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LEARNING FROM INCIDENTS AND INSIGHTS SESSION

BLACKOUT - RELATED FINDINGS FROM POWER SYSTEM TESTING ON DP VESSELS

By

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Abstract

Power system blackouts remain a major challenge during the commissioning and operation of offshore Dynamic Positioning (DP) vessels. Drawing on operational experience, DNV has investigated blackout incidents across various vessel types, identifying common causes and comparing findings across the industry. This paper explores the main factors behind these blackouts and demonstrates how both modeling and physical testing are essential for improving DP system reliability. While dynamic simulations help predict system behavior, they cannot capture all real-world issues. Many problems only emerge during physical testing, particularly under complex or unexpected conditions. This paper highlights the most frequent issues encountered during testing and explains how they can be detected and addressed early. By combining analytical models with hands-on testing, this study presents a more effective approach to reducing risks and ensuring a smoother transition from commissioning to contract acceptance—while also supporting compliance with industry verification and validation practices. This integrated methodology enhances the safety and reliability of power system performance in offshore operations.

Abbreviation / Definition

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DP	Dynamic Positioning
DG	Diesel Generator
ME	Main Engine
HT	High Temperature
OMD	Oil Mist Detector
AVR	Automatic Voltage Regulator
PMS	Power Management System
IAS	Integrated Automation System
FMEA	Failure Modes and Effects Analysis
MBT	Model-Based Testing
UPS	Uninterruptible Power Supply
GHGE	Greenhouse Gas Emissions
OEM	Original Equipment Manufacturer

Introduction

Dynamic Positioning (DP) vessels are critical assets in offshore operations, where uninterrupted power supply is essential for safety and mission success. Despite stringent design and operational requirements, power system blackouts continue to pose significant risks during both commissioning and routine operation. Understanding the root causes of these incidents is vital for improving system reliability and ensuring compliance with industry standards. This paper presents a comprehensive review of blackout events, drawing on lessons learned from both DP and non-DP vessels. It highlights the importance of combining analytical modeling with physical testing to identify vulnerabilities, validate protection strategies, and enhance the overall robustness of marine power systems.

Review of Blackout Incidents Across Marine Sectors

Understanding the root causes of blackout events in marine power systems is essential for improving the reliability of Dynamic Positioning (DP) vessels. While DP-classed vessels operate under stringent redundancy and fault tolerance requirements, valuable insights can be drawn from blackout incidents occurring in other ship segments, where such constraints are less rigorously applied.

A review of 74 blackout events across non-DP vessels was conducted to identify recurring technical and operational failure modes. These vessels, although not subject to DP-specific design rules, share many of the same core systems - generators, switchboards, automation, and protection logic - making them a relevant reference point for understanding systemic vulnerabilities.

- Sensor/Instrument Failures – 18
- Fuel/Lube System Failures – 16
- Breaker/Control System Failures – 14
- Human Error – 10
- Governor/Overspeed Events – 6
- Software/Logic/Automation Faults – 6
- Excitation/Alternator Faults – 4
- Load Sharing/Synchronization Failures – 4

These figures are approximate and reflect dominant failure themes per incident. Many cases involved multiple contributing factors.

Notably, approximately 30 incidents occurred while only a single diesel generator (DG) or main engine (ME) was online. In these cases, the blackout mechanism was typically simple, and fault propagation was not a factor. This suggests that proper system configuration - particularly maintaining redundancy - could have prevented the blackout entirely.

Incident Type	**Description**	**Typical Causes**
Sensor/Instrument Failures	Failures in speed pickup, HT sensors, OMDs, etc.	Aging sensors, vibrations, calibration errors
Fuel & Lube System	HT pressure loss, lube oil issues, valve stuck, filter bypasses	Maintenance lapses, design flaws, wear & tear
Breaker / Switchboard Faults	CB opening unexpectedly, relay issues, tie breaker faults	Faulty logic, auxiliary contact wear, UPS problems
Human Errors	Misinterpretation of alarms, valve misoperation, test on wrong DG	Inadequate training, procedural gaps
Software / Automation Errors	Logic errors, console failures, software updates gone wrong	Vendor code issues, insufficient testing
Excitation / Alternator	Alternator ground faults, AVR problems	Poor insulation, stator issues, aging components

Over the reviewed cases, incidents, although individually varied in origin, reveal clear systemic patterns in terms of their root causes, contributing factors, and preventability.

Common Technical Causes

Sensor and Instrumentation Failures
A significant number of blackouts were triggered by faults in critical sensors such as speed pickups, oil mist detectors (OMDs), and high-temperature (HT) pressure or lube oil level transmitters. These components are essential for engine protection but are prone to failure due to vibration, heat, aging, or calibration drift. In many cases, false shutdowns of the only running DG were initiated by unreliable sensor readings.

Fuel and Lubrication System Issues
Failures in HT cooling loops, lube oil systems, or fuel delivery - often due to valve malfunctions, filter bypasses, or air ingress - were also common. These issues frequently emerged during transient conditions such as generator start-up or load changes, highlighting the sensitivity of these systems to dynamic operational stresses.

Breaker and Switchboard Control Failures
Unexpected circuit breaker openings, relay misoperations, and UPS-supported control system faults were identified in several cases. In some instances, breakers opened without a clear upstream fault, pointing to auxiliary contact wear or logic errors. These failures often bypassed redundancy logic, resulting in total power loss despite the availability of other generators.

Excitation and Alternator Faults
Ground faults, AVR malfunctions, and excitation loss were among the less frequent but more severe failure modes. These faults typically required OEM-level diagnostics and were often not detected until after the blackout occurred.

Software and Automation Logic Errors
Several incidents were linked to failures in integrated automation systems (IAS) or power management systems (PMS), particularly during software updates or configuration changes. In some cases, logic faults prevented backup DGs or emergency generators from connecting, significantly delaying recovery.

Load Sharing and Synchronization Failures
A smaller subset of incidents occurred during generator synchronization or load transfer. These failures underscore the importance of robust automation and clear crew procedures during transitional operations.

Common Operational Causes

Human Error and Procedural Oversights
Human factors were a recurring theme across multiple categories. Errors included incorrect manual interventions, failure to reset systems after testing, and misinterpretation of alarms. These incidents often occurred during operational transitions such as fuel switching, port departure, or mode changes. The interface between crew actions and automation logic remains a critical vulnerability.

Summary of Findings

Despite the diversity of failure modes, several systemic patterns emerged:

- Most blackouts involved the loss of a single DG without subsequent fault propagation.
- Fuel control and excitation systems were the most common sources of DG failure with propagation potential.
- Automation and software faults - especially those introduced during updates - represent a growing risk area.
- Human error remains a significant contributor, particularly in systems with complex or poorly documented procedures.

Importantly, many of the reviewed incidents could have been prevented through improved system configuration, better crew training, or more robust automation logic. These findings reinforce the value of proactive design validation - through both modeling and physical testing - to identify and mitigate vulnerabilities before they lead to operational failures.

Modeling for Blackout Prevention

Modern offshore vessels rely on increasingly complex power plant control and protection systems to ensure optimal efficiency and reliability. As these systems grow in sophistication, it becomes more difficult to predict power plant behavior across all operational configurations and fault scenarios. Modeling offers a structured and scalable method for analyzing and verifying system performance, especially during design and commissioning.

By simulating a wide range of operating conditions and fault types, modeling enables early identification of potential vulnerabilities - particularly in power plants where the physical arrangement of mission-critical equipment creates fault propagation paths between redundant systems. This analytical approach supports the verification of protection coordination, system stability, and interactions with other onboard systems, all without exposing equipment to the risks associated with live fault testing. Moreover, it provides a unified and standardized method for evaluating system integrity across different vessel types, enhancing consistency and confidence in design and commissioning processes.

Two primary modeling approaches are commonly used in DP power system analysis:

- Steady - state models, widely used across the industry for load flow analysis, protection coordination, and basic fault studies.
- Dynamic models, which simulate electromagnetic transients and allow detailed analysis of fast events such as short circuits, load rejections, or unintended system interactions - where protective responses to one fault type may inadvertently trigger under different fault conditions.

These models offer significant flexibility, allowing analysts to simulate fault cases that would be unsafe or impractical to test physically. As a result, modeling can reduce the number of live tests required while still providing a high level of confidence in system performance.
The accuracy of a model can be validated by comparing its predictions with selected live test results. This feedback loop not only improves model fidelity but also builds trust in its use for further analysis. A hybrid approach - combining simulation with targeted physical testing - is particularly effective for evaluating closed bus - tie configurations, where fault tolerance must be demonstrated with high confidence.

Case Study: Modeling Based Blackout Prevention

The following blackout scenarios were encountered during DP vessel analysis and testing, where modeling played a critical role in identifying and resolving vulnerabilities - often during the design stage, before any live trials were conducted. These cases are drawn from actual offshore projects and demonstrate how simulations can uncover complex system behaviors that are difficult to detect through traditional review methods or even physical testing.

Short Circuits in Closed Bus Configurations

One of the failure modes that must be analyzed in detail is the short - circuit fault. This analysis must be performed under worst - case conditions, which need to be clearly defined and justified. While analytical methods can help reduce the number of cases by trimming similar scenarios, a brute - force simulation approach across edge - case configurations often reveals that worst - case conditions can arise in multiple, unrelated ways.

The inclusion of the second barrier concept - required by class societies for DP3-class vessels and informed by hands-on experience with first barrier failures - assumes a hidden fault in any element of the primary protection layer. This significantly increases the number of scenarios that must be considered during analysis. The complexity of system interactions during fault conditions, combined with the diversity of operational configurations, renders traditional analytical approaches insufficient for ensuring proper protection coordination and preventing cascading failures.

This subchapter highlights one of the most prevalent and recurring issues found during modeling - across multiple vendors and system configurations - demonstrating that the industry is still learning the intricacies of closed bus protection design.

The Challenge of Fault Current Splitting

A key challenge in closed bus systems is ensuring selectivity and discrimination - the principle that only the protection device closest to the fault should react. In open bus systems, this principle is typically upheld. However, in closed bus configurations, designers often prioritize controlled splitting the power plant into isolated segments before allowing downstream protections to act, bending the traditional rules of selectivity.

To achieve this, many systems rely on blocking - based logic, where directional protection devices detect fault current direction and exchange blocking signals to suppress unnecessary trips.

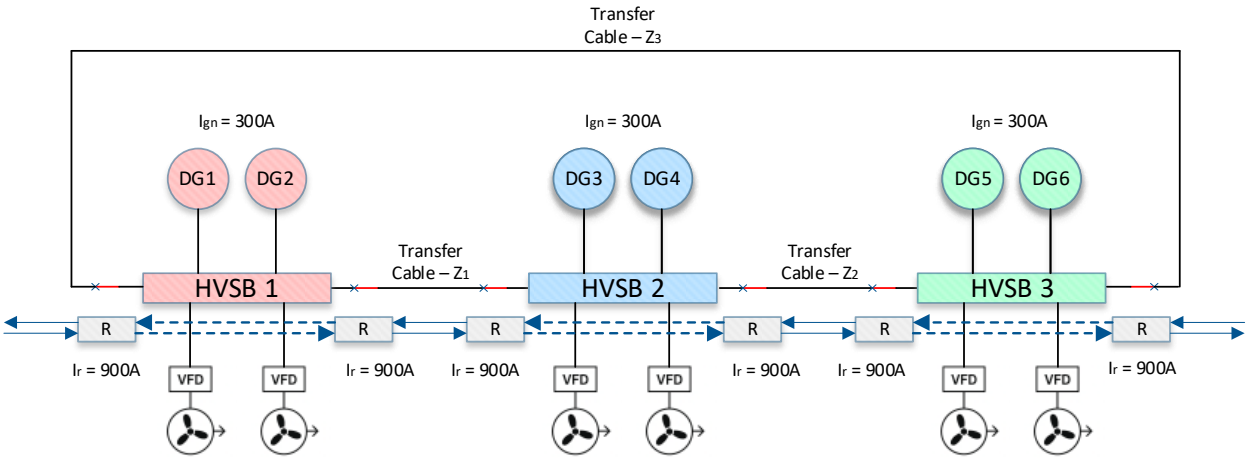

Figure 1. High - level schematic of a closed bus DP power plant with directional protection and blocking logic. $Z_1 = Z_2$, $Z_3 = Z_1+Z_2$

For this logic to function correctly, all relevant protection devices must detect the fault current and activate simultaneously. This ensures that blocking signals are exchanged in time to prevent unintended trips. However, in closed bus configurations, fault current splits between multiple paths, and the magnitude of current in each path depends on the relative impedances.

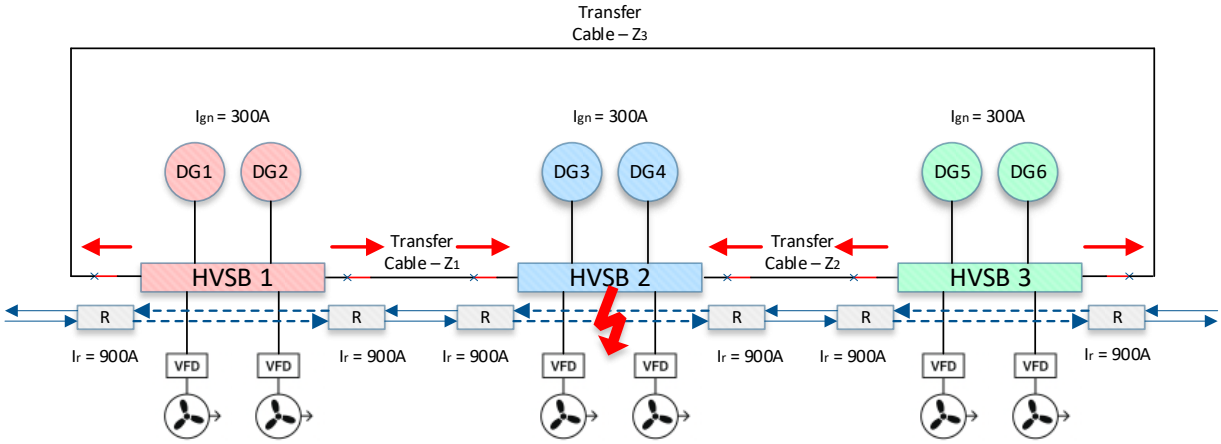

Figure 2. Illustration of fault current splitting across bus ties in a closed bus configuration. Fault location and current paths are marked.

The existing verification schemes may not fully capture system behaviour, as certain failure modes fall outside the traditional scope of discrimination studies. Additionally, protection logic details are often withheld to safeguard intellectual property, which limits the ability of class societies and advisory engineers to perform a comprehensive assessment. This gap underscores the need for complementary methods - such as simulation and targeted testing - to ensure that system behaviour is thoroughly evaluated under realistic fault conditions.

The Operational Context and the Hidden Risk

Closed bus configurations are not implemented for safety - they are introduced to optimize fuel consumption, reduce generator running hours, and improve GHGE performance. As such, the power plant is often expected to operate with a minimal number of generators, and in some cases, with one switchboard energized but without any generators connected to it.

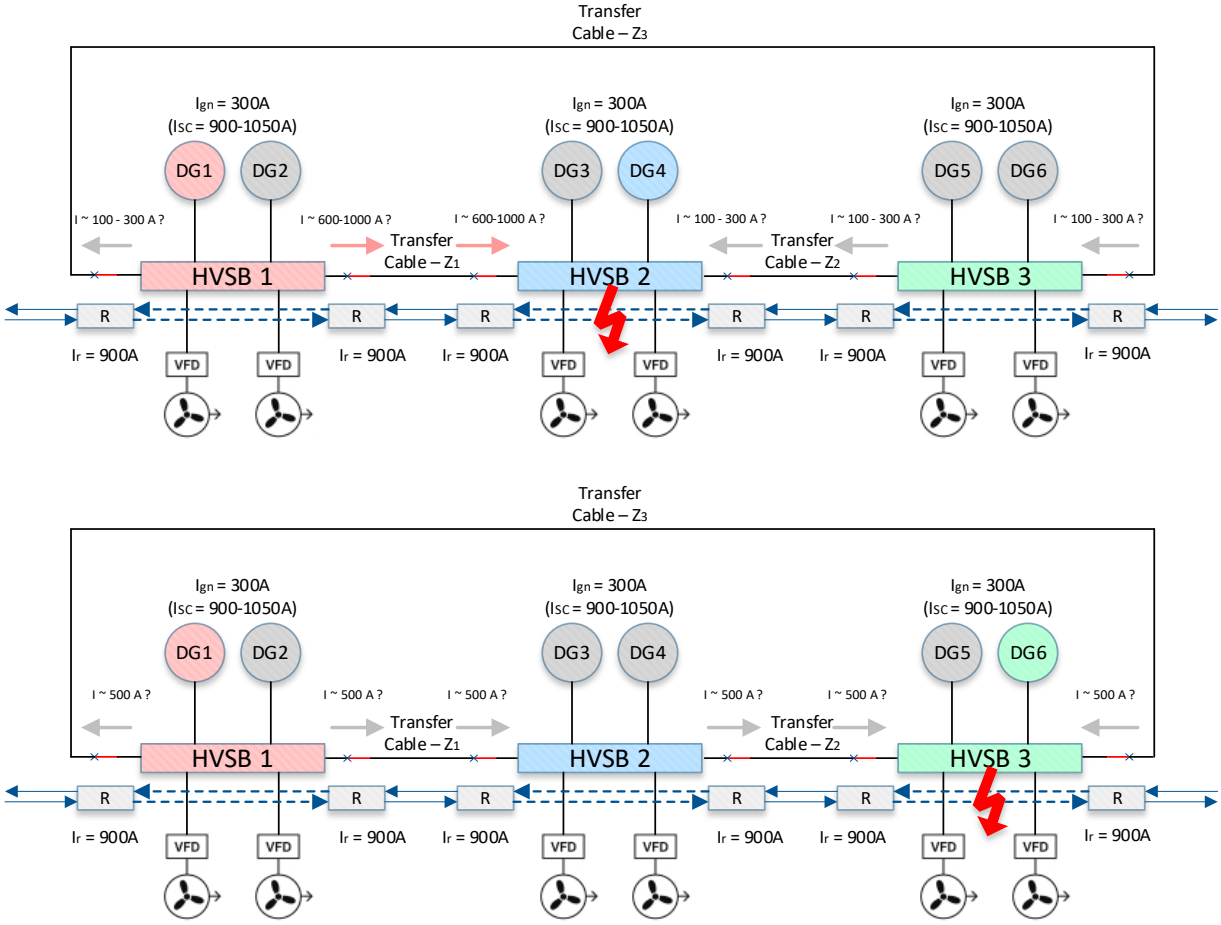

Figure 3. Minimal generator configuration with fault location and current paths marked. Fault current levels are insufficient to trigger protection. $Z_1 = Z_2$, $Z_3 = Z_1+Z_2$

In this configuration, fault current may flow through parts of the system at levels too low to activate protection relays, especially if the protection is tuned for full generator fault current. This leads to a dangerous condition: no protection operates, no blocking signals are exchanged, and the fault propagates - resulting in a total blackout.

This is a common and recurring issue. In many projects involving closed bus systems, simulations have revealed that at least one protection device fails to detect sufficient fault current, preventing it from issuing a blocking signal. The result is either:

- No protection operates, leading to a full blackout, or
- The wrong device trips, causing unnecessary disconnections and loss of redundancy.

This example highlights the importance of:

- Analyzing a wide range of configurations, including edge cases
- Using simulations to uncover hidden failure modes
- Conducting design workshops to explore mitigation strategies or implement minor design adjustments

Modeling consistently identifies this vulnerability before live testing. In every case where this issue was flagged during simulation, the protection logic was adjusted in advance, and the system passed its short - circuit test. This has:

- Prevented repeated testing
- Avoided costly delays
- Reduced the risk of equipment damage

Directionally Misled: Fault Location Challenges in Closed Bus Tie Configurations

As highlighted earlier, there is a need to design a reliable method for fault location detection. The use of directional detection and blocking - based logics is widespread in the industry, but various approaches are employed to achieve this goal.

Logic tables are often extensive, defining rules that - assuming the protection devices detect the fault - allow the system to successfully identify the fault location and respond accordingly. However, this has also been found to be one of the most frequently overlooked areas in terms of verification.

While the principles behind these logics may appear reasonable and digestible, certain power plant configurations can interfere with their operation in ways that were unforeseen by the designers. As with the previous example, there are many configurations to consider, and it is easy to prematurely conclude that the worst - case scenario has been identified, and no further analysis is needed.

There is no better tool for uncovering these design gaps than a power plant model with the protection logics implemented and tested across edge - case scenarios.

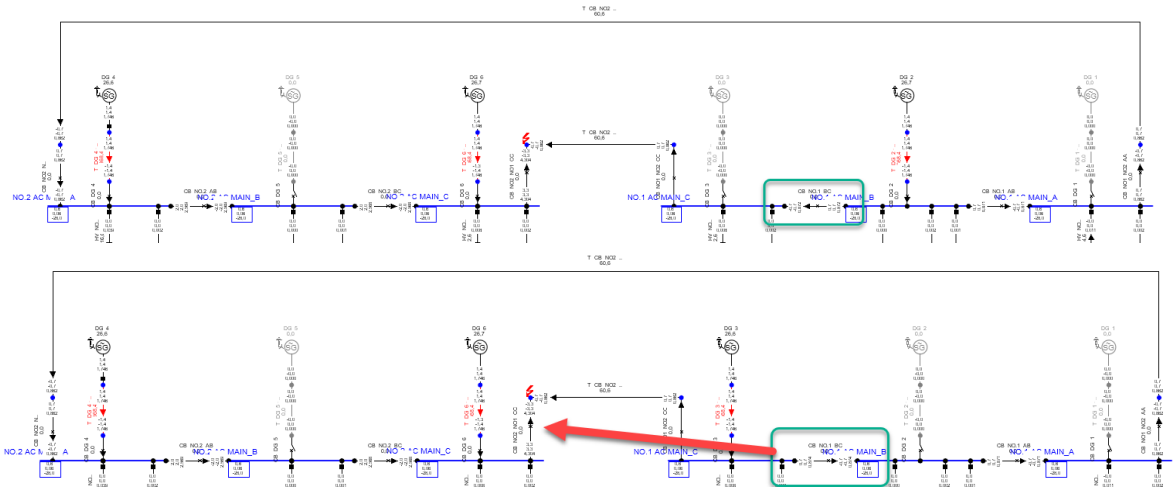

Figure 4. Impact of generator configuration on fault location detection logic.

This issue can also arise during transitions between linear closed bus and closed ring configurations. While a logic scheme may function correctly in one topology, it may fail in the other due to changes in current paths, impedance distribution, or directional detection assumptions. It is critical to validate that the

protection logic remains effective across all intended operating modes, especially in systems where reconfiguration is part of normal DP operations.

The Overlooked Threat: Negative Sequence Protection Settings

Another potential blackout scenario - often underestimated in design reviews - involves the configuration of negative sequence protection in generators. While most attention is typically focused on short-circuit faults, negative sequence protection is frequently overlooked, despite its critical role in detecting unbalanced conditions such as phase loss or asymmetrical loading.

Throughout the analyzed power plant protection designs, it has been observed that some systems apply identical, definite-time settings across all generators. In the event of a negative sequence fault, this results in the simultaneous disconnection of all generators, leading to a full blackout. This issue - along with other risks related to phase imbalance in closed bus configuration power plants - was also discussed in a 2022 paper by the author.

The risk can be mitigated by implementing time-overcurrent characteristics, which stagger the response of each generator and help preserve system integrity under fault conditions. Simulations are instrumental in evaluating these settings, ensuring that protection coordination is maintained even during asymmetrical fault scenarios.

Beyond Closed Bus: Modeling in Open Bus Configurations

While most modeling efforts focus on closed bus systems, the value of simulation extends to open bus configurations as well. Although detailed modeling in open bus systems is sometimes viewed as excessive - given their inherently simpler fault propagation paths - several cases have demonstrated that simulations can uncover design flaws that are routinely overlooked during traditional reviews.

These issues have not been identified during FMEA studies, design reviews, or class approvals, as these processes often rely on discrimination studies that present incomplete or overly optimistic assumptions. This underscores a critical point: even in open bus configurations, power plant simulations offer a valuable layer of verification, enabling a more comprehensive evaluation of system integrity.

Moreover, modeling can help assess FMEA findings that reveal subtle but critical risks. One recurring issue is the installation of equipment from different redundancy groups within a single physical location. While logically separated in design documentation, such arrangements introduce a common-mode failure risk that undermines fault tolerance - especially in fire, flooding, or mechanical damage scenarios. This vulnerability is often underestimated by stakeholders, as it is not immediately apparent in schematic reviews or standard verification workflows.

By simulating fault conditions and evaluating the physical layout alongside electrical separation, modeling provides a more holistic view of system resilience. It enables engineers to identify and mitigate risks that stem not only from electrical design but also from spatial and environmental factors. This integrated approach strengthens the overall reliability of DP vessels, even in configurations traditionally considered less complex.

Limitations of Modeling

While modeling is a powerful tool for identifying and mitigating blackout risks, it is not without limitations. These must be acknowledged to ensure that simulation results are interpreted appropriately and used in conjunction with other verification methods.

Simulations inherently assume that all systems are configured correctly and that sensors, wiring, and logic behave as intended. In practice, however, issues such as sensor miswiring, incorrect CT polarity, or human error during construction phase can lead to outcomes that the model cannot predict. These types of failures - often rooted in physical implementation rather than design - fall outside the scope of even the most detailed simulations.

This is where physical testing becomes indispensable. While modeling can reveal systemic vulnerabilities and guide design improvements, only hands-on testing can uncover real-world issues introduced during installation, integration, or operation. The two approaches are not in competition - they are complementary. Together, they form a more complete assurance strategy, bridging the gap between theoretical performance and operational reality.

This synergy is exemplified by the successful application of Model-Based Testing (MBT) methodology, which integrates simulation outputs into structured test procedures. MBT has proven effective in revealing additional vulnerabilities in protection systems - particularly those related to logic implementation, sensor wiring, and fault detection thresholds - that may not be evident during design reviews or standard commissioning tests. By aligning simulation insights with physical verification, MBT strengthens the validation process and enhances confidence in system robustness under real-world conditions.

Conclusion

Blackout incidents on DP vessels often result from a combination of technical failures, human error, and limitations in system design or configuration. This paper demonstrates that while modeling is invaluable for identifying potential vulnerabilities and optimizing protection strategies, it cannot replace the insights gained from physical testing. A hybrid approach—integrating simulation with targeted onboard trials—offers the most effective means of ensuring system reliability and safety. By systematically addressing both design and operational risks, the industry can reduce the frequency and impact of blackouts, supporting safer and more efficient offshore operations.