A Risk Based Case for Closed Bus High Voltage DP Operations

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Abstract:

Recent developments in high voltage (HV) switchgear and their associated protections has prompted an accelerating movement towards the implementation of Dynamic Positioning (DP) facilities with closed bus capabilities. This shift in technology and classification society approvals has been in opposition to the accepted theories of oil company and drilling contractor management, where the acceptance of the "risk" of closed bus operations is often deemed to be too high to be acceptable. This paper focuses in two parts:

1. An assessment of all IMCA DP incident reports from 2011 to 2015 for possible differences in the outcome of these real-world incidents if a closed bus philosophy was implemented.
2. A risk assessment case study of a new-build DP semi-submersible specifically designed, commissioned and acceptance tested in "Ring" bus configuration.

Introduction

Recent developments in high voltage (HV) switchgear and their associated protections has prompted an increasing trend towards the implementation of Dynamic Positioning (DP) facilities with closed bus capabilities. This shift in technology and classification society approvals has been in opposition to the traditional approach of oil company and drilling contractor management, where the acceptance of the risk of closed bus operations is often deemed to be too high to be acceptable. But is this really the case? Other facilities, including hospitals, airports, factories and network distribution have been using closed bus and ring bus configurations to assist in reducing the risk of high-likelihood low-consequence failures associated with parallel (open bus) generator configurations (Fehr 2012). Is there any data to support the belief the DP industry has that these risks are outweighed by the high-consequence, low risk incidents of closed-bus operations?

In order to answer these questions, a thorough analysis of the data in International Maritime Contractors Association (IMCA) DP station-keeping incident reports from 2011 to 2015 was performed. IMCA, which monitors DP vessels from supply vessel to flotel to drilling rig provides access to a cross section of sectors and regions that would be unavailable to industry professionals within a single company. While not all DP incidents are reported to IMCA for reference, it does provide a global sampling and a far larger quantity of incidents across the industry than one company can provide.

This global sample provides insight into the operation and incident characteristics and trends over the 5-year period and helps to identify what failures are regular in the industry. The data begins to assist decision makers in forming a picture of what the true threats in DP power management are.

The second part of the quest to answer the question of Closed bus operation risk is a case study of a specific vessel, including the risk assessment of the vessel, comparing the operations of the vessel in “Ring” bus versus “Open” bus. This vessel, and the process by which it was designed, commissioned, tested, and risk assessed provide a blue-print for the operation of a high-reliability DP power management system.

Literature Review of IMCA DP Station-Keeping Incidents from 2011 to 2015

During the 5-year period from 2011 to 2015 a total of 333 station keeping incidents were reported to IMCA; of these, 45 were attributed to "Power" and a further 12 to "Electrical", “Propulsion” and "General" but which bus-tie configuration was an element of the event.

	2011	2012	2013	2014	2015	TOTAL
Total Quantity of DP Incidents reported to IMCA	54	64	64	71	80	333
IMCA "Power" Incidents	7	6	13	9	10	45
Other Incidents affected by Power Configuration	2	2	0	0	8	12
Total Incidents affected by Power System	9	8	13	9	18	57

All 333 incidents were reviewed to confirm if bus-tie configuration had impacted the incident or not, resulting in an additional 12 incidents which were added to the analysis below to provide additional data and support the assessment (a total of 57 incidents).

Methodology

In order to determine if the HV bus configuration would have affected the outcome of the incidents reported to IMCA, an analysis of the available information was first performed.

1. All reports, regardless of attributed "Main Cause" were reviewed to confirm they were not incorrectly assigned and where applicable, were added to the pool of

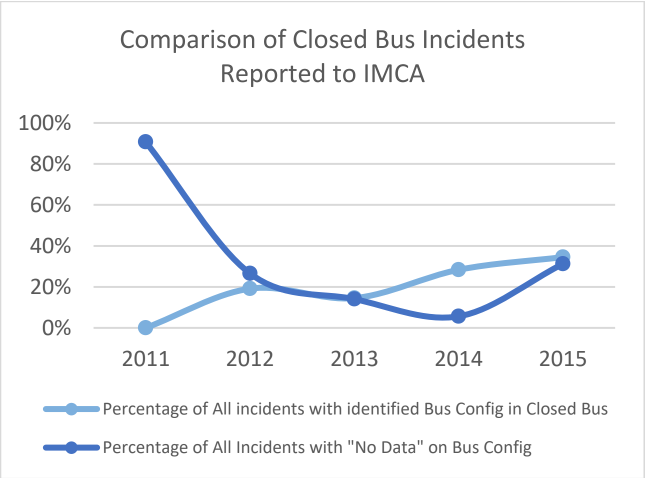
"Power" related incidents – resulting in 12 additional cases.
2. The incident pool was then systematically assessed for information provided to IMCA regarding the DP set-up and the causes and outcomes of the incident.
3. Each incident was reviewed against what the equivalent outcome would be in the other bus configuration (i.e. if the incident occurred in open bus, what would have been the outcome in closed bus?), and an assessment of if the outcome would have been better, worse or no different in closed bus configuration was undertaken.

Where incidents have not been reported to IMCA during this period, they have been excluded from this paper to maintain the integrity of the sample. The 5-year period selection was a function of attempting to keep the most up to date information (2015 was the last year available at time of review) and latest technologies with a sufficiently large sample size: Data prior to 2011 was of insufficient quality to be able to reliably determine what caused the incident and what the operating situation of the vessel was at the time of the incident and so has been removed from the sample set.

Observations

The primary outcome of this report was to determine if the operation in closed-bus configuration would result in higher-risk to operations based on real-world data. Some interesting observations were available as a result of the exercise:

1. While IMCA data was selected for the breadth of the industry from which IMCA receives data, the selection of DP related incidents (333 over 5 years) was substantially below the quantity of incidents seen in industry during this time frame. It is fair to state that a number of incidents relating to DP operations are not being reported to IMCA for distribution to the industry. An increased sample size would improve the industry's ability to use these incidents to direct changes in behaviors and systems as a result of definitive data rather than the instincts of facility managers and the data available to individual companies. This is well documented by IMCA themselves in presentations to The DP Conference in previous years. (Giddings 2007, Giddings 2012)
2. An increasing trend towards closed bus configuration operations was observed over the 5 year period. This trend was visible in reports of both incidents with and without power configuration impacts. Using the incident reports unrelated to power, it is possible to observe a steady increase in closed-bus operations. Additionally, the quality of reports to IMCA steadily improved, with a decreasing trend for reports with no data on the bus configuration.
3. Incorrectly testing or failing to reset protections and subsequent failure of the protection systems after testing was identified as a factor in four incidents, 2 of which resulted in loss of position. This represented another series of preventable incidents.
4. The "Spinning reserve" requirements of facilities were an increasing cause of IMCA reports as vessels were unable to maintain their station in heavy weather while maintaining the "spinning reserve" requirements dictated in their operating guidelines. In 2015, six incidents of this style were reported, amounting to 33% of power related incidents for the year. These incidents, which did not result in loss of position, were encountered in both open and closed bus configurations.



Forty-three of the 57 incidents did not report a loss of position associated with the incident. Of the 14 situations where a loss of position was reported, 3 had reported insufficient information, and 2 events were unaffected by bus configuration. 6 events were analyzed as having better outcomes in closed bus operation and 3 were analyzed as having worse outcomes in closed bus (these 3 incidents are reviewed in depth below).

Loss of Position Incidents	Bus Config	Outcome analysis
IMCA-1552	Open	Insufficient Data
IMCA-1580	Open	Closed Bus Better
IMCA-1409	Closed	Closed Bus Worse
IMCA-1428	Closed	Closed Bus Worse
IMCA-1431	Open	Insufficient Data
IMCA-1308	Closed	Closed Bus Worse
IMCA-1336	Open	Closed Bus Better
IMCA-1344	Open	Closed Bus Better
IMCA-1207	Closed	Closed Bus Better
IMCA-1247	Open	Closed Bus Better
IMCA-1248	Closed	Unaffected
IMCA-1254	Closed	Unaffected
IMCA-1120	No Data	Insufficient Data
IMCA-1123	Open	Closed Bus Better

Results

Of the 333 DP incidents reported to IMCA between 2011 and 2015, 57 were impacted by their bus configurations. The 57 incidents impacted by bus configuration could then be split into 4 categories:

Bus configuration would not impact outcome of incident	23
Closed bus configuration would have improved the outcome of the incident	24
Open bus configuration would have improved the outcome of the incident	3
Insufficient data provided to determine if the bus configuration could have impacted the incident	7

The majority of incidents which occurred in open bus which would have been positively impacted by closed bus operations were partial blackouts where the systems caused section blackouts as a result of failures on a specific bus (18 out of the 36 open bus configuration incidents, accounting for 50% of open bus power related incidents). While a decrease in available power to the full system was possible, these incidents would have resolved with power remaining available to all station-keeping and propulsion throughout the incident.

In only 3 cases would open bus configuration have resulted in an improved incident outcome. Each of these incidents are outlined below:

1. IMCA-1308: The Generators were operating in closed bus and asymmetric mode with 2 generators on. A loss of 1 engine caused the other to take full load and blackout 2 sections (4 thrusters). Asymmetric operation is not possible in open bus, so the event would not have occurred in open bus configuration.
2. IMCA-1409: A short circuit in the Port Drilling drive unit caused a power surge in the thruster steering HPU system resulting in five thrusters stopping. If the short circuit had occurred in open bus, it would have only lost half the thrusters. This highlights a problem with voltage dip ride through testing of this facility.
3. IMCA-1428: A local short circuit on Generator No. 1 caused a full black out when the bus ties failed to open on the failure of Generator No. 1. This highlights a problem with protection system testing of this facility: possibly the settings had not been re-set correctly after the most recent tests.

Therefore, in a situation where a DP-2 or DP-3 vessel has been competently tested and is in correct working order, closed bus operation has the same or better risk profile as open bus operation when considering actual faults which have occurred in industry.

A case study of a new-build DP semi-submersible

The following is a case sturdy of a new-build semi-submersible delivered in July 2016. This vessel was delivered with the dual notation of DNVGL's DYNPOS-AUTRO and DYNPOS-ER, and accepted with the main operating mode being DYNPOS-ER in Ring Bus configuration. While DYNPOS-ER is generally not recognised as having the same level of redundancy as a DP3 facility, the dual-notation required all the DP3 redundancy to be incorporated into the build, providing the Rig Owner and their Client with an exceptionally robust and versatile rig.

The power system aboard the vessel was designed to operate in ring bus configuration with DYNPOS-ER notation to give greater reliability and flexibility to the operating capability of the vessel. With the nature of ring bus and the reliability required to meet the dual DYNPOS-ER and DYNPOS-AUTRO notations the protection of the power system was designed and built to a far greater capability than is found on conventional DP-3 vessels.

The following equipment was incorporated in the protection scheme aboard the vessel:

- ABB Relion Protection Relays
- ABB Diesel Generator Monitoring System (DGMS)
- ABB ACS6000 Thruster Drives
- ABB ACS800 Drilling Drives
- ABB Event Based Fast Load Reduction (EBFLR)*
- KM Vessel Management System
- Woodward Atlas II Governor
- ABB Unitrol 1020 Automatic Voltage Regulator
- KM AutoChief 600 Engine Control and Safety System
- NOV Drilling Power Limit System (DPLS)

The individual systems were fully integrated to provide a robust and comprehensive protection package.

In preparation for Client acceptance the Rig Owner worked with Class Society DNV to confirm the power management philosophy would comply with the requirements of class and client, resulting in the rig being the first rig to have class-approved operating configurations with less generators than HV switchboards.

Client acceptance of this rig required a risk-based approach to the operating methodology, and a formal assessment of the fault scenarios was performed, comparing the outcomes for both "Ring-Bus" configuration and "Open Bus/4-Split" methodology to determine what, if any difference to the risk profile of the facility would be experienced in the perceived "higher risk" operating mode of "Ring-Bus"

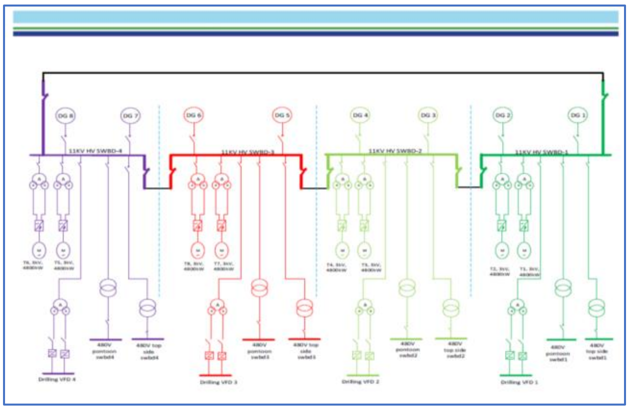


Figure 1 Ring Bus vessel configuration. Image reproduced from DNV GL

Despite industry beliefs to the contrary, the Rig Owners were able to provide a sound argument based in logic and engineering principles to confirm that the risk of worst case failure design intent failures (or worse) while operating in ring bus was equal to or better than operations in 4-split. Part of this process was a side-by-side comparison of the outcome of a range of incidents and scenarios, comparing the ring bus configuration's outcome against the same situation in open bus.

The risk based analysis for that facility is provided as Appendix A. A summary of relevant outcomes is below:

	Ring Bus	**Open Bus**
Number of risks assessed	27	27
Risks ranked as "Low"	26	24
Risks ranked as "Medium"	1	3
Situations resulting in Full Blackout	4	4
Situations resulting in loss of quadrant	6	10

Considering those scenarios which the crews and specialist engineers were able to generate, there were no situations which the fully tested and compliant ring-bus configuration would be worse than open bus configurations. This tells the observer that in this case, there was no discernible negative impact to power incident risk as a result of closed bus configuration. This is powerful information to decision makers who are concerned about the risk of closed bus operation

This comparison using a side-by-side assessment methodology allows decision makers to consider the risks of power management philosophies in a logical fashion.

A Note on 3-Phase Short Circuit Faults

Many decision makers concerned with the closed bus vs open bus configuration assessment are concerned about the low likelihood, high severity risks which, due to low likelihood, are not well described in the above reviews.
Key to this concern the possibility of a 3-Phase short circuit. While this fault was of particular concern to closed bus operations in the early days of DP technology modern switchgear has eliminated the possibility of this style of fault from new and recent-build facilities. This has not precluded classification societies and clients demanding testing of voltage-dip ride through capabilities for new builds. This testing, while possible using current methods, is heavily invasive, often open to interpretation, and has potential to damage equipment. An updated and industry-consistent methodology is required.

Protection System Testing

There is no disputing that testing of protection systems needs to improve industry-wide. Our conclusions regarding operations in closed bus configuration are based on the assumption that protection systems have been fully implemented, thoroughly tested and are set in their ready position. This can only occur as the result of a detailed testing and re-setting program and should be undertaken only with specialist supervision.

Conclusion

Using a scenario based risk assessment of the operating modes and performing a side by side analysis of the risk of closed bus operation vs open bus operation has, in two widely differing methodologies, proven the value in considering closed bus operations for DP vessels. This risk-based methodology can be applied to any vessel where closed bus operations are being considered.

While each facilities' arrangements are different and the risk profiles for each vessel varies depending on engine-thruster configuration and the HV protections, there is an opportunity to decrease the risk of sector blackout and improve engine efficiency in modern DP vessels using closed bus configurations and a robust assessment methodology.

The most risk reduced vessel arrangement is a ring or closed bus configuration on a thoroughly tested vessel with intact protection systems. Regardless of bus configuration, methods for ensuring protection systems are intact should be developed and utilized within industry to ensure risk of power system failure and subsequent loss of position remains As Low As Reasonably Practicable.

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Appendix A

Risk Assessment Comparison of Closed and Open Bus Configurations

Risk Analysis		Closed Bus Operation				Open Bus Operation			
ID	Description	Likelihood	Consequence	Sev	RISK	Likelihood	Consequence	Sev	RISK
1	Control System Failure (Any) - Full Blackout	B - Has occurred in industry	Full Blackout, Auto Recovery	3	LOW	B - Has occurred in industry	Full Blackout, Auto Recovery	3	LOW
2	Control System Failure (Any) - Full Blackout, Logic blocks restart	B - Has occurred in industry	Full Blackout, Logic blocks restart	4	LOW	B - Has occurred in industry	Full Blackout, Logic blocks restart	4	LOW
3	Control System Failure (Kongsberg) - Full Blackout, Logic blocks restart	C - Has occurred in Company	Full Blackout, Logic blocks restart	4	MED	C - Has occurred in Company	Full Blackout, Logic blocks restart	4	MED
4	Control System Failure (ABB) - Loss of Quadrant	C - Has occurred in Company	Loss of Sector, Logic blocks restart	3	LOW	C - Has occurred in Company	Loss of Sector, Logic blocks restart	3	LOW
5	Short circuit – damaged generator cable	D - Multiple occurrences per year in Company	Temporary phase back and reduction in total output power until standby engines start. No loss of position keeping capability.	2	LOW	D - Multiple occurrences per year in Company	Loss of one generator. If only one generator on in engine room, then loss of one quadrant.	2	LOW
6	Short circuit – damaged thruster cable	C - Has occurred in Company	Loss of one thruster	1	LOW	C - Has occurred in Company	Loss of one thruster	1	LOW
7	Short circuit – damaged bus-tie cable	B - Has occurred in industry	Revert to Close bus mode, no loss of position keeping capability.	1	LOW	B - Has occurred in industry	No effect	1	LOW
8	Loss of engine on a bus, standby engine does not start	E - Multiple occurrences per year at Facility	Temporary phase back and reduction in total output power until standby engines start. No loss of position keeping capability while next standby engine is starting.	1	LOW	E - Multiple occurrences per year at Facility	Loss of one quadrant.	2	MED
9	Failure of Relay Protection System	C - Has occurred in Company	Loss of one quadrant.	2	LOW	C - Has occurred in Company	Loss of one quadrant.	2	LOW
10	Emergency Shutdown (ER)	E - Multiple occurrences per year at Facility	Temporary phase back and reduction in total output power until standby engines start. No loss of position keeping capability while next standby engine is starting.	1	LOW	E - Multiple occurrences per year at Facility	Loss of one quadrant.	2	MED
11	Fire/Flood in Engine Room (Loss of Engine Room), ER ESD activated.	C - Has occurred in Company	Temporary phase back and reduction in total output power until standby engines start. No loss of position keeping capability while next standby engine is starting.	1	LOW	C - Has occurred in Company	Loss of one quadrant.	2	LOW
12	Squall	E - Multiple occurrences per year at Facility	Position keeping in 30m/s, ±20deg.	1	LOW	E - Multiple occurrences per year at Facility	Position keeping in 30m/s, ±20deg.	1	LOW
13	Mal-operation	D - Multiple occurrences per year in Company	Loss of one quadrant	2	LOW	D - Multiple occurrences per year in Company	Loss of one quadrant	2	LOW
14	Sabotage	B - Has occurred in industry	Full Blackout, Logic blocks restart	4	LOW	B - Has occurred in industry	Full Blackout, Logic blocks restart	4	LOW
15	Fault: Engine over speed due to intake of flammable gas or control system failure	C - Has occurred in Company	Tie-breakers open on over-frequency, HV bus splits, engines shut down due to over-speed protections. Loss of all over-speeding engines.	2	LOW	C - Has occurred in Company	Engines shut down due to over-speed protections. Loss of all over-speeding engines.	2	LOW
16	Fault: Engine mechanical failure due to loss of cooling water, loss of lube oil pressure, or general mechanical failure	C - Has occurred in Company	Loss of single engine, reduction in output power until standby engine starts.	1	LOW	C - Has occurred in Company	Loss of single engine, reduced power on quadrant. If only one generator on in engine room, then loss of one quadrant.	1	LOW
17	Fault: Phase to Ground Short - Failure located on feeder or supply cables (Transformers, Generators)	C - Has occurred in Company	Affected section isolated, feeder lost.	2	LOW	C - Has occurred in Company	Affected section isolated, feeder lost.	2	LOW
18	Fault: Phase to Ground Short - Failure located on Bus	A - Has never occurred in industry	Affected section isolated (HV bus ties opened), bus lost.	3	LOW	A - Has never occurred in industry	Affected section isolated, bus lost.	3	LOW
19	Fault: Phase to Ground Short - Failure located on HV bus-tie cable.	C - Has occurred in Company	Loss of cable, system continues to operate in closed bus mode.	1	LOW	C - Has occurred in Company	No effect.	1	LOW
20	Fault: Phase to Phase Short - Failure located on feeder or supply cables (Transformers, Generators)	B - Has occurred in industry	Affected section isolated, feeder lost.	2	LOW	B - Has occurred in industry	Affected section isolated, feeder lost.	2	LOW

Risk Analysis		Closed Bus Operation				Open Bus Operation			
ID	Description	Likelihood	Consequence	Sev	RISK	Likelihood	Consequence	Sev	RISK
21	Fault: Phase to Phase Short - Failure located on Bus	A - Has never occurred in industry	Affected section isolated (HV bus ties opened), bus lost.	3	LOW	A - Has never occurred in industry	Affected section isolated, bus lost.	3	LOW
22	Fault: Phase to Phase Short - Failure located on HV bus-tie cable.	B - Has occurred in industry	Loss of cable, system continues to operate in closed bus mode.	1	LOW	B - Has occurred in industry	No effect.	1	LOW
23	Fault: Phase to Phase Short - Infant mortality drive faults on Thruster and Drilling Drives	C - Has occurred in Company	Voltage Dip, no impact to station keeping	1	LOW	C - Has occurred in Company	Voltage Dip, no impact to station keeping	1	LOW
24	Fault: Dead-short of a semi-conductor device (IGCT and IGBT).	C - Has occurred in Company	Voltage Dip, no impact to station keeping	1	LOW	C - Has occurred in Company	Voltage Dip, no impact to station keeping	1	LOW
25	Fault: 3-Phase Short Circuit - Failure located on feeder or supply cables (Transformers, Generators)	A - Has never occurred in industry	Affected section isolated, feeder lost.	2	LOW	A - Has never occurred in industry	Affected section isolated, feeder lost.	2	LOW
26	Fault: 3-Phase Short Circuit - Failure located on Bus (extremely unlikely, no identified case with modern switchgear)	A - Has never occurred in industry	Affected section isolated (HV bus ties opened), bus lost.	3	LOW	A - Has never occurred in industry	Affected section isolated, bus lost.	3	LOW
27	Fault: 3-Phase Short Circuit - Failure located on HV bus-tie cable. (extremely unlikely, no identified case with modern switchgear)	A - Has never occurred in industry	Loss of cable, system continues to operate in closed bus mode.	1	LOW	A - Has never occurred in industry	No effect.	1	LOW