical Systems

Advanced offshore vessels are complex systems, and safe operation depends on the capability of multiple systems to work together, from electrical generation to automation, navigation, communication, and auxiliary equipment. Ships employ power management systems (PMS), diesel generators, switchboards, protection frameworks, uninterruptible power supplies (UPS), and crucial electrical loads [7], [12]. These systems interact in ways that make the reliability of the electrical supply crucial for offshore operations.

Blackout Problem: System-Level Recovery Challenge

Electrical blackout events on offshore vessels present a composite recovery situation that requires several interconnected systems to restore electrical services. Recovery can be delayed when a generator is unavailable, auxiliary equipment fails, the PMS is not functioning properly, or automation signals are not operating or are out of sync with the PMS [5]. Hence,

blackout restoration is not an individual equipment troubleshooting issue but requires a system-level diagnostic and recovery procedure.

Existing Practice and Research Gap

Original equipment manufacturer (OEM) manuals as well as system documentation are often used to assist in offshore vessel recovery procedures. Documents containing useful equipment specific troubleshooting data, cannot give a common recovery procedure for multiple interacting systems in composite blackout conditions. This creates a need for an integrated framework for equipment assessment, fault identification, and restoration prioritization.

Research Aim

The purpose of this research is to develop an integrated framework for blackout recovery and fault diagnosis for offshore vessels, involving evaluation of generators, verification of auxiliary systems, analysis of PMS and electrical checks, and recovery sequencing, to assist in effective decision-making during blackout events.

Research Objectives

- *To identify crucial electrical, automation, and auxiliary system dependencies that shape*

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the blackout recovery performance of offshore vessels and their contribution to overall system resilience.

- *To develop a comprehensive blackout recovery and fault diagnosis framework that incorporates generator readiness, PMS verification, automation assessment, electrical distribution checks, and recovery priorities.*
- *To implement a recovery pathway with a systematic approach to evaluating blackout conditions and to facilitate better decision-making than an equipment-level troubleshooting approach.*
- *To test the proposed framework with representative blackout scenarios to assess its effectiveness in enhancing recovery planning, fault identification, and system-level coordinated response.*

Novel Contribution

The significant result of this research is a structured blackout recovery framework combining electrical, automation, and auxiliary system considerations into a single decision support methodology. The proposed framework offers a coordinated recovery pathway, as opposed to traditional equipment-focused troubleshooting. The framework is assessed through scenario analysis and demonstrates the potential for enhancing the electrical resilience of offshore vessels.

I. Related Work

Integrated Electrical, Automation, and Auxiliary System Dependencies in Offshore Vessel Blackout Recovery



Fig. 1. Adaptive Power Management of Hierarchical Controlled Hybrid Shipboard Microgrids

Interconnected electrical systems on ships operated offshore consist of diesel generators, “power management systems (PMS)”, automation networks, UPS units, switchboards and auxiliary equipment [4]. Existing research efforts are primarily concerned with the reliability of individual systems, but recovery from a blackout depends on interactions between subsystems [5], [18], [19]. This limitation underscores the significance of comprehending electrical, automation, and auxiliary dependencies in an integrated fashion to enhance vessel-level electrical resilience and recovery capability.

Blackout Recovery Framework Development Through Generator, PMS, and Electrical System Integration

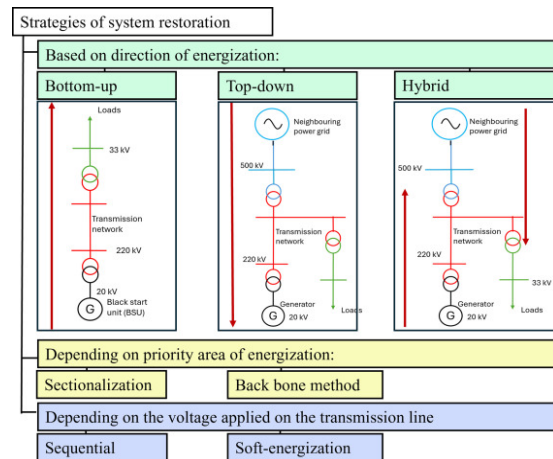


Fig. 2. Restoration experience from historical blackouts and a decision support framework for parallel restoration

Successful offshore blackout recovery cannot generally be achieved through isolated equipment-level troubleshooting alone, because restoration depends on the coordinated operation of generation, power distribution, auxiliary systems, automation, and control power [6]. OEM manuals contain adequate information for individual components but lack integrated recovery approaches. Hence, there is a need for a structured blackout recovery methodology that can incorporate fault diagnosis, system verification and restoration priorities.

Structured Recovery Sequencing and Decision Support for Offshore Electrical System Resilience

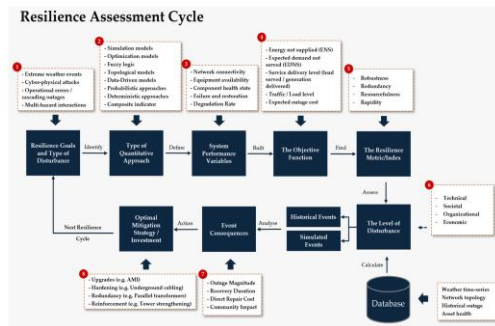


Fig. 3. Structured Resilience Assessment Cycle

In blackout conditions, engineers have to comprehend alarms and operating states, and understand several systems interact, while under significant time pressure. Current recovery operations often rely on operator experience and do not follow best practices. High Reliability Organizations and safety-critical checklists show that structured procedures can help enhance decision support [1], [2], [3]. Further development is needed for recovery sequencing and electrical resilience management in offshore applications.

Scenario-Based Evaluation of Integrated Blackout Recovery and Fault Diagnosis Methodologies

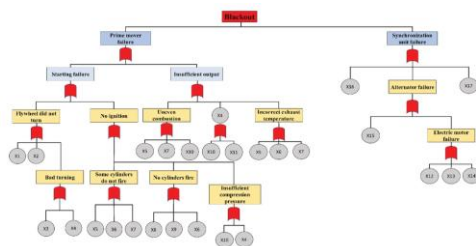


Fig. 4. Ship blackout incident framework

A difficulty with validating blackout recovery approaches is the lack of real offshore operational data and emergency event records. There has been limited controlled evaluation in previous industry studies. Scenario-based evaluation is an alternative method for assessing how the framework performs by examining representative failures, recovery decisions, and fault identification processes without the need for actual vessel operating data [9], [10].

Literature Gap and Research Contribution

Offshore vessel blackout recovery is recognized in the literature as a system-level problem involving generators, PMS, automation, electrical distribution, and auxiliary systems, yet integrated diagnostic and restoration procedures remain limited [8], [11], [20], [21], [26]. This research proposes a structured approach to verify systems, design recovery sequences, and provide decision support for blackout recovery and fault diagnosis to fill this gap. Representative blackout scenarios are utilized to evaluate the framework in order to enhance electrical resilience.

II. Methodology

Research Design and Approach

This research takes a framework development approach to build an integrated blackout recovery and fault diagnosis method for offshore vessels. The methodology involves four phases: identification of critical vessel subsystems, development of a system-level recovery plan, formulation of recovery priorities, and scenario-based evaluation. The proposed method combines electrical, automation, and auxiliary system concerns to address the limitations of equipment-level isolation.

Data Source

Secondary data sources are employed in this research, including published research articles, offshore electrical system standards, technical literature, and documented blackout recovery practices. The proposed framework is built and analyzed based on engineering analysis and representative blackout scenarios. No real vessel operational data was used; the framework was not validated against actual vessel performance.

Identification of Critical System Dependencies

The first phase is utilized to determine the key subsystems that impact blackout recovery performance, such as diesel generators, power management systems (PMS), automation systems, auxiliary equipment, and electrical distribution systems. The recovery capability of the offshore vessels is a combination of elements, and can be expressed as:

$$Rc = f(G, P, A, X, E)$$

Where Rc represents overall recovery capability as a composite function of generator readiness (G), PMS condition (P), automation availability (A), auxiliary system readiness (X), and electrical distribution status (E). The function f represents the composite interaction among these subsystems; its exact form is determined by the specific vessel configuration and recovery context.

Development of Integrated Blackout Recovery Framework

Based on the identified system dependencies, the integrated blackout recovery framework is implemented by combining subsystem verification, fault diagnosis, and restoration sequencing [13]. The framework examines the readiness of critical systems before initiating recovery actions. The particular recovery readiness index is shown as:

$$RI = \sum_{i=1}^n w_i S_i$$

Where RI represents the recovery readiness index, w_i represents the significance weight of subsystem i , S_i represents the condition status of subsystem i , and n represents the total number of evaluated subsystems. The weights reflect the relative importance of each subsystem in the blackout recovery process and are assigned based on engineering judgment and literature review.

The formulation enables prioritization of the critical systems impacting blackout recovery performance.

Recovery Sequence Formulation

A structured recovery sequence is established to assist in diagnosing blackout conditions and planning recovery actions [14], [16], [17], [25]. The sequence involves: identification of blackout extent, assessment of generators, verification of PMS, assessment of automation status, verification of electrical distribution and control power, restoration of critical electrical loads, restoration of remaining vessel systems, and assurance of stable system operation. The recovery procedure is represented as follows:

$$Rs = \{D, Gv, Pv, Au, Ev, Lr, Sr, Cs\}$$

where Rs represents the recovery sequence, D represents blackout diagnosis, Gv represents generator verification, Pv represents PMS verification, Au

represents automation assessment, Ev represents electrical verification, Lr represents critical load restoration, Sr represents restoration of remaining systems, and Cs represents system assurance. The eight terms correspond to the eight recovery steps listed above.

Scenario-Based Framework Evaluation

Since the real-time data for operation of offshore vessels is not available, the proposed framework is evaluated through representative blackout scenarios. Scenarios take into account common failure modes such as generator unavailability, PMS failure, and auxiliary system failure. Framework effectiveness is assessed by comparing recognized recovery actions with expected corrective actions using:

$$Fe = \frac{Nc}{Nt} \times 100$$

Where Fe represents framework effectiveness, Nc represents correctly recognized recovery actions, and Nt represents total expected recovery actions.

Evaluation Criteria

The recommended framework is assessed in terms of critical failure source identification, incorporation of multiple vessel subsystems, structured recovery decisions, and blackout response planning. The assessment emphasizes the effectiveness of system-level diagnosis and recovery coordination rather than vessel restoration time. The method offers a feasible evaluation tool and transparency about data limitations due to unavailable operational data.

Flowchart



Fig. 5. Methodology framework flow Diagram

The recommended methodology follows four sequential phases: integrated framework development, system identification, recovery sequence formulation, and scenario-based evaluation for structured blackout recovery analysis.

III. Development Of Integrated Blackout Recovery And Fault Diagnosis Framework

Framework Concept and Architecture

This research aims to address the disadvantages of individual equipment-level troubleshooting for offshore vessels during blackout by proposing an Integrated Blackout Recovery and Fault Diagnosis Framework (IBRF). Offshore vessel blackout recovery involves complex interactions between diesel generators, power management systems (PMS), automation systems, auxiliary equipment, and power distribution systems [13]. Thus, blackout recovery is viewed as a system-level diagnostic and restoration problem rather than a single equipment failure.

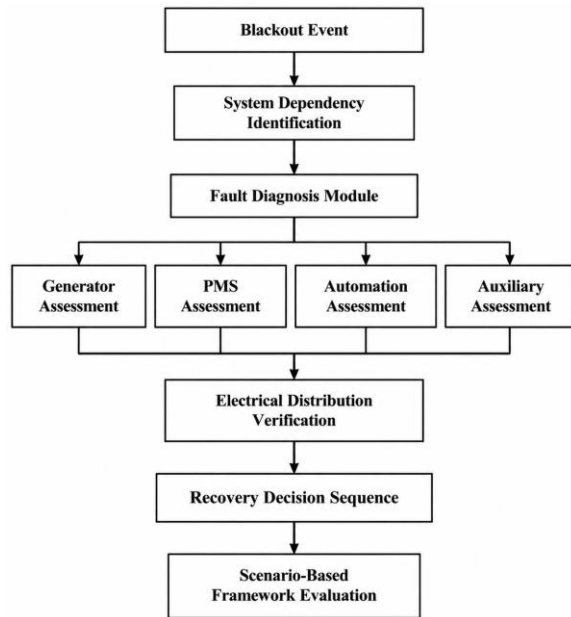


Fig. 6. Integrated Blackout Recovery and Fault Diagnosis Framework Architecture

The recommended framework combines four functional stages: system dependency identification, fault diagnosis, recovery sequence formulation, and scenario-based system evaluation. The architecture of the proposed framework is shown in the above Integrated Blackout Recovery and Fault Diagnosis Framework Architecture.

System Dependency Assessment

Offshore vessel blackout recovery depends on the cooperation of several interrelated subsystems, including diesel generators, power management

systems, automation systems, auxiliary systems, and electrical distribution networks [13]. The proposed framework identifies dependency relationships between these critical components to gain a deeper understanding of factors affecting recovery capability.

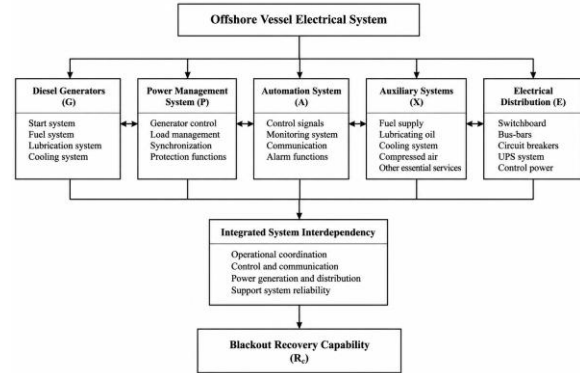


Fig. 7. Offshore Vessel Electrical System Dependency Model

The above dependency model illustrates the relationship between subsystems of major vessels. PMS coordinates and distributes power from generators (diesel) to power the load. Automation systems provide monitoring and control, while auxiliary systems prepare the system for operation by supplying fuel, lubrication, cooling, and supporting services [13]. Power delivery components, including switchboards, bus-bars, UPS systems, and circuit breakers, enable the delivery of power to critical loads [12]. Blackout recovery capability results from the interaction of these subsystems. The framework assesses recovery capability based on the generator, automation, PMS, auxiliary, and electrical distribution conditions identified in the methodology phase.

Fault Diagnosis and Recovery Assessment Module

The recommended framework evaluates the condition of each subsystem and prescribes recovery actions. Generator readiness is evaluated in conjunction with related auxiliary and control conditions, as generator availability depends on numerous operational factors. The generator readiness factor is shown as:

$$Gr = Sg \times Ax \times Cc$$

where Gr represents generator readiness, Sg represents generator start availability, Ax represents auxiliary system availability, and Cc represents control system availability.

Incorporation of PMS and automation verification as part of the framework is necessary because automatic recovery relies on the correctness of control signals, communication status, and operating conditions [11], [15]. Similarly, electrical distribution is assessed, including bus-bar availability, switchboard status, UPS status, and critical load readiness.

Structured Recovery Decision Sequence

The framework involves a defined recovery procedure after the system assessment and fault identification to inform decision making throughout blackout situations. The recommended recovery sequence contains:

1. Determine blackout extent
2. Identify available generation sources
3. Verify generator readiness and auxiliary conditions
4. Assess PMS and automation status
5. Verify electrical distribution and control power availability
6. Restore critical electrical loads
7. Restore remaining vessel systems
8. Assure stable system operation

The recovery sequence is shown as:

$$Rs = \{D, Gv, Pv, Au, Ev, Lr, Sr, Cs\}$$

where Rs is the recovery sequence as defined above (see Recovery Sequence Formulation), comprising D, Gv, Pv, Au, Ev, Lr, Sr, and Cs.

Table 1. Recovery Sequence And Verification Parameters

Recovery Stage	Verification Parameter
Generator assessment	Start availability, fuel, lubrication
PMS verification	Control signal, communication

Automation assessment	Alarm and monitoring status
Electrical verification	Switchboard, UPS, bus-bar
Load restoration	Critical Loads

Scenario-Based Evaluation Framework

Real offshore operational data is not available, so the proposed framework is assessed using representative blackout scenarios. The evaluation assesses whether the framework can detect failure sources, suggest recovery actions, and provide reasonable directions for recovery.

Table 2. Representative Blackout Evaluation Scenarios

Scenario	Failure Condition	Framework Assessment
Scenario 1	Generator fails to start	Generator and auxiliary verification
Scenario 2	Automatic PMS/automation recovery fails	Automation and control assessment
Scenario 3	Power remains unavailable after generator recovery	Electrical distribution assessment

The effectiveness of the framework is assessed utilizing:

$$Fe = \frac{Nc}{Nt} \times 100$$

where Fe is the framework effectiveness as defined previously (see Scenario-Based Framework Evaluation).

The recommended IBRF framework offers a structured approach to integrating fault diagnosis, system verification, and recovery sequencing, which

can support improved blackout recovery planning and offshore vessel electrical resilience.

IV. Scenario-Based Evaluation And Assessment Of The Proposed Framework

Evaluation Approach

The recommended Integrated Blackout Recovery and Fault Diagnosis Framework (IBRF) is tested using typical blackout scenarios to assess its ability to detect system failures and enable structured blackout recovery decisions. Offshore vessel blackout events occur as a result of interactions between diesel generators, power management systems (PMS), automation systems, auxiliary equipment, and electrical distribution networks [6]. The evaluation emphasizes the system's capability to recover rather than individual equipment troubleshooting.

Operational vessel data and access to industrial implementations are not available in real-time, so a scenario-based evaluation approach is utilized [22]. This strategy tests the framework against pre-defined failure points and determines its capability to supply necessary diagnostic steps and recovery priorities.

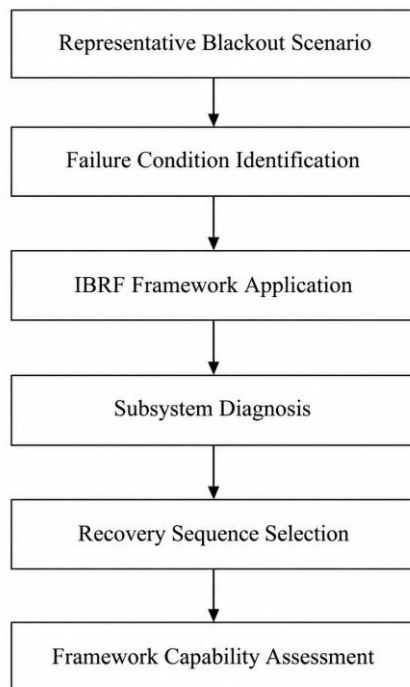


Fig. 8. Scenario-Based Evaluation Process of the Proposed IBRF Framework

Scenario Development and Failure Mode Identification

Critical dependencies identified during framework development are utilized to develop three representative blackout scenarios [23]. These scenarios involve failures related to generation availability, automation and control reliability, and electrical restoration.

The scenarios were chosen because recovery from a blackout relies on generator readiness, PMS verification, auxiliary system availability, UPS status, and restoration priority.

Table 3. Representative Blackout Scenarios For Framework Evaluation

Scenario	Failure Condition	Main System Involved	Required Diagnostic Area
S1	Generator fails to start	Generator and auxiliary systems	Start condition, fuel, lubrication, cooling, control availability
S2	Automatic PMS/automation recovery fails	PMS and automation systems	Control signals, communication, synchronization
S3	Power remains unavailable after generator recovery	Electrical distribution system	Switchboard, UPS, bus-bar, essential loads

Framework Coverage Assessment

A quantitative framework coverage assessment is proposed to evaluate whether the recommended Integrated Blackout Recovery and Fault Diagnosis Framework (IBRF) contains the necessary components to recover from a blackout situation on an offshore vessel. Criteria are based on the literature review and framework development, covering major

recovery requirements including generator readiness assessment, power management system (PMS) verification, auxiliary system evaluation, automation evaluation, electrical distribution verification, and recovery sequencing.

The assessment assumes that to successfully recover from a blackout, generator availability must be restored while the operational condition of associated systems must also be assured [24]. Electrical distribution components, including UPS systems, switchboards, circuit breakers, and bus-bar integrity, are also included, as it is impossible to ensure the availability of essential vessel services without reliable power distribution and control supply.

The framework coverage score is evaluated as:

$$F_c = \frac{\sum_{i=1}^T W_i}{W_T} \times 100$$

where F_c represents the framework coverage score, W_i represents the weight assigned to each satisfied evaluation criterion, and W_T represents the total evaluation weight. The weights are assigned based on the relative importance of each subsystem in the blackout recovery process, derived from engineering analysis and literature review.

The weighting distribution reflects the significance of each subsystem within blackout recovery decision-making.

Table 4. Framework Requirement Coverage Assessment

Evaluation Requirement	Weight (%)	IBRF Coverage
Generator readiness assessment	20	Covered
PMS verification	20	Covered
Automation assessment	15	Covered
Auxiliary system evaluation	15	Covered

Electrical distribution assessment (UPS, switchboard, bus-bar)	15	Covered
Recovery sequencing	15	Covered
Total	100	Complete framework coverage

The evaluation demonstrates that the necessary technical features for organized blackout recovery are included in the proposed IBRF structure. The results indicate complete inclusion of the predefined framework prerequisites, representing 100% requirement/criterion coverage in the scenario-based assessment. This does not represent operational recovery performance. This research was conducted against criteria defined by the author, does not use real vessel operational data, does not include controlled experiments, crew feedback, or field verification, and does not measure actual recovery time, fault-diagnosis accuracy, or operational reliability [27]. The evaluation shows only that the framework covers the criteria defined for it and should not be interpreted as evidence of any improvement in actual offshore vessel recovery time.

Scenario-Based Fault Diagnosis Assessment

To determine whether the recommended framework can handle different blackout situations, typical failure scenarios are analyzed. Crucial areas examined include the ability to recognize errors, the order in which recovery plans are developed, and the decision support provided.

The evaluation follows the three-level scoring approach:

- 0 = Not addressed
- 1 = Partially addressed
- 2 = Fully addressed

The scenario evaluation score is calculated as:

$$S_e = \frac{S_o}{S_m} \times 100$$

where S_e represents the scenario evaluation score, S_o represents the obtained assessment score, and S_m represents the maximum possible assessment score.

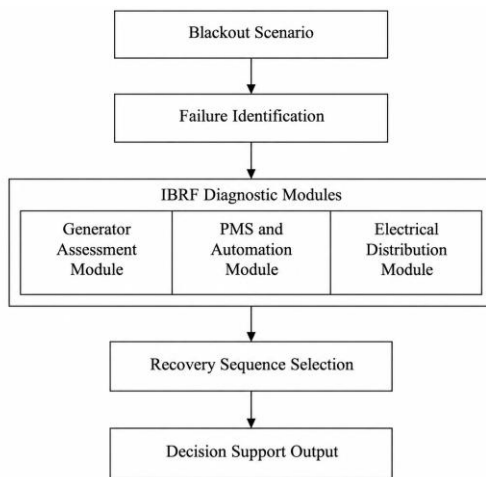


Fig. 9. Scenario-to-Framework Mapping for Blackout Recovery Evaluation

Table 5. Scenario-Based Framework Evaluation

Scenario	Fault Identification	Recovery Sequence	Decision Support	Total Score
Generator availability failure	2	2	2	6
PMS and automation failure	2	2	2	6
Electrical distribution failure	2	2	2	6

The maximum possible score is:

$$S_m = 18$$

The obtained score is:

$$S_o = 18$$

Therefore:

$$S_e = \frac{18}{18} \times 100$$

$$S_e = 100\%$$

The evaluated score indicates 100% coverage of the specified scenario assessment criteria. This does not indicate real vessel recovery efficiency, as operational parameters, real-time blackout records, and experimental verification results lie beyond the scope of this research.

Qualitative Assessment Through Literature Mapping

Comparing components of the recommended framework to those identified in previous studies on offshore electrical reliability and shipboard power systems supports the framework's validity. Previous studies indicate that a robust shipboard power system requires coordinated fault handling, dependable power management, efficient automation control, and proper restoration plans rather than using individual equipment in isolation [28].

In the blackout recovery plan, based on the author's industrial experience and practitioner knowledge, significance is given to PMS verification, generator readiness, UPS/bus-bar status, auxiliary system checks, restoration priorities, and testing procedures. Hence, the suggested IBRF extends the system approach by adding organized fault diagnosis and scenario-based evaluation for vessels whose operational data cannot be directly accessed.

V. Discussion And Limitations

The recommended IBRF is not a replacement for OEM manuals but an additional layer that uses structured data to incorporate equipment specifics and operate at the vessel level. By combining generator appraisal, automation assessment, PMS confirmation, auxiliary subsystem evaluation, and prioritized approaches to electrical repairs, this system reduces the complexities involved in diagnosis, aiding in making sound, structured, and informed decisions for blackout recovery.

Limitations

The research is limited by the lack of real offshore vessel operational data, controlled experiments, crew feedback, and field verification, and has a limited scope. Consequently, the proposed framework is evaluated under scenarios rather than through real-time performance measurement. Further studies

should incorporate data from vessels, digital twins, MATLAB/Simulink simulations, and operational recovery analysis to validate the recommended framework.

VI. Conclusion And Future Directions

This research developed an offshore vessel blackout recovery and fault diagnosis framework incorporating equipment reliability evaluation, system-level fault diagnosis, structured recovery protocols, and automation awareness. The framework provides a coordinated recovery pathway that addresses the limitations of isolated troubleshooting strategies. Prospective studies should focus on industrial validation, advanced simulation, and data-driven blackout prediction approaches [29]. The framework has been proposed and assessed through scenario-based evaluation; operational effectiveness on real vessels has not yet been demonstrated.

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