Regulatory frameworks for Dynamically Positioned vessels operating in closed bustie mode: the grey zone

Abstract

For many years the design of DP vessels operating in closed bustie mode has been evaluated by the industry and the classification societies basing their acceptance criteria on the following requirements from IMO MSC Circ. 645:

"3.2.3 For equipment class 2 […] the power system may be run as one system during operation, but should be arranged by bus-tie breakers to separate automatically upon failures […].

3.2.4 For equipment class 3 […] bus-tie breakers should be open during equipment class 3 operations unless equivalent integrity of power operation can be accepted according to 3.1.3 (i.e. Failure in one system should in no case be transferred to the other redundant system)."

Until recent times the concept of "equivalent integrity of power operation" remained valid without definition of acceptance criteria common to this industry.

Recently, a growing awareness of the risks arising from closed bustie DP operations pushed some classification societies and industry organizations to move forward, developing rules and guidelines where design requirements and test procedures are intended to elaborate the concept of "equivalent integrity of power operation", while others maintained their position. These deviations in the regulatory framework represent a source of confusion and uncertainty but, what is worse, non-uniformity in the design requirements between societies.

The recent upgrade of DP rules of some classification societies foresee that acceptance criteria for High Voltage DP power systems operating in closed bustie mode shall be based on the results of live short circuit tests (otherwise called "fault ride through tests").

This test consists in an intentional creation of a short circuit at the High Voltage switchboard level, to prove that the power and control systems are able to detect and isolate the fault, without any blackout occurrence.

Internationally recognized organizations seem to embrace those requirements and demand to perform a live short circuit tests every 5 years during the lifespan of the vessel.

Other classification societies and internationally recognized organizations are not in favor of carrying out those type of tests, which are claimed to be dangerous to the personnel and stressful for the equipment.

Keywords: Closed bustie, Dynamic Positioning, Fault ride through, Live Short Circuit Test

Abbreviations

DP	Dynamic Positioning
GOOSE	Generic Object Oriented Substation Events
HV	High Voltage
IED	Intelligent Electronic Device

LV	Low Voltage
Un	Nominal Voltage

1. Introduction

The scope of the paper is to analyze and present the grey zone where the overall regulatory framework for DP systems operating in closed bustie is laying today.

Challenges and risks arising from operating DP power systems in closed bustie mode will be presented together with the escalation of class and industry requirements versus different DP class notations.
It will be moreover discussed if new rules and guidelines recently issued are fully applicable, representative and/or comprehensive, whit special focus on the requirement to perform live short circuit tests.

2. Closed bustie and open bustie DP power systems

The DP system consists of components and systems acting together to achieve reliable position keeping capability. The DP system includes the power system (power generation and power management), thruster system and DP control system, together with all the auxiliary systems needed to their correct operations, as cooling systems, lubrication systems, hydraulic and compressed air systems, where applicable.

Dynamic Positioning systems considered for the purpose of this paper are redundant in the components and functions (i.e. DP2 and DP3 systems); these DP systems are characterized by a certain number of *redundant groups*: in case of any failure disabling one redundant group, the vessel will still be able to maintain position and heading with the remaining one(s).

Figure 1 shows a simplified typical single line diagram of a power system foreseen for a rig where the power generation, distribution and thruster systems are divided in four redundant groups (identified by four different colors): each redundant group comprises two diesel generators, one switchboard and two thrusters; the switchboards can be connected together via bustie breakers.

When the bustie breakers are open, the system is operated in *open bustie mode*: operating the system in this mode ensures that electrical failures affecting one redundant group will not influence the behavior of the other redundant groups. In open bustie mode, at least one diesel generator per switchboard should be connected all the time, in order to provide power to all the thrusters. More generators can be connected depending on the environmental conditions.

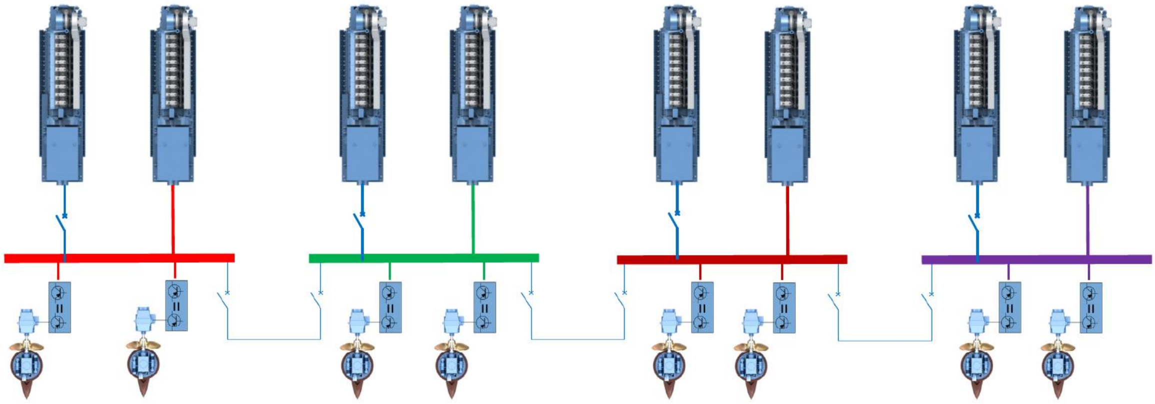

Figure 1 – DP power system operating in open bustie mode

When the bustie breakers are closed, the system is operated in *closed bustie mode* (see Figure 2): when the system is operated in this mode, each redundant group is electrically joined to all the others. In closed bustie mode, it is sufficient to connect a minimum number of two diesel generators in order to provide redundancy and power to all the thrusters. More generators can be connected depending on the environmental conditions.

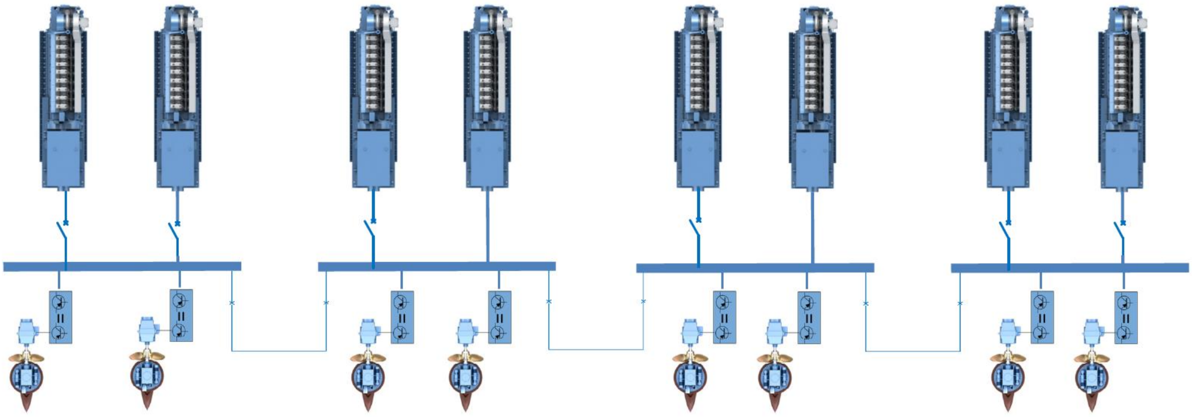

Figure 2 – DP power system operating in closed bustie mode

3. Advantages of operating a DP power system in closed bustie mode

There are different reasons why closed bustie systems are increasingly popular between the vessel owners and operators.

First of all operating the DP power system in closed bustie mode provides a consistent reduction in the operational costs: machineries are subjected to less running hours and, since their load conditions are more sustained, they work at higher efficiency.

Less running for the engines means increased lifespan and reduced maintenance costs; working at higher efficiency means less fuel consumption at equal power provided.

A simple numerical example is given in Figure 3: assuming each diesel generator has a nominal power equal to 3000 kW, and the total power consumption of thrusters and other loads is equal to 3000 kW as well, operating in open bustie mode will require four diesel generators on line, all loaded at 25% of their nominal power.

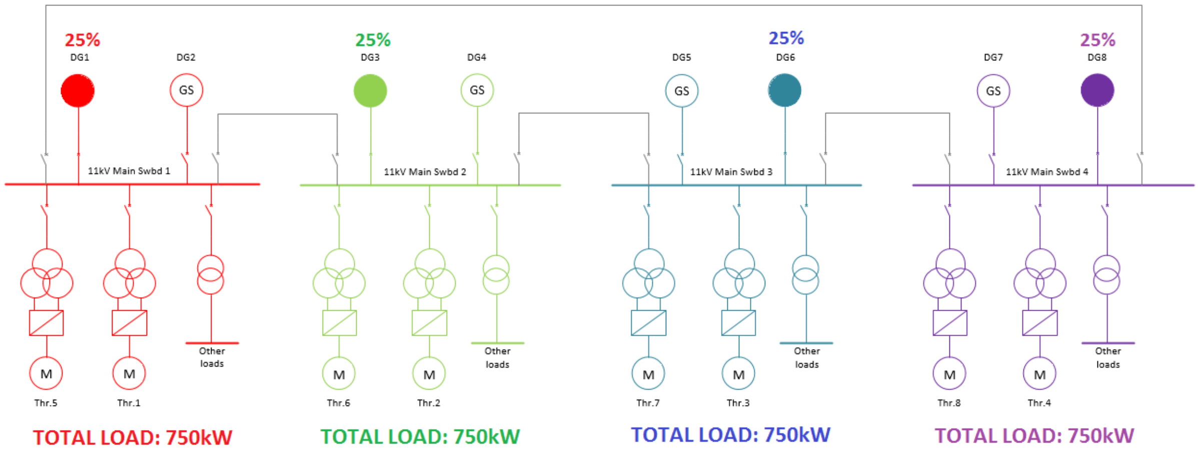

Figure 3 – Open bustie load conditions

Operating the system in closed bustie mode on the same load conditions (see Figure 4) will enable to use only two diesels generator, both loaded at 50% of their nominal power, with a reduction of 50% of overall machinery working hours, and a reduction between 15% and 20% of overall fuel consumption.

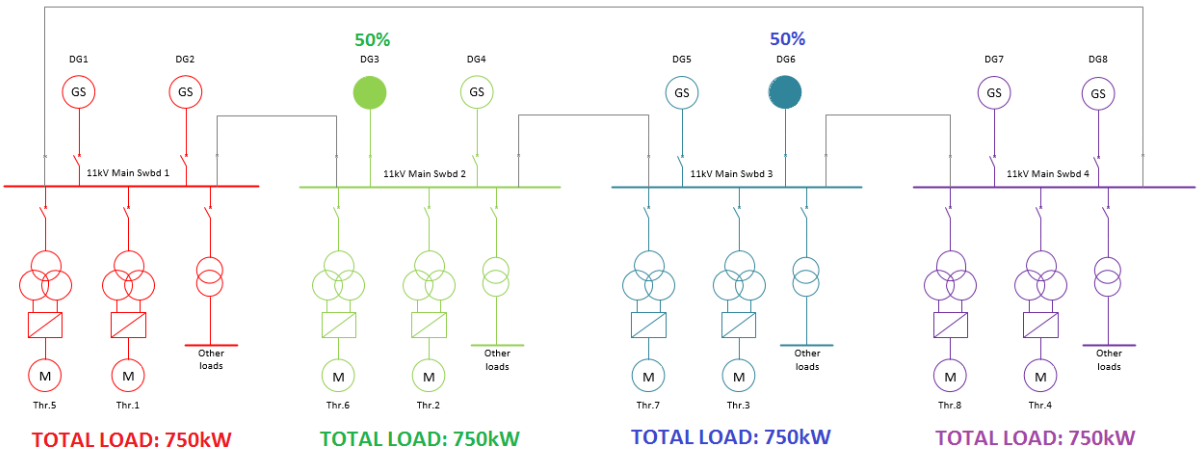

Figure 4 – Closed bustie load conditions

Another important advantage to be highlighted for systems operated in closed bustie is the increase of system reliability (see Figure 5). In case of a failure event disabling one main engine or one diesel generator, for systems operated in open bustie mode, the thrusters belonging to the same redundant group will be de-energized as well; this usually requires termination of the ongoing DP operations.

For closed bustie systems, the same failure will not disable any thrusters, which will remain powered by the other(s) generator(s) connected to the closed busbar; eventually the Power Management System will connect a standby generator to reinstate the pre-fault power generation conditions.

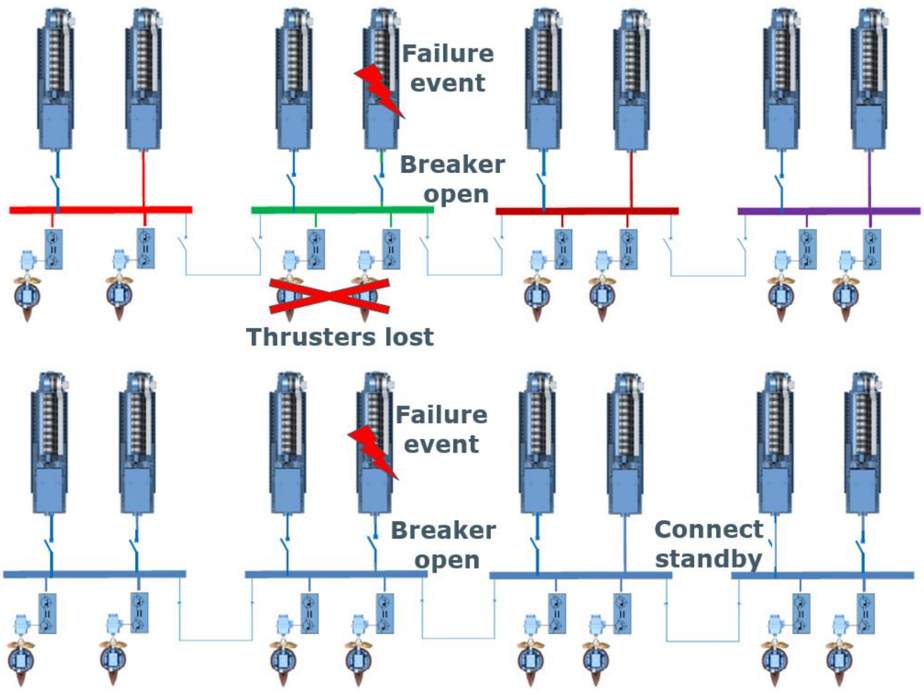

Figure 5 – Open bustie vs. closed bustie reliability

4. Challenges of designing a DP power system in closed bustie mode

When operating the DP power system in closed bustie mode, all the redundant groups are electrically joined: this add specific challenges that have to be considered and addressed during the design stage of the vessel, in order to assure that the required level of redundancy is always in place and that the vessel will not experience undesired black-out events.

This challenges can be divided in two categories:

- Barriers in place for load sharing related failure modes
- Barriers in place for short circuit related failure modes

Load sharing related failure modes are not addressed in this paper, since live short circuit test is not related to those type of failures.

Short circuit related failures bring along with them the following specific criticalities:

- Need of specific protection schemes
- Low voltage ride through capability
- Transient stability

4.1 Specific protection schemes

When a closed bustie system is affected by a short circuit event, all the generators inject high current to the power network; this high currents will flow through all the switchboards between the generators and the point of failure (see Figure 6).

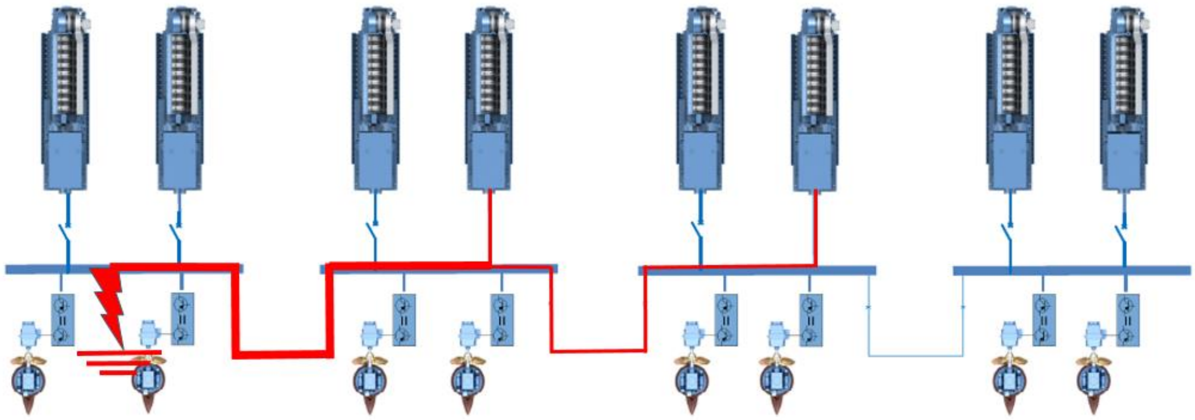

Figure 6– Short circuit event in closed bustie systems

Traditional overcurrent based protections are therefore not suitable to locate and isolate the fault, since they will all be triggered by the fault event and they all disconnect the generator simultaneously causing a black out event.

Usual protection schemes applied for closed bustie systems are based on a zone protection concept (directional or/and differential protection schemes) where the Intelligent Electronic Devices acting (IEDs) on the circuit breakers communicate with each other via GOOSE protocol. This protocol, as well as protection schemes and IEDs used in closed bustie systems, are commonly used onshore in the power generation and distribution industry since many years.

4.2 Low voltage ride through capability

Interrupting the short circuit current in coordinated and selective manner is not the only challenge of closed bustie systems: during a short circuit event at the main busbar, the voltage level drops to zero throughout all the power system for the time interval needed to the protection system to locate and isolate the fault.

During this time interval, which can be quantified in 500 ms, different loads can be lost due to lack of voltage in the system: contactors can drop out in the motor starters, pumps and ventilation fans can be disabled as well as control systems.

It is therefore part of the designer responsibility to assure that all the components and systems needed for DP operations will be able to survive a low voltage event for the time needed by the protection system to clear the fault event.

This required feature is known as "low voltage ride through capability" of the power distribution system.

4.3 Transient stability

Another criticality related to the design of closed bustie systems is to assure that the "transient stability" is fulfilled: the transient stability of an electrical system is its capability to maintain its steady state of equilibrium or to come back to it following any disturbance.

An electrical system is in steady state condition when:

- All the rotating machines connected to the power network are synchronized to a stable and constant frequency (i.e. the power generated match the power consumed by the electrical loads)

- The voltage in the power network is stable and constant

A short circuit event is of course one of the most severe disturbance the power network can experience: during a short circuit event, both voltage and power at the generators' terminals drop to zero; the generators therefore accelerate with the risk of losing synchronism.

After the clearance of the short circuit, the system experiences a transient stage of instability where the power generated and load demand do not match with each other: the protection system might have disconnected (depending on the fault location) one thruster, or one generator, or one entire switchboard with the connected loads and generators. Moreover the generators are coming from an "accelerating condition".

What it follows is therefore an electromechanical transient stage where regulators try to restore the voltage and the balance between generated power and loads. This transient stage lasts for seconds and can be stable, if the system recovery to steady state conditions of equilibrium, or unstable, if oscillations lead the system to collapse with consequent total blackout.

The only way to assess the transient stability of a power system is to perform computer based "dynamic simulations" by creating a software model of the electrical power system and its relevant regulators.

Several failure events under different load conditions have to be simulated and analyzed, since each one of them will lead to a different electromechanical transient stage: from the mathematical point of view, the electromechanical transient is given by the solution of a system of differential equations which therefore depends on the initial the conditions (i.e. number of generators connected and load conditions before the short circuit event).

5. Overview of the regulatory framework

Despite concepts as "low voltage ride through" or "transient stability" are still not widely acknowledged from the maritime and oil and gas industry, relevant progresses have been made in the last few years, mainly thanks to classification societies as ABS or DNVGL and internationally recognized organizations as IMCA or MTS, who first introduced these concepts in their rules and guidelines.

On the other hand, other regulation bodies still seem to ignore the challenges related to the design of closed bustie systems, allowing closed bustie operations of vessel not designed to cope with the specific criticalities they might face; these regulation bodies will not be considered in the analysis of the regulatory framework presented in this paper.

Figure 7 represents how the requirements for the DP systems escalate depending on the desired design solution.

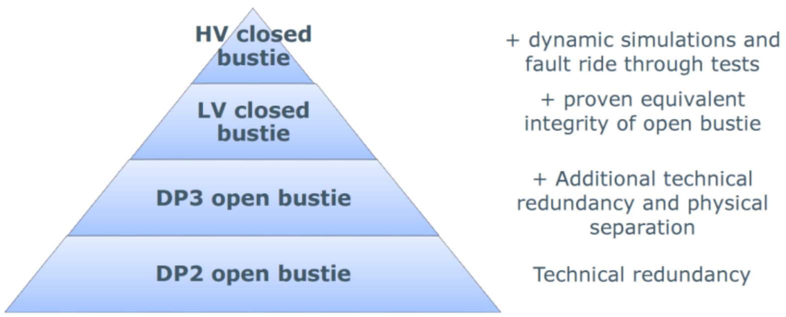

Figure 7 – DP systems and requirements escalation

DP2 systems are redundant systems in terms of equipment and functions: any failure of active components should not defeat the vessel station keeping capability. Failure of compartments (i.e. fire or flooding events) shall not be considered.

DP3 systems are redundant systems in terms of equipment and functions: any failure of active and passive components should not defeat the vessel station keeping ability. Failure of compartments (i.e. fire or flooding events) shall be considered as well.

DP vessels operating in closed bustie mode, with generators connected to HV busbars (i.e. Un ≥ 1000 V), should additionally prove their ability to survive short circuit failures without undesired blackout events. This ability should be proven by performing dedicated computer based simulations at the design stage, and live short circuit tests at intervals of five years.

DP vessels operating in closed bustie mode, with generators connected to LV busbars (i.e. Un < 1000 V), should prove their ability to survive short circuit failures by "proven equivalent integrity of open bustie". For this type of systems the concept of "equivalent integrity" is not well defined by rules.

6. Live short circuit test

The successfully completion of a live short circuit test is one of the criteria needed to prove the reliability of the design of HV closed bustie systems.

A live short circuit test consists in an intentional creation of a short circuit at the High Voltage switchboard level: since the test is not intended to verify the short circuit current withstand capability of switchboards and circuit breakers, which are already type tested, it is performed with the minimum number of generators foreseen for DP operations (typically with two generators connected).

This allows to perform the test with reduced current level, if compared to what the breakers and the switchboards can withstand: despite that, the generators and the cables involved in the test will experience their nominal short circuit current.

With this respect it is worth to mention that generators can withstand only a certain number of short circuit events, after which they can be considered as permanently compromised; this introduces of course a limitation on the number of live short circuit tests that can be performed by a single generator.

If we refer to any other industries using HV and LV generation and distribution system, these type of tests are always considered as potential destructive tests and therefore used for type testing purpose only, to be performed in dedicated and certified laboratories by specialized personnel: live short circuit tests are never used as performance tests as a criteria for equipment or systems acceptance, with the only one single exception of DP closed bustie HV systems.

6.1 Live short circuit test and protection system

One of the characteristics that should be proven to validate the design of a DP closed bustie system is the effectiveness of the protection scheme implemented within the power generation and power distribution system.

The short circuit is applied at a specific location of the power system, belonging to one specific protected zone, or redundant group. The live short circuit test will only verify the effectiveness of the IEDs and equipment dedicated to protect the zone where the short circuit is applied: an example is given in Figure 7 where only the IEDs installed in the

Protection zone 2 and Protection zone 3 are actively tested during the live short circuit test.

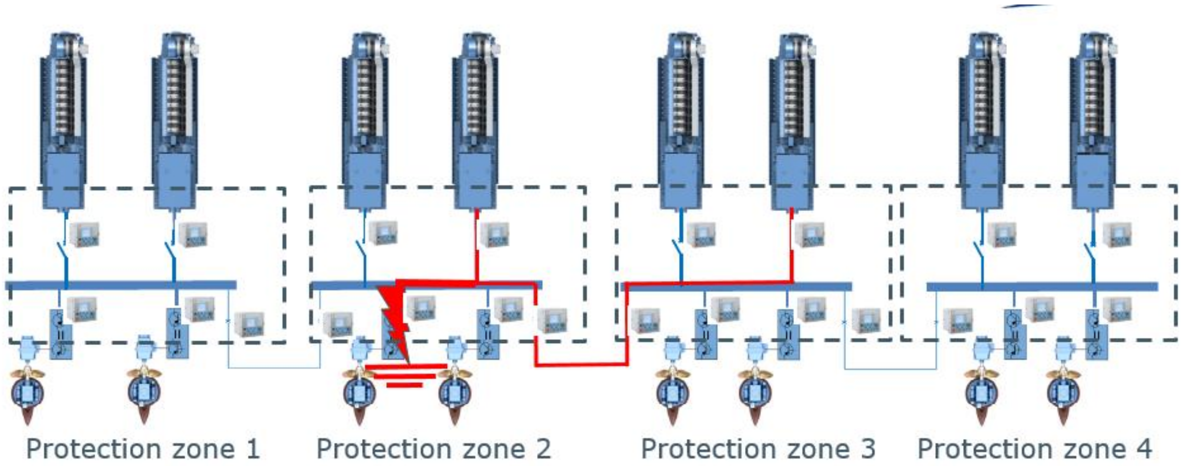

Figure 7 – Live short circuit test and protection system

For IEDs and equipment dedicated to protect the other zones, this test is significant only in case of spurious behavior of the protection system (e.g. spurious tripping of a circuit breaker that was supposed to remain connected); beside that, the live short circuit test will not assure that IEDs and equipment dedicated to protect the other zones will act properly when required to.

6.2 Live short circuit test and low voltage ride through

During the live short circuit test the voltage will drop to zero throughout the entire plant for the time needed by the protection system to locate and isolate the fault. This will enable to entirely verify the low voltage ride through capability of the power distribution system.

It is anyhow worth to mention that it is possible to trigger a temporary zero voltage situation by opportunely switching the generator breaker and the bustie breaker, without any short circuit current flowing within the power system. By using this alternative method it is possible to verify the low voltage ride through capability of the entire system without any restriction on the number of tests that can be performed.

6.3 Live short circuit test and transient stability

By performing the live short circuit test it is possible to validate the transient stability of the system only for the particular the pre-fault conditions (i.e. number of generators connected and load conditions) recorded during the test.

This does not prove that the system will have the same transient response in case of different initial conditions, and nether that it will always be able to regain to steady state of equilibrium in case of short circuit.

In order to increase the level of confidence with respect to system transient stability it is necessary (and required by the rules) to perform dynamic simulations of short circuit events with different initial conditions, using a software based model of the power system and its relevant controllers.

By comparing the results recorded during the live short circuit test, and the equivalent dynamic simulation it is possible to validate the software based model.

7. Regulatory framework and grey areas

Several grey areas can been identified in the regulatory framework of DP closed bustie systems.

The most relevant contradiction is related to the fact that acceptance criteria for HV and LV closed bustie systems are not the same, despite they present the same criticalities.

A live short circuit test for LV systems in not practical since it will have high chances to result in a destructive test: short circuit in LV system are characterized by very high levels of current and the design of the switchboards is less robust than HV switchgear in sustaining electrodynamic stresses: for this reason rules and guidance do not require live short circuit test for LV systems.

For inexplicable reasons, none of the rules and guidance today available to the offshore industry requires software based simulations to prove the transient stability of DP vessel with LV closed bustie system. Despite the behavior of these systems is described by the same set of equations that are applicable to HV systems, it seems that rules and guidelines do not consider transient stability as an issue when it comes to LV systems.

Another area of uncertainty that can be observed in the regulatory framework concerns the required characteristics of the software based model and the dynamic simulations: none of the rules and guidelines available provide a comprehensive description on the equipment and on level of details that should be included in the software model of the power system. As a result, the accuracy of the dynamic simulations provided can be often very poor and not representative of the real behavior of the system.

Moreover there is no an established verification criteria for the software model and related dynamic simulations explaining how quantitatively and qualitatively model and simulations should be validated with the measurement recorded during the tests.

Finally the methodology through rules and guidelines are updated is strongly following an empirical approach, but at the same time it is based on a very limited experience.

8. Conclusions

This paper has presented operational advantages and design challenges of DP vessels operated in closed bustie mode. The regulatory framework available to the offshore industry today has been analyzed with special focus on the requirement to perform a live short circuit test.

As per today the overall regulatory framework for DP closed bustie power systems is characterized by a high level of inconsistency: rules from different classification societies and guidelines from different international organizations present a wide spectrum of requirements often in contradiction one with the others.

Even considering only rules and guidelines aligned to the highest level of awareness of the criticalities related to the design of DP closed bustie power system, they present intrinsic contradictions:

- Despite High Voltage and Low Voltage systems operating in closed bustie mode present exactly the same criticalities, different approval criteria are in place
- Approval of High Voltage closed bustie systems mostly relay on the live short circuit test, which is a non-exhaustive and potential destructive test
- Computer simulations run on a software based model of the system are required to be performed but no specifications nether acceptance criteria for the model are provided

- Rules and guidelines updates are based on very specific experiences instead of applying analytic approach and/or referring to the experience gained by other industries

Operating a DP system in closed bustie mode presents undeniable advantages but in order to assure an acceptable level of reliability homogenous regulation frameworks based on analytic approach are needed. This frameworks shall include as well clear guidelines for computer modelling and related simulations to enable standardized and reliable design solutions.