# Voltage Dip Ride Through Testing for Dynamically Positioned Vessels

OneStep Power Solutions Inc.

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# Repeatable and Safe Voltage Dip Ride Through Testing for Dynamically Positioned Vessels.

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OneStep Power Solutions Inc. (OneStep Power) are pleased to present the Generator Voltage Response Tester (GVRT) and ZeroDip; technologies designed to provide vessel owners and their clients with assurance regarding the power system testing aboard Dynamically Positioned (DP) vessels.

## Executive Summary

This paper discusses in detail the results of four anonymised vessels which have undergone OneStep Power's voltage dip ride through testing.
The testing methodology was able to detect system instabilities and vessel arrangements not suitable for closed bus operations. Conversely, two vessels were found to ride through the testing safely and were found to be suitable for closed bus operations.

- Vessel A: A 6th generation DP3 drillship classed for closed bus operations was found compliant for voltage transient ride through.
- Vessel B: A 6th generation DP3 drillship classed for closed bus operations was found to have Automatic Voltage Regulator (AVR) instabilities and required tuning prior to returning to closed bus operations.
- Vessel C: A DP2 platform support vessel considering battery hybridization was found to require substantial power system upgrades before closed bus compliance could be demonstrated.
- Vessel D: A DP2 platform support vessel considering battery hybridization was found to be compliant for voltage dip ride through.

# Introduction

Dynamically Positioned (DP) vessels are used in a variety of applications in traditional oil and gas applications, cruise ships, and the offshore wind industry. Regulators, Class societies, DP FMEA providers and clients are demanding robust testing of power systems, either as part of class surveys, DP Failure Mode Effects Analysis (FMEA) testing, or client acceptance trials. One key missing piece of the power system testing regime has been the testing for voltage dip and transient over-voltage observed as a result of a system short circuit. OneStep Power's technology unlocks the potential to test system responses to a voltage dip safely, reliably and repeatedly.

This paper is written for an audience who is assumed to have an understanding of how power systems are arranged and operated, however, aren't necessarily proficient in the complexities of these systems.

Modern offshore activities are continually increasing in complexity and size, leading to an increased demand for power with higher reliability. This requirement for more power must, however, be balanced with the need for greater efficiencies as dictated by social responsibility as well as increasing regulation.

One method of delivering increased power requirements while decreasing overall emissions and environmental impact is to run the power system in a closed bus configuration. Overall, side-by-side risk assessments demonstrate closed bus operation leads to fewer incidents and greater capabilities[1]. As with all engineering solutions, there are some downsides to running in closed bus configuration: the biggest of these is the fact that a short circuit will cause a system-wide disturbance that can lead to total blackout. This has resulted in the offshore industry tending to favor redundancy over reliability.

Modern protection systems, when correctly designed, verified and validated[2] are more than capable of isolating the fault to the smallest section possible of the power system. Isolation of the fault, however, will not prevent all system disturbances. Testing of these disturbances and the response of the DP and associated subsystems to validate safe fault ride through has been the biggest barrier to closed bus operation.

Until the development of OneStep Power's Generator Voltage Response Tester (GVRT), the only way to test for the transient voltage response of a power system was to induce a live short circuit directly coupled to the bus bars.[3] This style of short circuit testing is dangerous and may only be performed a limited number of times, even on systems designed as "Built to test" due to the high currents and mechanical stresses[4]. In lieu of short circuit testing, a combination of primary injection testing, live earth fault testing and voltage response testing using the GVRT, can give a total system response. This testing regime will prove if a

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[1] Available on request from OneStep Power.
[2] Craig, M., Whiteford, S., Campos, D. (2019). A More Effective Power System Testing Regime. In: Dynamic Positioning Conference. [online] Houston: Marine Technology Society DP Committee. Available at: https://dynamic-positioning.com/proceedings/current-year/.
[3] Marine Technology Society Dynamic Positioning Committee (2015) A Method for Proving the Fault Ride-through Capability of DP Vessels with HV Power Plant, TECHOP_ODP_09_(D), MTS DP Committee, Houston.
[4] This is generally confidential information and is available upon request from generator manufacturers.

power system is fit to run in closed bus configuration, if it will need to be upgraded further, or is simply not suitable for closed bus operations.

Other testing requirements for dynamic positioning power systems are discussed in other publications[5].

# Testing for Voltage Dip Ride Through

While the requirements may vary slightly depending on the class rules applicable to the individual vessel, DP Vessels are generally required by class to be capable of riding through a fault while maintaining the following conditions:

- DP critical systems must remain online
- Mission critical systems may be required to remain online

Short circuits are characterized by the following:

- Rapid and un-sustained voltage dip immediately following the short circuit
- High stator current
- Transient over-voltage as the system returns to operation

Generator manufacturers have recognized the risk to the life of the generator as a result of a short circuit and most have identified a number of short circuits which the generator is warranted to survive[6].

The GVRT presents a method to challenge the power system aboard a DP vessel without the accompanying stator current increases which threaten the longevity of the generator. The GVRT can be used as evidence of the system's ability to ride through a fault, or, it can be used to prove the system in advance of a short circuit test to ensure the system's setup is suitable, and that the vessel will pass the physical short-circuit test the first time.

# The Generator Voltage Response Tester

OneStep Power Solutions inc have developed a technology for testing offshore and remote power systems. The Generator Voltage Response Tester (GVRT) connects to the generators to induce a voltage transient that is experienced by the entire distribution network and all consumers. The tests are to verify the ability of all equipment to ride through the voltage dip and transient overvoltage that would occur during a short circuit. As testing for transient undervoltage is generally performed by switchboard manufacturers, the initial design of the GVRT was to demonstrate the transient overvoltage only.

Following is a comparison between four test series conducted using OneStep Power technologies to verify a power system's ability to ride through voltage transients. While the initial intent of the GVRT was to confirm the ability of the consumers to ride

[5] Craig, M., Whiteford, S., Campos, D. (2019). A More Effective Power System Testing Regime. In: Dynamic Positioning Conference. [online] Houston: Marine Technology Society DP Committee. Available at: https://dynamic-positioning.com/proceedings/current-year/.
[6] This is generally confidential information and is available upon request from generator manufacturers.

through transient voltage conditions, it also demonstrated the GVRT's ability to test the stability of the automatic voltage regulator (AVR) connected to a generator under test.

# How the OneStep Power technologies work

OneStep Power's GVRT and ZeroDip technologies are software/hardware technologies which are temporarily installed aboard a vessel, typically in the switchboard rooms. The equipment is quick to install, independent of vessel configuration, and completely transparent to the vessel's systems.

The equipment is controlled from a PC in the engine control room, eliminating the need for personnel in the engine or switchboard rooms, thereby offering a significant reduction in the risk to personnel during testing operations. Tests can be repeated rapidly, so different scenarios can be tested as required.

Changes to protection system settings pose a significant threat to the operation of the vessel, making the ability to perform testing without changing protection settings a significant improvement to established testing methods. OneStep Testing Technologies operate independently of the vessel's power system settings, so protection settings remain in their original configuration.

During a voltage dip ride through test, the GVRT directs the generator to reduce voltage as rapidly as possible, and then resets to pre-test conditions, causing the automated voltage regulator (AVR) to present a transient over-voltage in response. This test provides a demonstration of the system-wide response to a short circuit event; testing the power system protection settings, the DP system survivability, and providing valuable information to crews and clients. When combined with the ZeroDIp's high speed breaker control, transient voltages mimicking a short circuit can be produced.

## Vessel A - 11kV DP3 Drillship

The first test series was conducted on a sixth generation DP3 drillship with an 11 kV power system classed for both open and closed bus operations. The system was made up of eight generators on three separate buses, three 5.3 MVA diesel generators in two engine rooms and two 10.8 MVA diesel generators in the third engine room. All generators were fitted with DECS 200 AVRs. All voltages were taken from the bus voltage transformers (VTs) from phase to neutral.

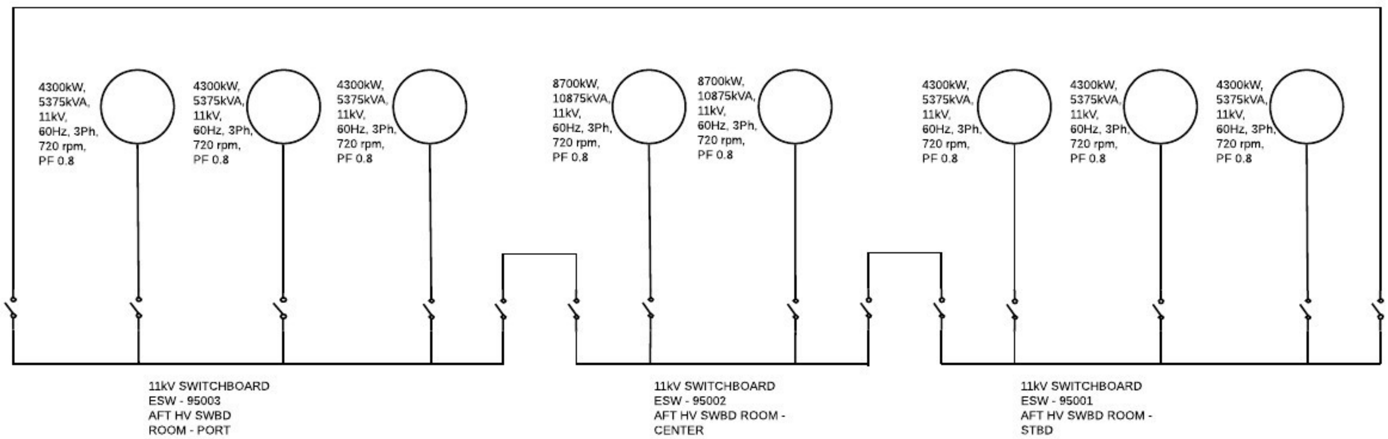


*Figure 1. Power System of 11kV DP3 Drillship*

In order to establish generator responses, two tests were conducted. The first of these was to induce a voltage dip on an unloaded generator. For the second test, all bus ties on the main 11 kV bus were opened, a single generator was connected to the bus, and a voltage drop was induced. The tests shown in figures 2-4 over page show the response of one of the 10.8 MVA generators connected to the center bus with both bus ties open and all DP equipment online.

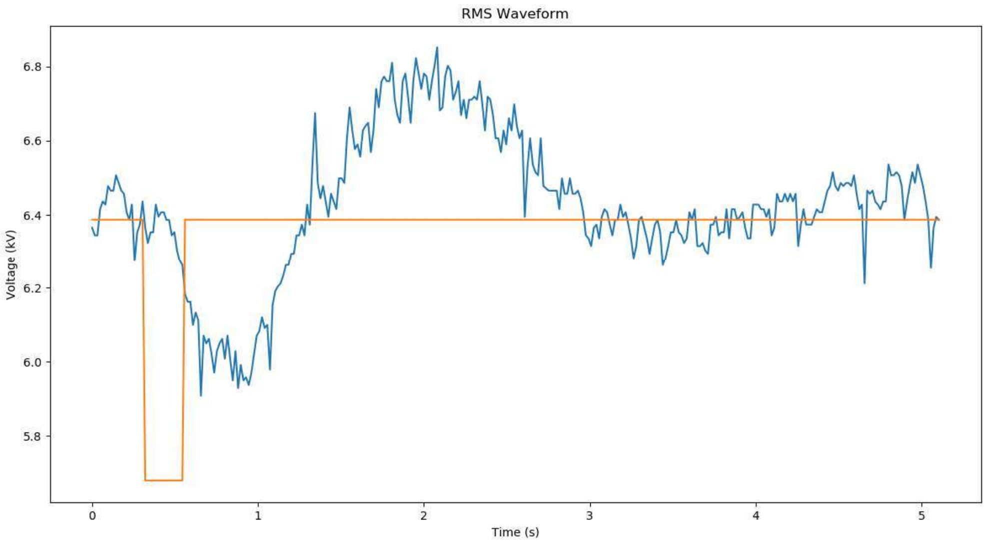


*Figure 2. RMS of Test-01 250 ms single 10.8 MVA generator (Orange line: Signal Voltage)*

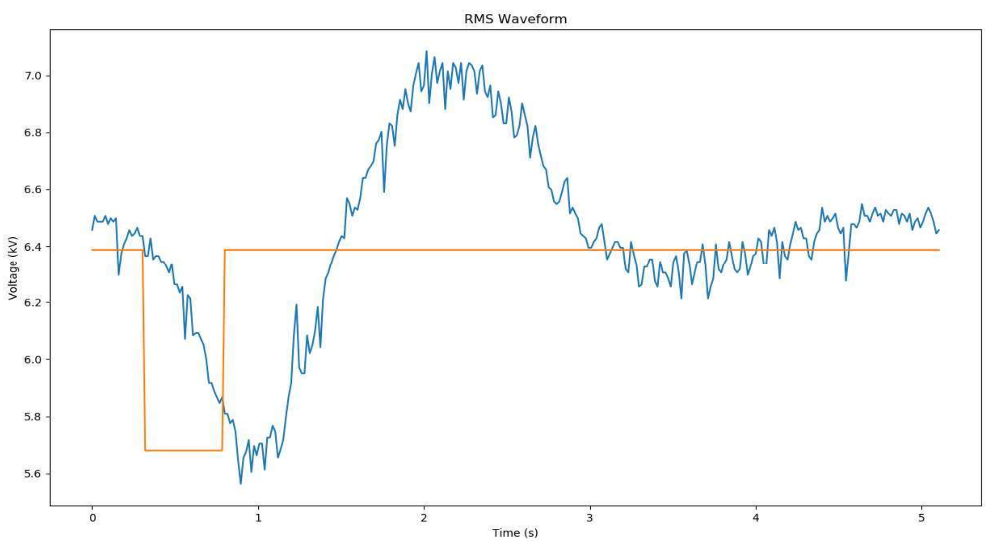


*Figure 3. RMS of Test-02 500 ms single 10.8 MVA generator*

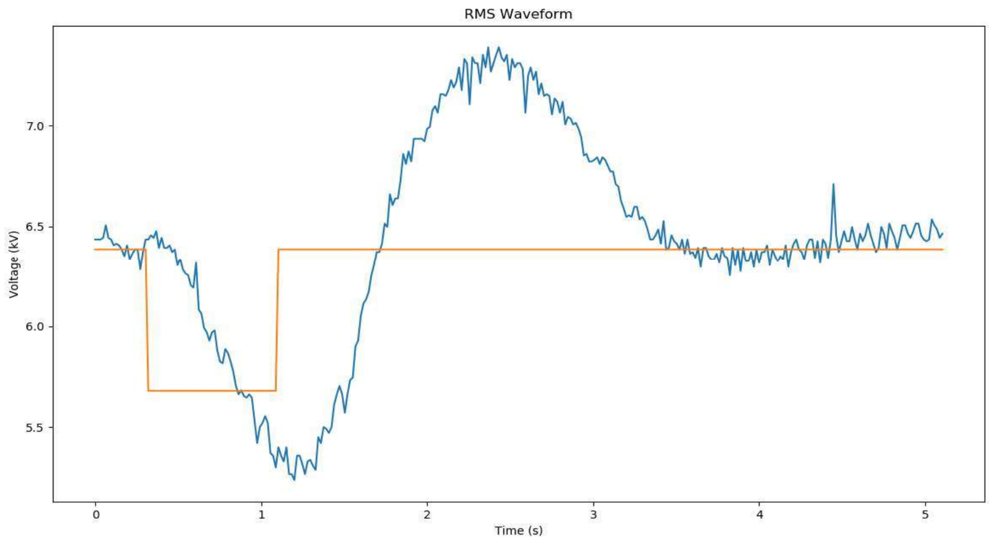


*Figure 4. RMS of Test-03 800 ms single 10.8 MVA generator*

These test results demonstrated that the longer the field is held low, the greater the voltage drop and subsequent voltage overshoot experienced. Very similar curves were observed with the unloaded tests conducted on the 5.3 MVA generators.

The result of the 800 ms test shown in figure 4 was an overvoltage alarm on the power management system (PMS), no equipment was lost and the ship remained in DP with no loss of position. On calculation, the overvoltage peaked at approximately 118%.

Once it was established that both generator models reacted with similar responses, testing was conducted in closed bus configuration with multiple generators online. For these tests three generators were online, one of the 10.8 MVA units and two of the 4.3 MVA units.

As can be seen in figures 5, 6, 7 and 8, the bus voltage reacted with similar curves though the voltage dips and transient overvoltages were not as extreme.

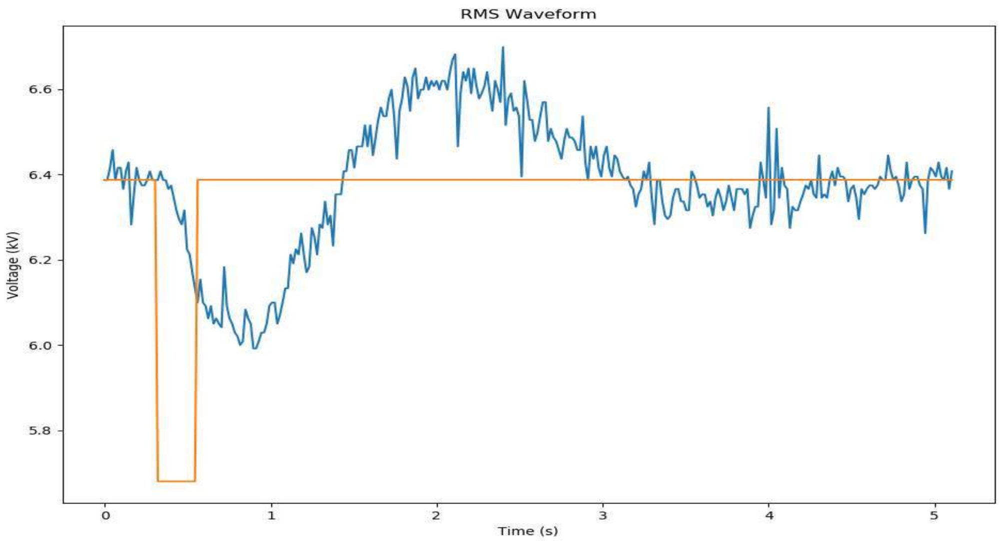


*Figure 5. RMS of Test-04 250 ms closed bus*

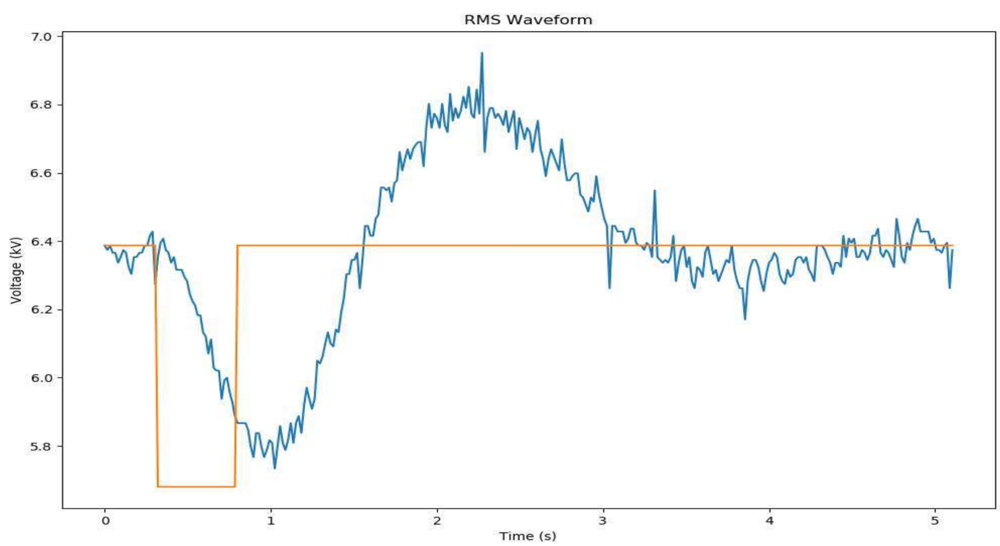


*Figure 6. RMS of Test-05 500 ms closed bus*

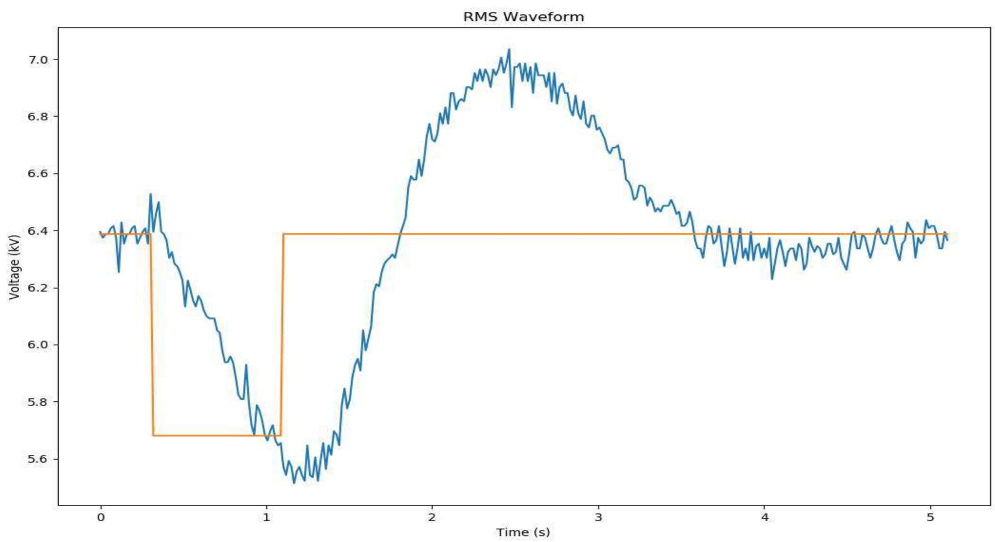


*Figure 7. RMS of Test-06 800ms closed bus*

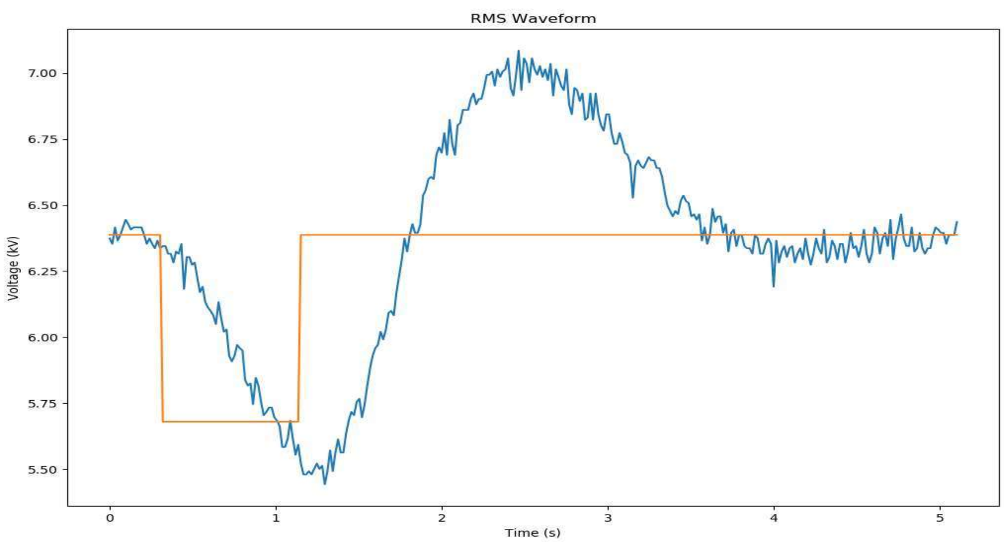


*Figure 8. RMS of Test-07 850 ms closed bus*

Figures 2 through 8 clearly demonstrate the ability to induce voltage disturbances on the power system using the method of interrupting the field current of a generator. The intent of the testing was not to drive the voltage of the system to zero, the voltage dip experienced was not considered enough to verify an extreme voltage deviation as would be experienced when a low impedance short circuit occurs. The transient overvoltage directly following the voltage dip was considered similar to what would be experienced as part of a short circuit. As fast breaker switching was already used to test for extremely low voltage transients the key outcome for this testing was the overvoltage reaction.

To give a better overview of the progression of the testing, the following graph of the closed bus responses was developed. This graph, figure 9, demonstrated the slopes of the decay and growth of the electrical potential on the bus. There was a non-linear decay when extrapolated that illustrated the relationship between the duration of the removal of the field current and the extent of the voltage dip and over-voltage.

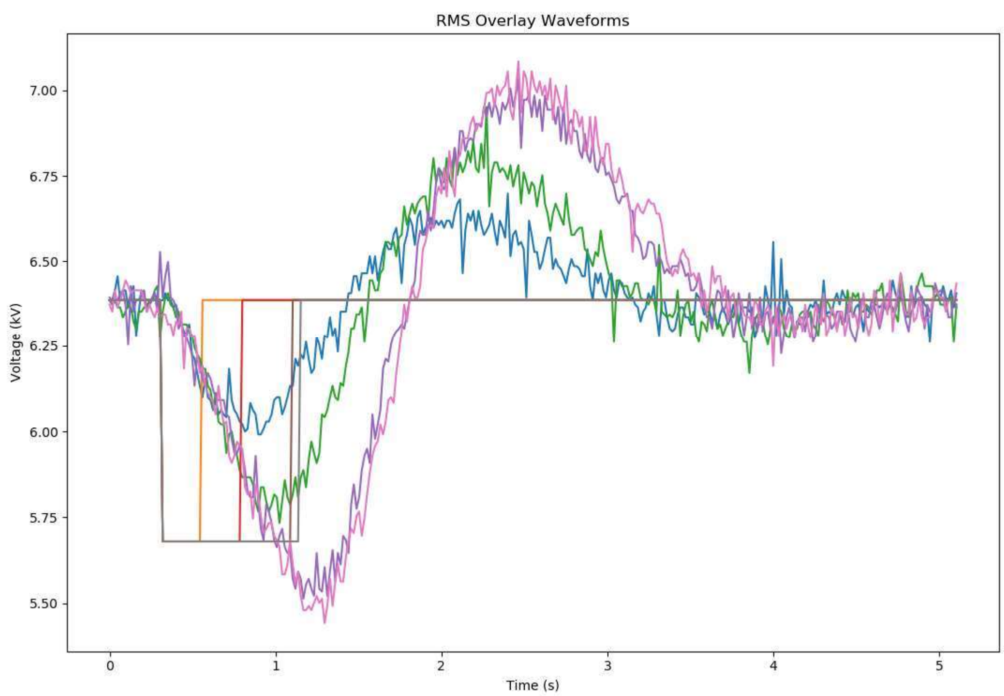


*Figure 9. RMS of Tests 04 to 07 (closed bus testing)*

# Vessel B - 11kV DP3 Drillship

This next set of graphs were derived from data captured on a sister-vessel of the vessel discussed in the previous section. The main generator and bus configuration was the same as shown in figure 1. On arrival, the test engineers were informed the ship had just had the AVR model upgraded. The information given was that the AVRs had been tuned using rig load and the vessel was deemed fit for return to service. Initial testing of the system demonstrated very unstable voltage responses; due to the unstable reaction of the generators it was not possible to conduct testing with multiple generators online. It must also be noted that there were no thruster loads during this testing as the vessel was in dock and all load was hotel only.

Initially two of the 5.3 MVA units were tested with the generator disconnected from the bus which resulted in an unstable response. As the new AVR had the ability to be set with multiple tuning parameters for operation online and offline, further testing was conducted with a single generator online. As can be seen in figures 10, 11, 12 and 13 the system voltage had a substantial overshoot when compared to the tests of the same time period on the sister vessel. The test that is shown in figure 13 resulted in an overvoltage alarm being generated on the power management system.

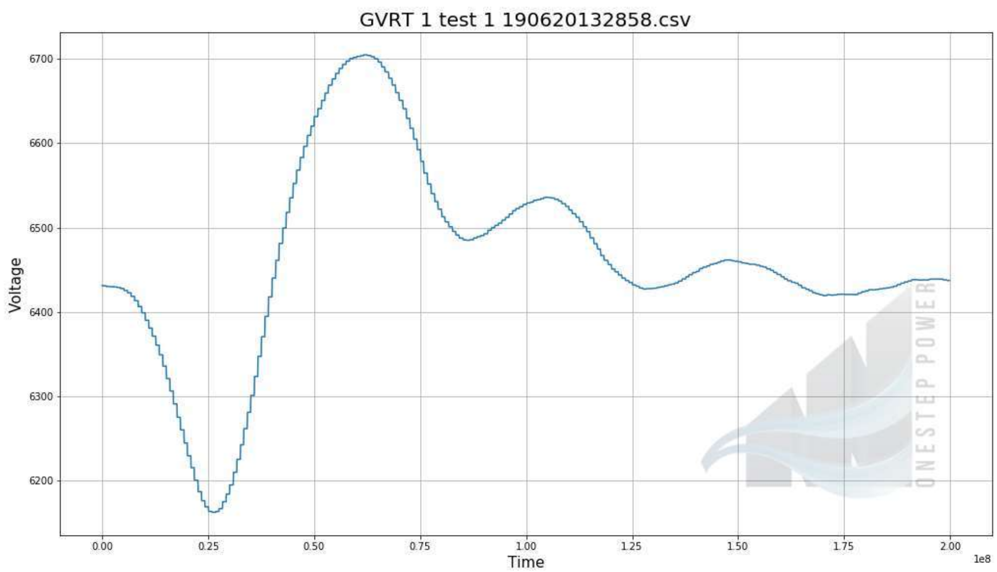


*Figure 10. Test-01 (GVRT-1, DG-2) Results*

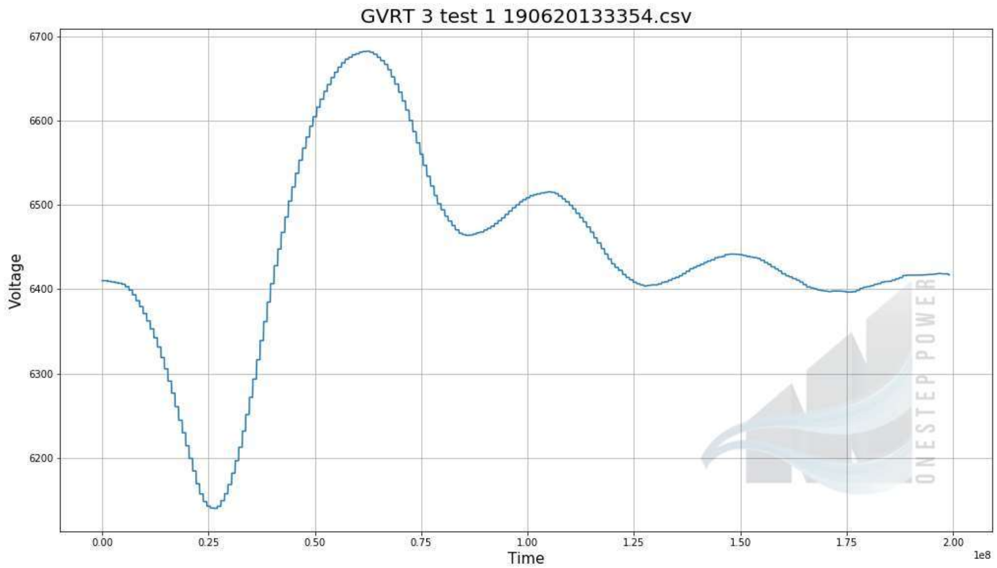


*Figure 11. Test-01 (GVRT-3, DG-4) Results*

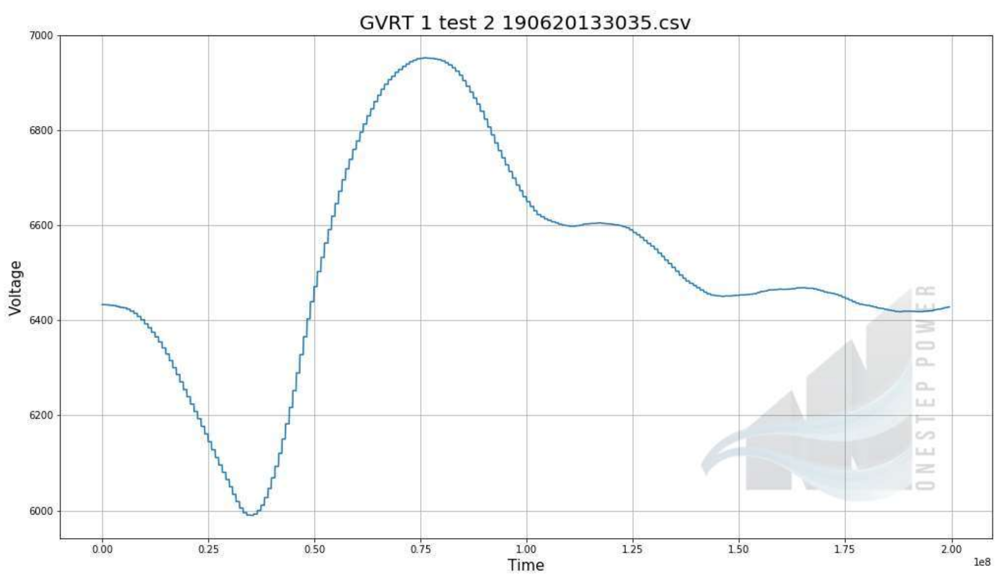


*Figure 12. Test-02 (GVRT-1, DG-2) Results*

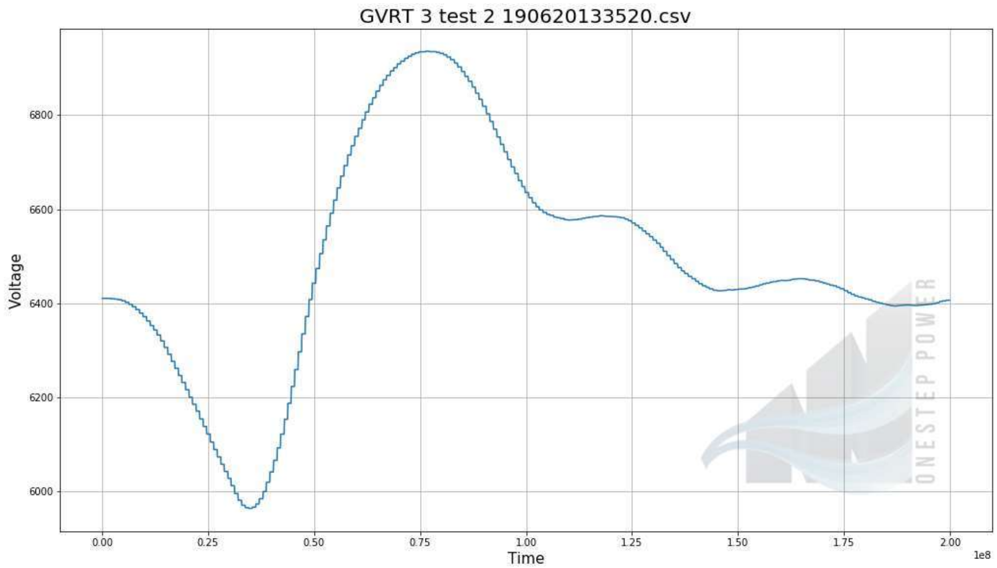


*Figure 13. Test-02 (GVRT-3, DG-4) Results*

These graphs indicate the generator AVRs had an underdamped response that may not have settled to the required 3% within 1.5 seconds, as per ABS[7] and DNV[8].

No further testing was conducted on this vessel and the vessel owner arranged for the AVR installer to return and re-tune the AVRs prior to commencing operations.

[7] ABS Steel Vessel Rules Part 4 Vessel Systems and Machinery, Chapter 8 Electrical Systems Section 3 Electrical Equipment, Subsection 3.13.2 Automatic Voltage Regulation System

[8] DNVGL-RU-SHIP Part 4 Systems and components, Chapter 8 Electrical Installations, Section 5 Rotating Machines, Subsection 2.2.3 Transient voltage regulation

## Vessel C - 690V DP2 Platform Support Vessel

After discussions with and requests from industry it was decided to design and incorporate a method of forcing the bus voltage to zero for a controlled time. OneStep Power's ZeroDip was designed to provide an integrated solution for high-speed breaker switching during the transients induced by the GVRT. The third vessel discussed had two buses with four 1.8 MW 690 V generators, two generators on each bus, as shown in figure 14.


*Figure 14. Power system of vessel 3*

Due to operational requirements the vessel under test was in port and not able to run the thrusters under load. A number of tests to verify generator operation were conducted. All generators had a similar response as shown in figure 15. The vessel failed the initial ZeroDip testing and the combined testing of zero dip and voltage transients was not conducted as no benefit could be gained.

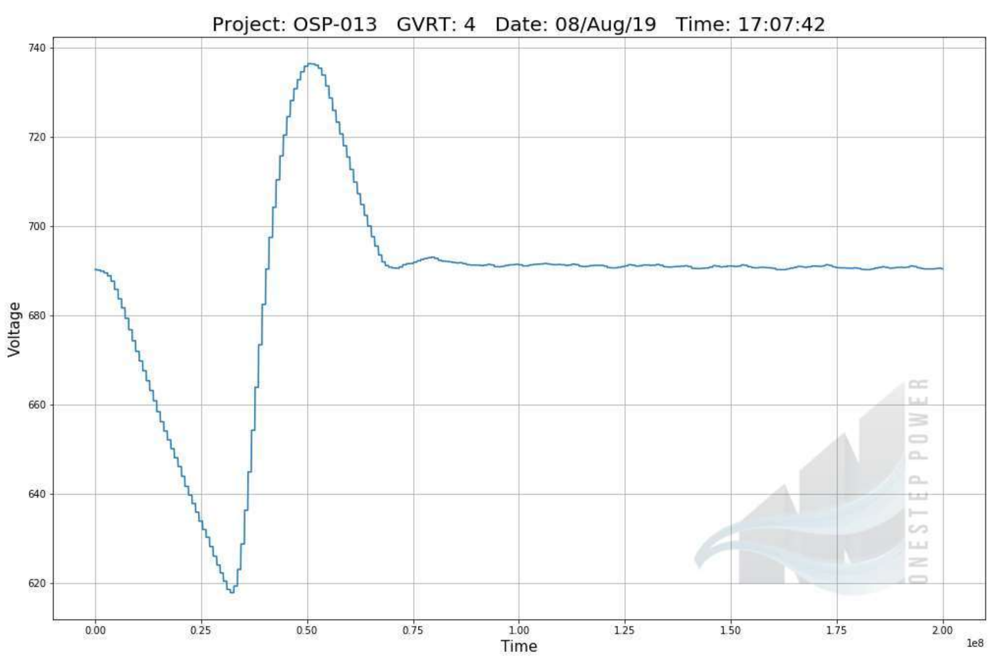


*Figure 15. Waveform of Test-01*

In order to prove a system's ability to ride through the voltage dip that would be experienced by the consumers during a three-phase symmetrical short circuit, the test duration was required to be greater than the bus tie circuit breaker trip times. The vessel under test had bus tie breakers set for 300ms. To be sure to account for possible delays a test time of 350 ms was selected for the test. In Figure 16 the bus voltage collapsed to zero and was reinstated approximately 350 ms later. While the voltage was restored to the 690 V bus, all 480 V, 208 V, thrusters and DP equipment was lost.

Note: the discrepancy in the voltage after re-application of the power was due to the open delta transformers being unevenly loaded caused by the loss of equipment after the voltage interruption.


*Figure 16. Waveform of Test-02*

As the vessel failed a 350 ms test, the time was reduced to 310 ms to ascertain if the system would ride through a loss of voltage for 300 ms. The test of 310 ms, shown in figure 17, also failed with the loss of all 480 V, 208 V, thrusters and DP equipment.


*Figure 17. Waveform of Test-03*

To verify the system response the test time was reduced to 200 ms. This test is shown in figure 18. Again all equipment from the 480 V bus and down was lost.

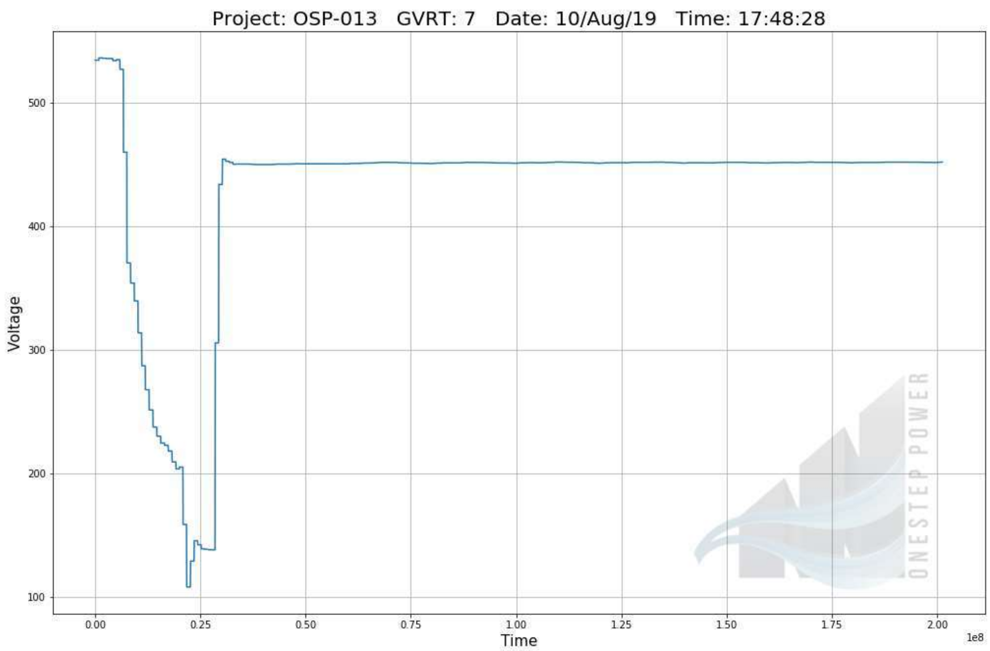


*Figure 18. Waveform of Test-04*

Further testing was halted as a combination of voltage dip followed by transient overvoltage would result in a failed test and no further useful information would be gained.

## Vessel D - 690V DP2 Platform Supply Vessel

The final test discussed in this paper was conducted on a vessel fitted with three 2.5 MW 690 V generators on two busses shown in figure 19. Testing on this vessel resulted in positive results with the power system passing, with only minor findings, all required tests up to and beyond the system design limits.

Continued discussions with industry resulted in the addition of AVR current measurements to the GVRT. Two modifications were made to the graphing for this vessel:

1. addition of current trace (orange line), and
2. full voltage scale on the graphs rather than a scale that highlighted differential.

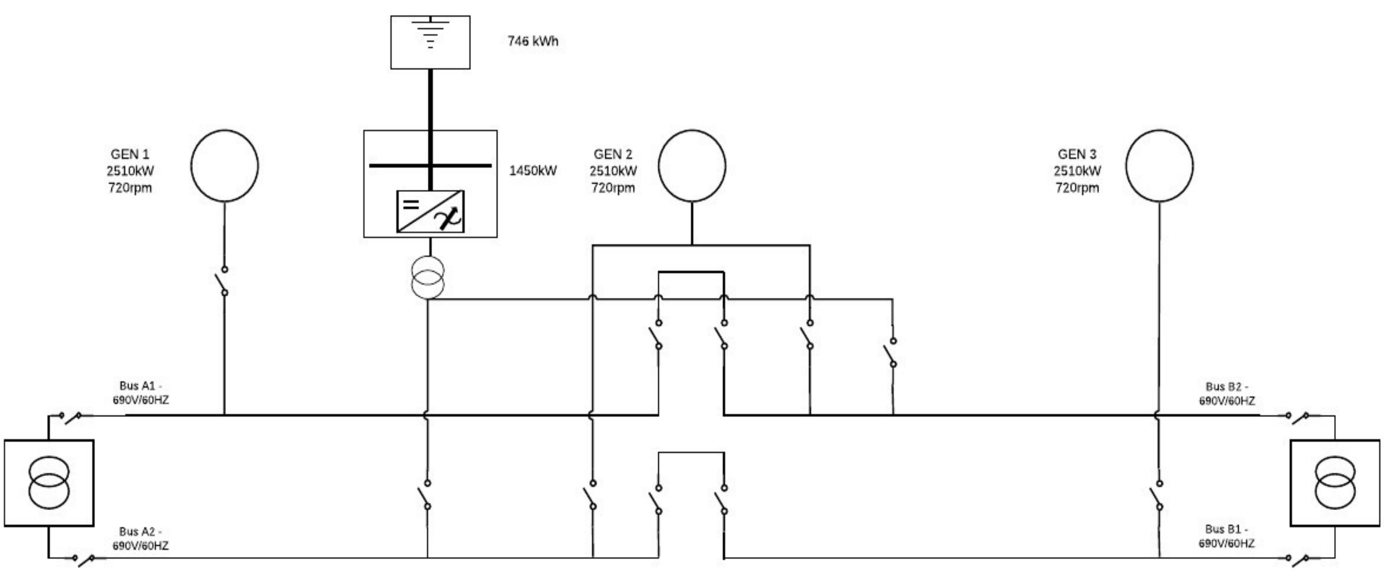


*Figure 19. Power system of vessel 4*

All generators were tested disconnected from the bus and were found to have good responses and no instability. Once the generator responses had been verified as acceptable, each generator was connected to the bus individually with bus ties open and tests conducted to confirm system and consumer responses on each bus. The first test was conducted for 250 ms and the result shown in figure 20. All generators and buses demonstrated similar responses with no loss of DP equipment.


*Figure 20. Results of Test 01, Generator #1 250 ms open bus*

The second generator was connected and the system was tested in closed bus. Figure 21 shows that the response was similar to the responses from the open bus testing with no loss of equipment.

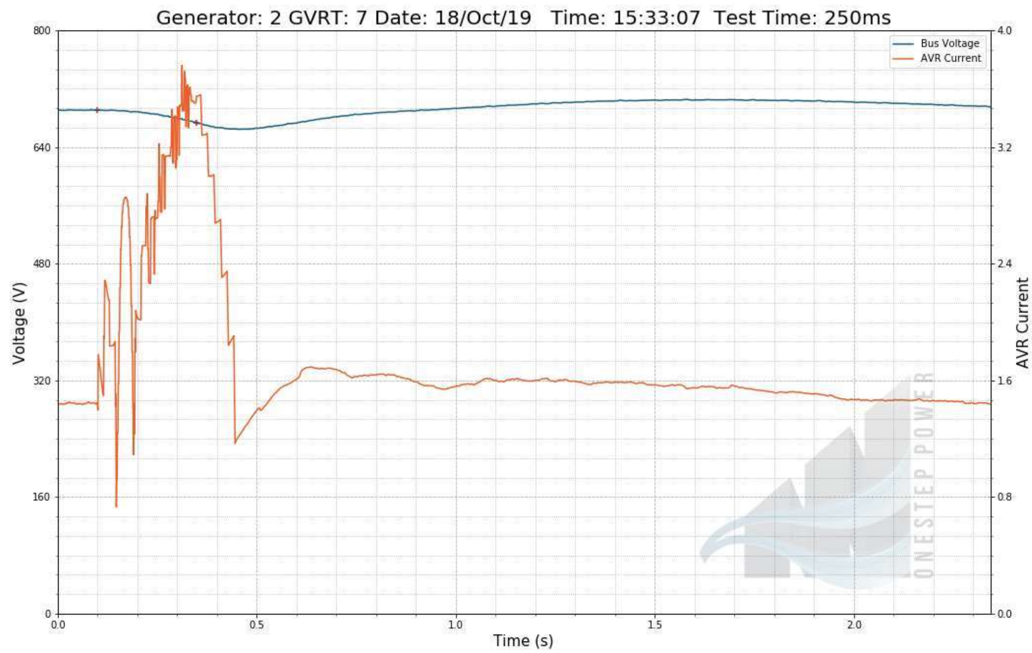


*Figure 21. Results of Test 02, Generator #2 250 ms closed bus*

The next set of testing was conducted with all generators online and an increased system load. The thrusters were placed in bias mode and the system power increased. A 350 ms test was conducted on all three generators with the resulting response shown in figure 22. As this was a common bus all generators had the same response and no vessel equipment was lost during this test. To increase the severity of the voltage dip and subsequent overvoltage, the test time was increased to 400 and 600 ms with results shown in figures 23 and 24.

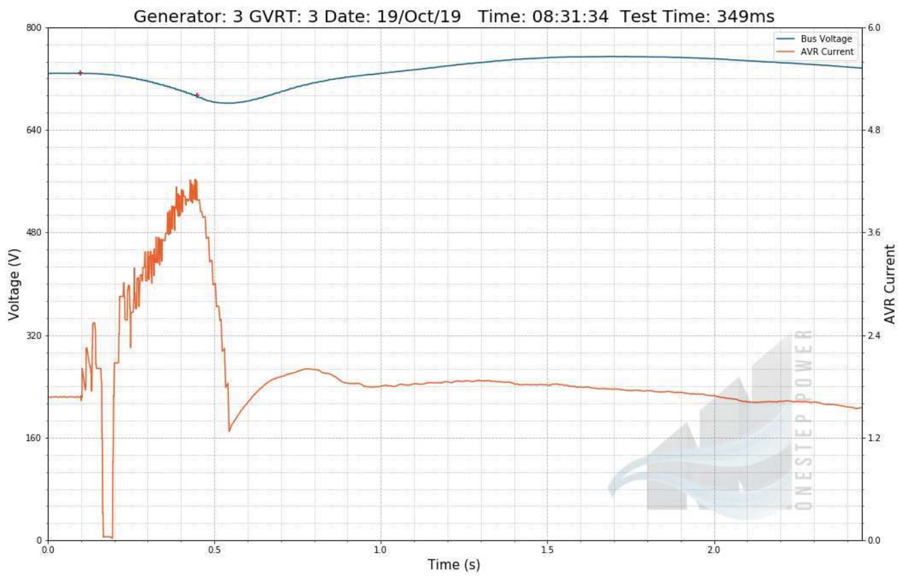


*Figure 22. Results of Test 02, Generator #3: 350ms*

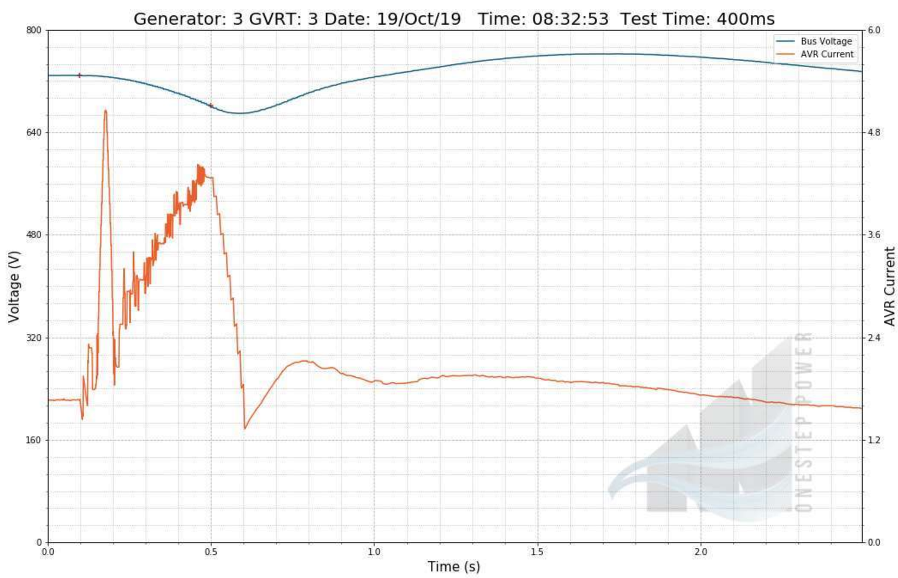


*Figure 23. Results of Test 02, Generator #3: 400ms*

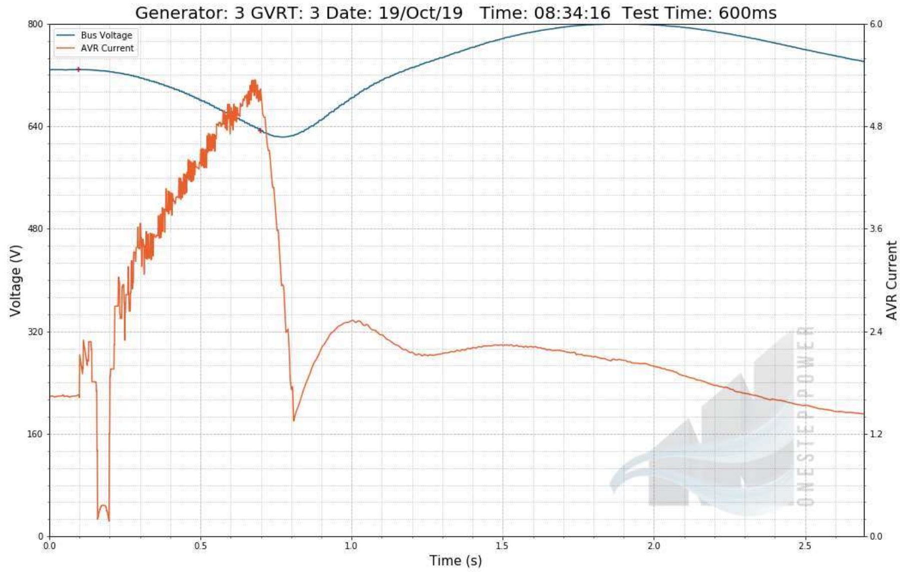


*Figure 24. Results of Test 02, Generator #3: 600ms*

Again it was noted that all generators had the same responses and no equipment was lost, however there was a low voltage alarm on the thruster control panels during the 600 ms test.

Testing for a zero volts dip without a transient overvoltage component was conducted following the GVRT testing. All systems passed this test. Figure 25, shows the response on Bus B of a 320 ms test. All other zero dip testing resulted with similar graphs and nothing would be gained by their addition.

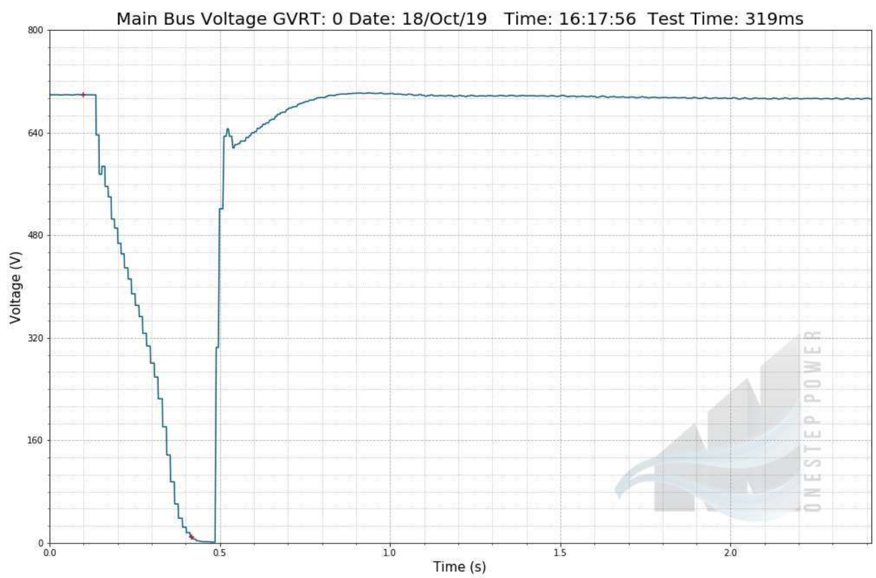


*Figure 25. Results of Zero Volts, Bus B: 320ms*

The first combined test of zero dip and transient voltage testing resulted in section protection operating and opening all bus tie breakers, thus leading to blackout on the section under test. This blackout is not a failure as the open bus ties left the adjacent section live, in the event of an actual short circuit this is the response that would be expected. This event demonstrated the efficacy of the voltage dip ride through testing.

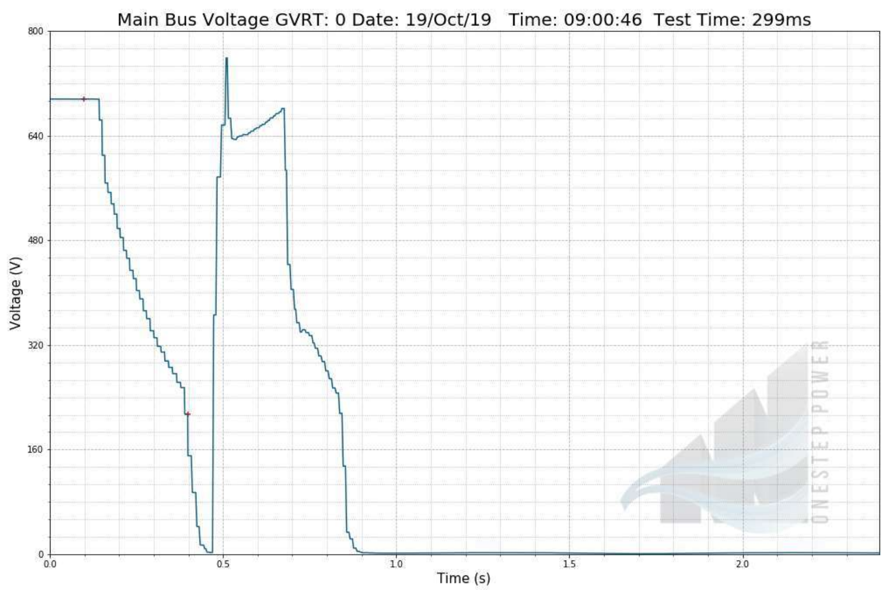


*Figure 26. Results of Test 04, Bus B: Fail (Segment protection tripped bus tie)*

To enable testing to continue, the section protection trip  was lifted from the trip circuit. Figures 27 through 34 show the results from the combined testing of zero dip and transient overvoltage. As can be seen in the graphs the longer the test time the greater the transient overvoltage.

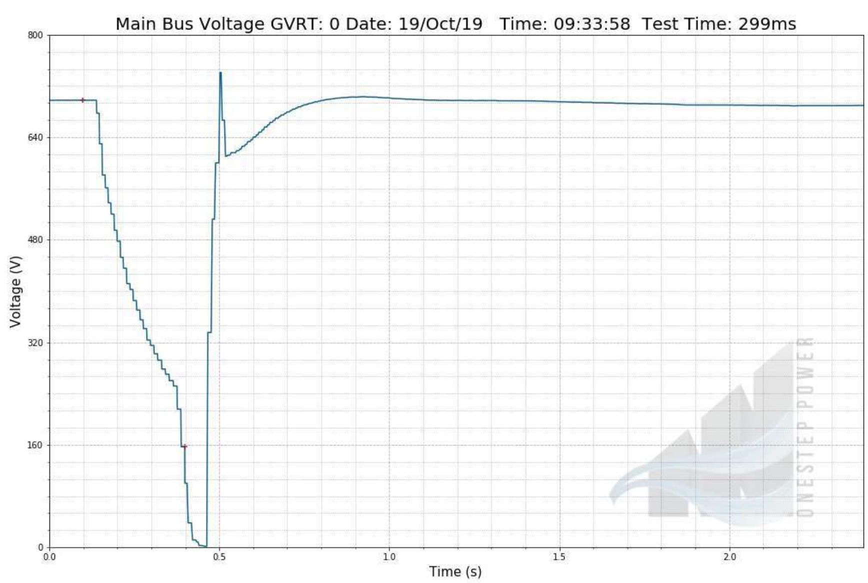


*Figure 27. Results of Test 04, Bus B: Pass (Segment protection temporarily disconnected)*

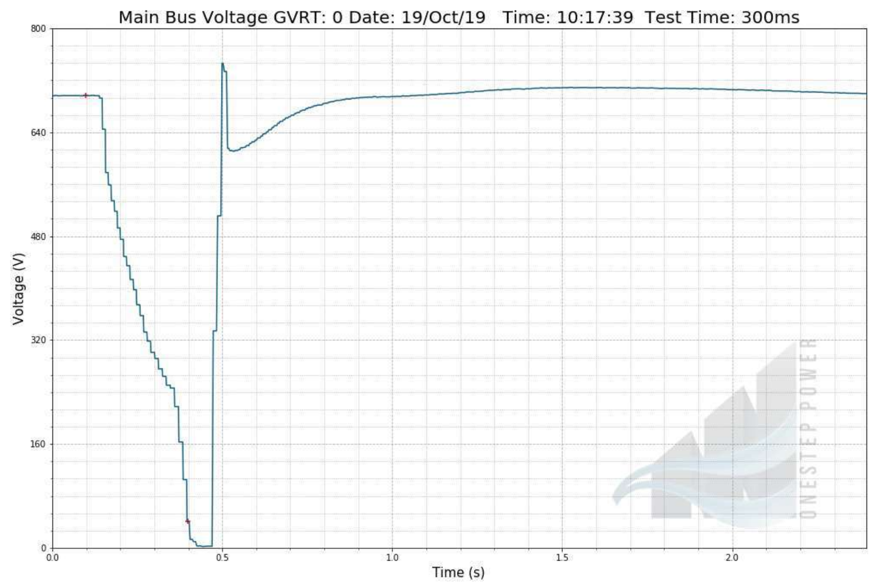


*Figure 28. Results of Test 5, Bus B: Pass (300ms)*

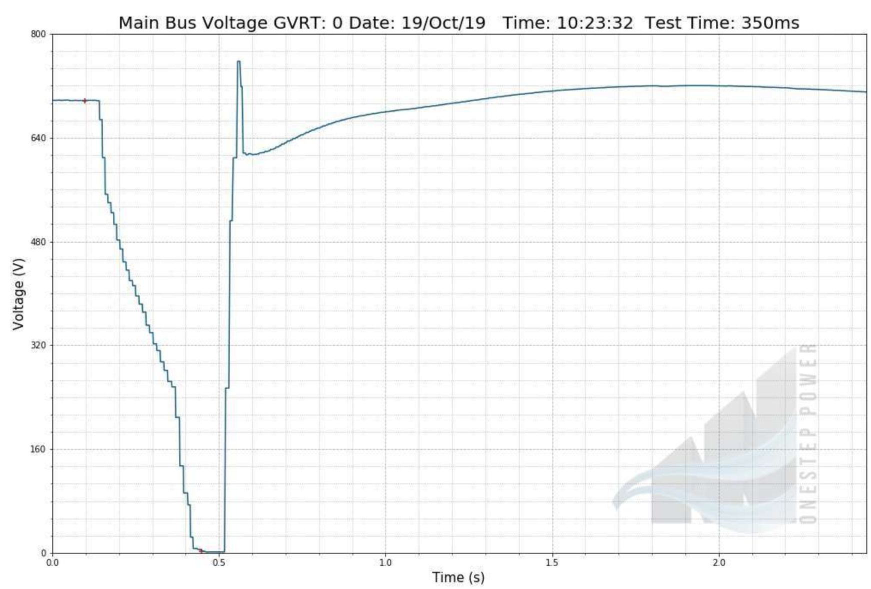


*Figure 29. Results of Test 5, Bus B: Pass (350ms)*

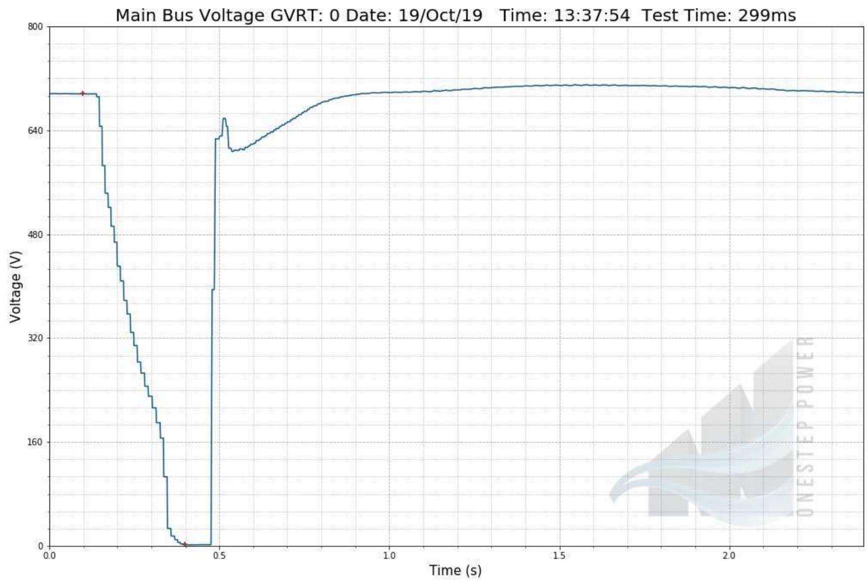


*Figure 30. Results of Test 12, Bus A: Pass (300ms)*

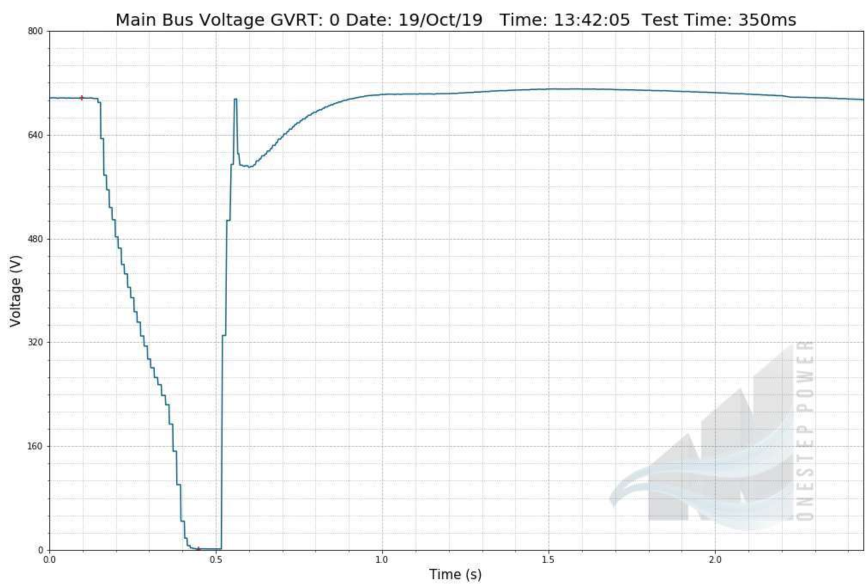


*Figure 31. Results of Test 12, Bus A: Pass (350ms)*

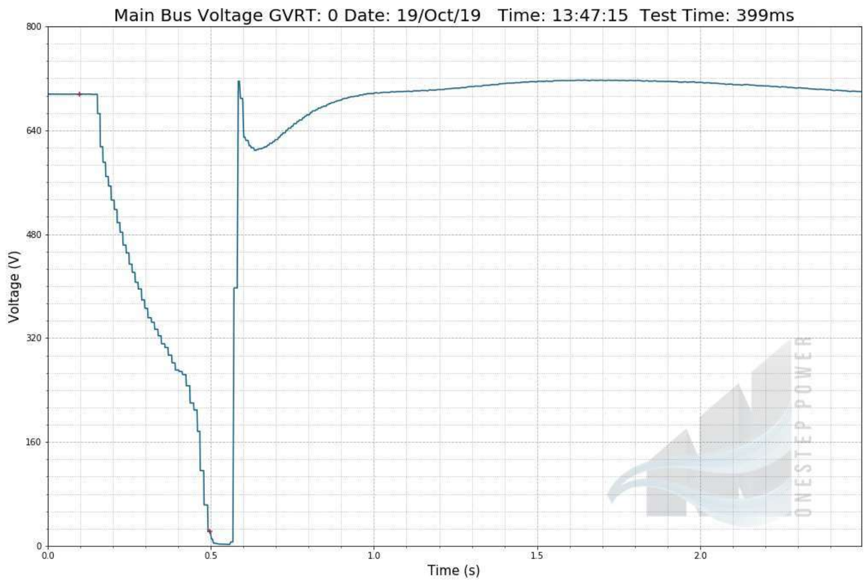


*Figure 32. Results of Test 12, Bus A: Pass (400ms)*

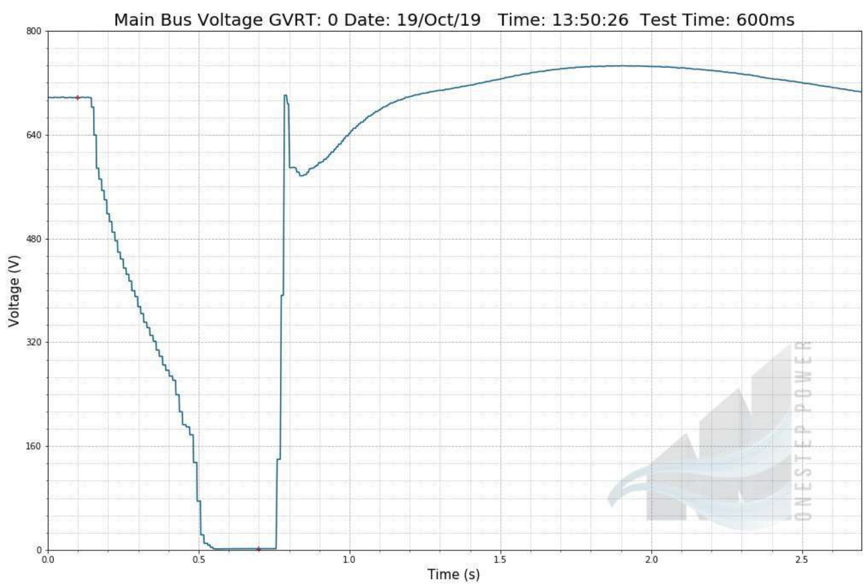


*Figure 33. Results of Test 12, Bus A: Pass (600ms)*

The final test conducted aboard the vessel, shown in figure 34, was conducted on the system with two generators online on Bus A with all thrusters and DP systems online. The voltage dropped to zero prior to the system inducing an overvoltage of ≈115%.

No equipment was lost during this test indicating that DP system and all auxiliary systems are capable of riding through both the undervoltage and overvoltage that would be experienced by a power system during a short circuit.


*Figure 34. Results of Test 12, Bus A: Pass (800ms)*

# Conclusion

It is possible to induce system wide disturbances safely and precisely with both the Generator Voltage Response Tester and the ZeroDip device. In addition to demonstrating the full spectrum of transient and zero voltage fault ride through, this testing solution has also identified an incorrectly tuned AVR. This is vital information that vessel operators can utilize in conducting risk assessments and managing critical DP operations.

Use of the GVRT on a power system demonstrates power system responses to system wide voltage disturbances. The combined use of GVRTs and ZeroDip is an excellent indicator of the ability of a power system to respond to a system wide voltage disturbance. Vessels B and C proved the GVRT and ZeroDip test suite was able to identify power system instability and provide evidence of the suitability of the test methodology.

OneStep Power's technologies provide a safe, repeatable and non-destructive method to testing for fault ride through capabilities aboard dynamically positioned vessels.

## Disclaimer

*All measures and decisions based on this analysis and these findings are the sole responsibility of the client.*

*OneStep Power does not accept:*

- *any liability for the identification, indication or elimination of dangers and non-compliances (in the broadest sense of the word), nor for any damage caused by any of these;*
- *any obligation to report all facts or circumstances established during the visit. This obligation comes completely under the authority and responsibility of the client;*
- *any liability for the client's obligations resulting from (legal) rules and/or statutes;*
- *any liability or responsibility whatsoever in respect of or reliance upon this report by any third party.*

*The execution of improvements recommended by OneStep Power does not indemnify the client against any legal or contractual obligations and offers no safeguard against the elimination of dangers or damages resulting from the client's products, services, company assets, et cetera.*

## Record of Amendments

| Date | Section | Amendment |
|---|---|---|
| 20 Jan 2020 | All | New Document |

## List of Holds

| Section | Description of Hold |
|---|---|
| | |
| | |