GENERAL DYNAMICS
Information Technology

Site Visit Report

USCG
ISC SEATTLE, WA,
WAGB-10 POLAR STAR

Date: 11/08/2006

GENERAL DYNAMICS INFORMATION TECHNOLOGY
3430 CAMINO DEL RIO NORTH, SAN DIEGO, CA. 92108 (619)-881-8989

Visit Date: 26 September, 2006

Site Location: USCG Integrated Support Command, Pier 36, Seattle, WA
Aboard WAGB-10 Polar Star

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Purpose Of Visit: PROVIDE TESTING SERVICES FOR EVALUATING A NEW VOLTAGE STABILIZATION METHOD FOR UNGROUNDED ELECTRICAL SYSTEMS

References: (a). "Results of 60-Hz Load Center Switchboard Line-to-hull (ground) Capacitance Investigations Aboard USS John C. Stennis (CVN-74) From 24 to 26 September 1997, and Considerations on Implementing High-Resistance Grounding", NSWCCD-81-TR-2000/04 September 2002. James P. Goodman, Naval Surface Warfare Center, CARDEROCK Division, West Bethesda, MD.

I. Background:

GDIT has researched numerous Commercial-Off-The-Shelf (COTS) equipment, components and systems that could dramatically lesson the funding impact of bringing shore site electrical distribution systems into compliance with OSHA and NEC. One of these systems, the "Phaseback" unit, could have a direct and immediate impact on improving shore site electrical safety and lessen the daily exposure of US Navy military and civilian personnel to potentially life threatening conditions.

Phaseback is used to stabilize ungrounded voltage systems, thus protecting them from hazardous voltage transients and voltage surges. Such anomalies will, over time, break down the insulation of the electrical systems' components. Failure of the insulation can lead to cascading electrical malfunctions which may result in electrical fires, explosions, and/or personnel electrical shock. A portion of this study was designed to determine the real-time effects of Phaseback when installed as part of a pier electrical service for moored ships, i.e., a Shore Tie electrical service.

II. Study Goals:

A. Measure and evaluate the effects on <u>line-to-line</u> system voltages in the presence of ground faults while fed from shore service ungrounded DELTA service transformer.
B. Measure and evaluate the effects on <u>line-to-hull</u> system voltages in the presence of ground faults while fed from shore service ungrounded DELTA service transformer.
C. Measure and evaluate the effects on <u>line-to-hull</u> system voltages in the presence of ground faults while fed from ship service generators utilizing star (WYE) wound alternators.

III. Discussion: History and Characteristics of Ungrounded Voltage Systems

A. Ungrounded voltage systems such as 450-volt, AC, 60-HZ DELTA systems are used by most Coast Guard and Navy vessels. The selection of an ungrounded rather than a grounded electrical system has been chosen for its service reliability and ability to continue operations with a fault on the system [B-1]. Pierside ungrounded voltage systems used to power moored ships also tend to reduce hull corrosion, a possible life-cycle cost reduction.
B. An "ungrounded system" is in reality grounded through the capacitance-to-ground of the system conductors, as well as any line-to-hull (ground) capacitors in user equipment power line filters [B-2]. This may also be referred to as parasitic capacitance. See ***Figure 1***.

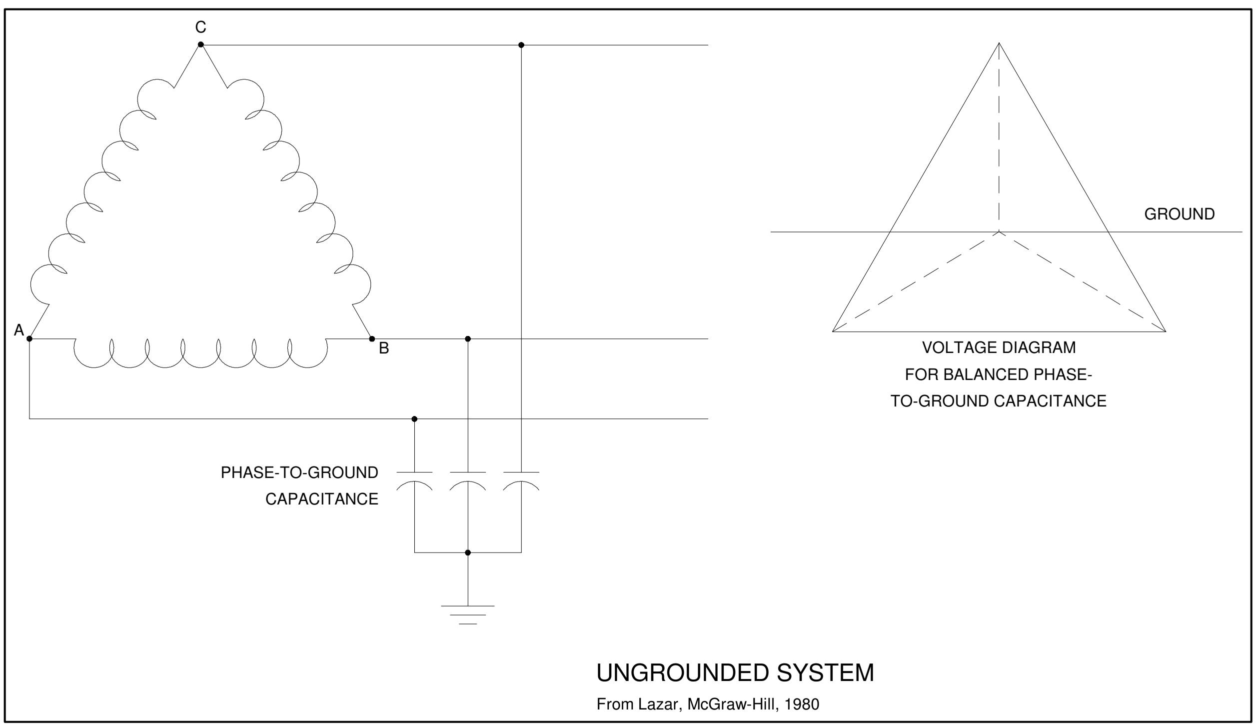

Figure 1- Ungrounded voltage system

C. As with all energized electrical systems, ungrounded voltage systems are capable of presenting life-hazardous voltages should they be contacted by personnel. [B-1]

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D. An ungrounded voltage system is less stable than a grounded voltage system [B-2]. When a ground fault develops on one phase, the two remaining ungrounded phases increase to the full line-to-line voltage. See ***Figures 2, 8,*** and ***13***. Under certain fault conditions, ungrounded voltage systems may develop 6 to 7 times the normal system voltage [B-3]. In addition, ungrounded voltage systems are the most destructive to equipment [B-2]. Very little current flows during the first ground fault. However, a fault on a second phase may then cause a phase-to-phase fault. Fault currents can be very high and thus become a hazard to personnel as well as equipment. A line-to-hull (ground) fault on one circuit usually results in damage to equipment and service interruption in other circuits [B-2].

Note: Figure 2 depicts a textbook example of a "bolted" fault in which one phase voltage drops to zero volts, caused by a direct short. In practice this seldom happens, rather, the insulation resistance slowly degrades while still exhibiting significant resistance to hull.

E. Destructive transient overvoltages may appear from line-to-hull (ground) during normal switching of a circuit subjected to a line-to-hull (ground) fault [B-2]. Repeated restriking of the arc during interruption of a line-to-hull (ground) fault may generate dangerous and sustained overvoltages. These in turn can cause insulation failures at other system locations besides the point of fault.

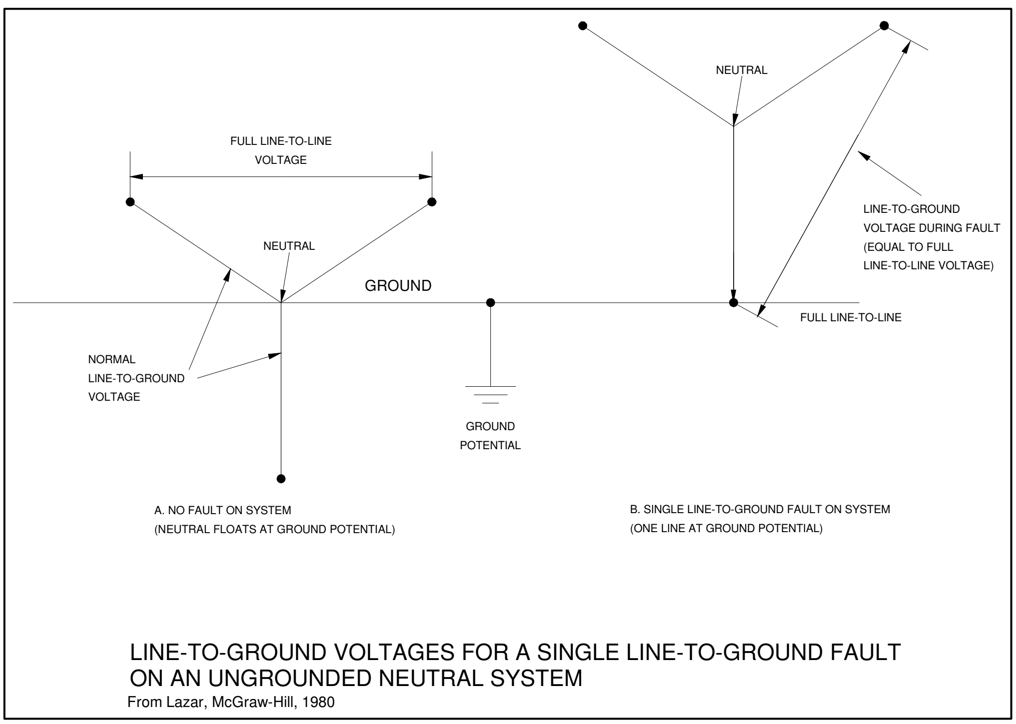

Figure 2 - Single Line-to-hull (ground) Fault

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IV Test set up

A. ***Figure 3*** shows a test diagram for the ship testing.

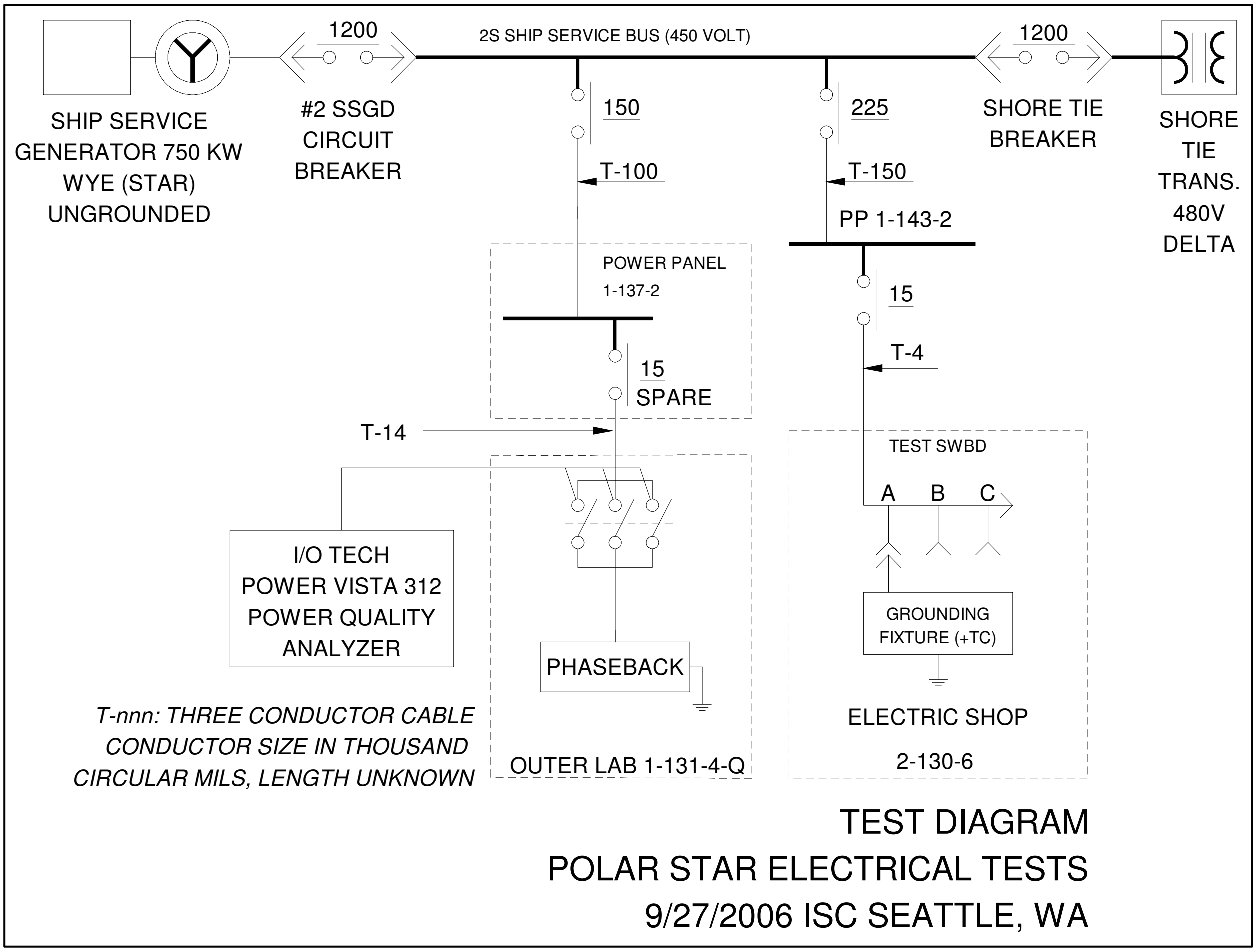

Figure 3 - Test Diagram for Polar Star Electrical Tests

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V. Line-to-Line Ground Fault Effects on DELTA Shore Tie Transformer

A. ***Figure 4*** shows the ungrounded system voltage from the DELTA Shore Tie transformer in line-to-line measurement mode.

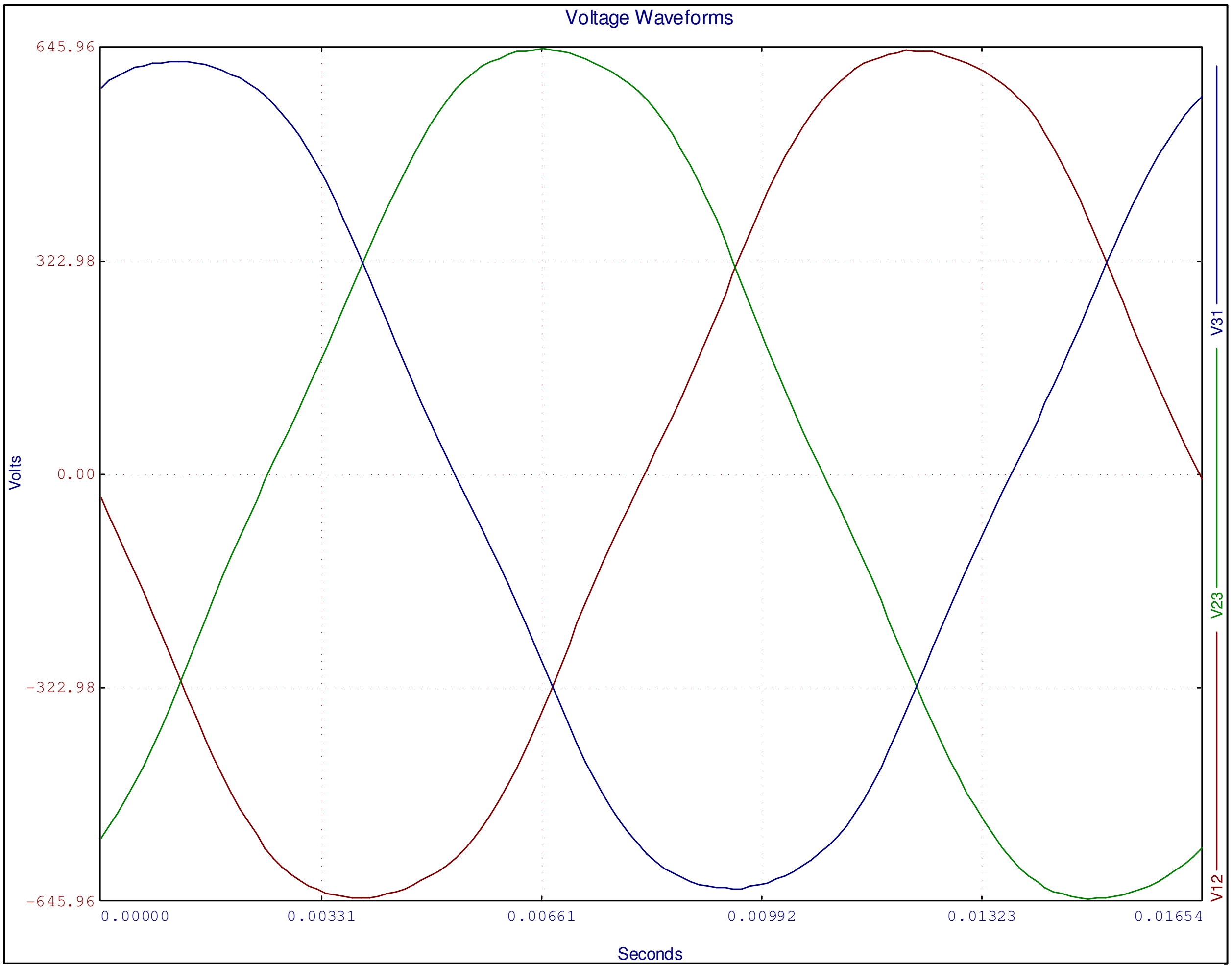

Figure 4 - Shore Tie Voltages, measured line-to-line without induced ground fault

B. Shore tie transformer voltages measured: Phase A-B = 463V, Phase B-C = 464V, Phase C-A = 453V. Voltage imbalance measured 1.6%.

C. File ID: PS DELTA Shore.dem, Shot 1

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D. ***Figure 5*** shows the Shore Tie transformer with a ground applied to Phase A. The Line-to-line system voltages are unaffected by the induced ground fault.

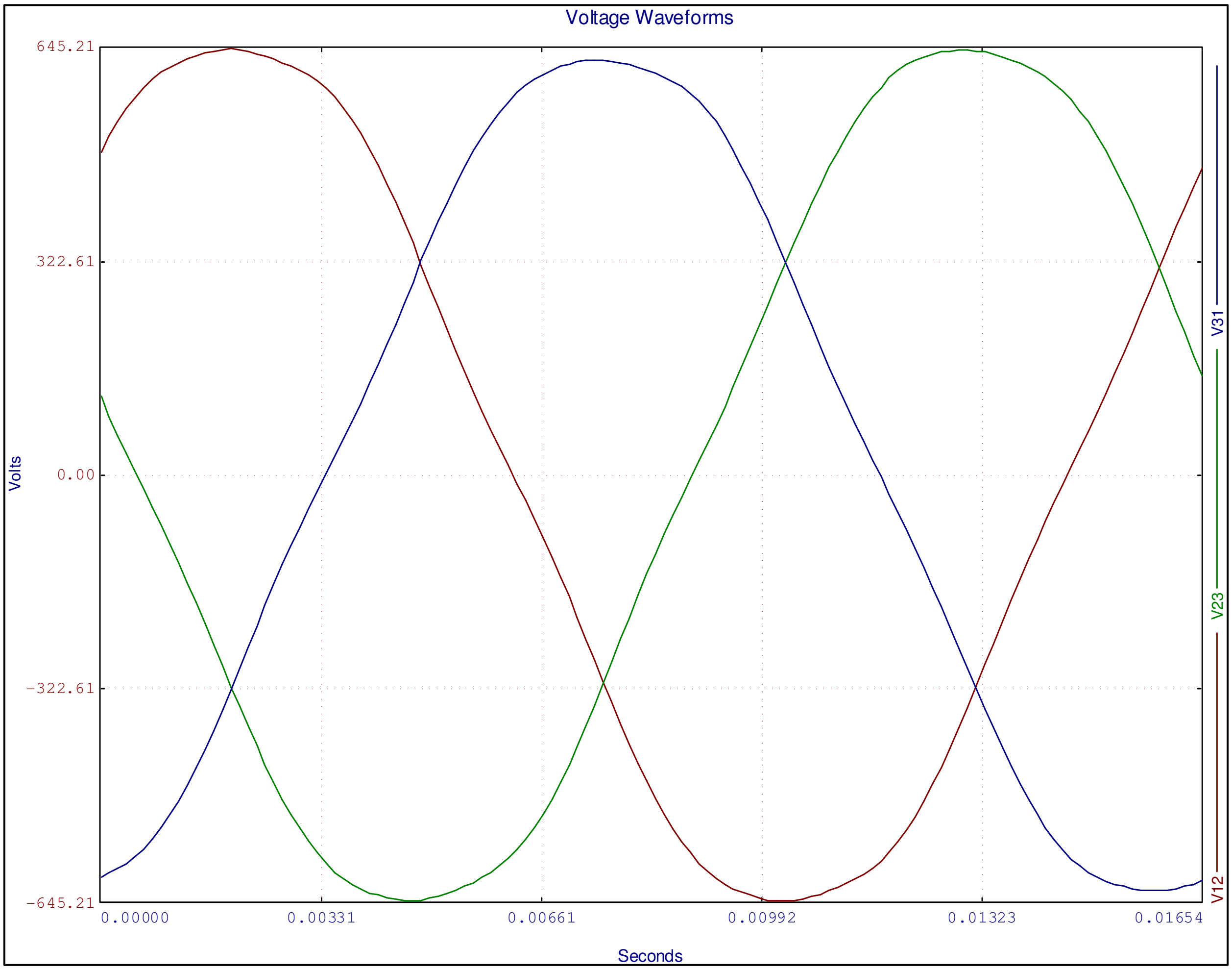

Figure 5 - Shore Tie Voltages, measured line-to-line with induced ground fault

E. Shore tie transformer voltages measured: Phase A-B = 465V, Phase B-C = 464V, Phase C-A = 454V. Voltage imbalance measured 1.5%.

F. File ID: PS DELTA Shore.dem, Shot 54.

VI. Line-to-hull (ground) Fault Effects on DELTA Shore Tie Transformer

A. ***Figure 6*** shows the ungrounded system voltage from the DELTA Shore Tie transformer in line-to-hull (ground) measurement mode.

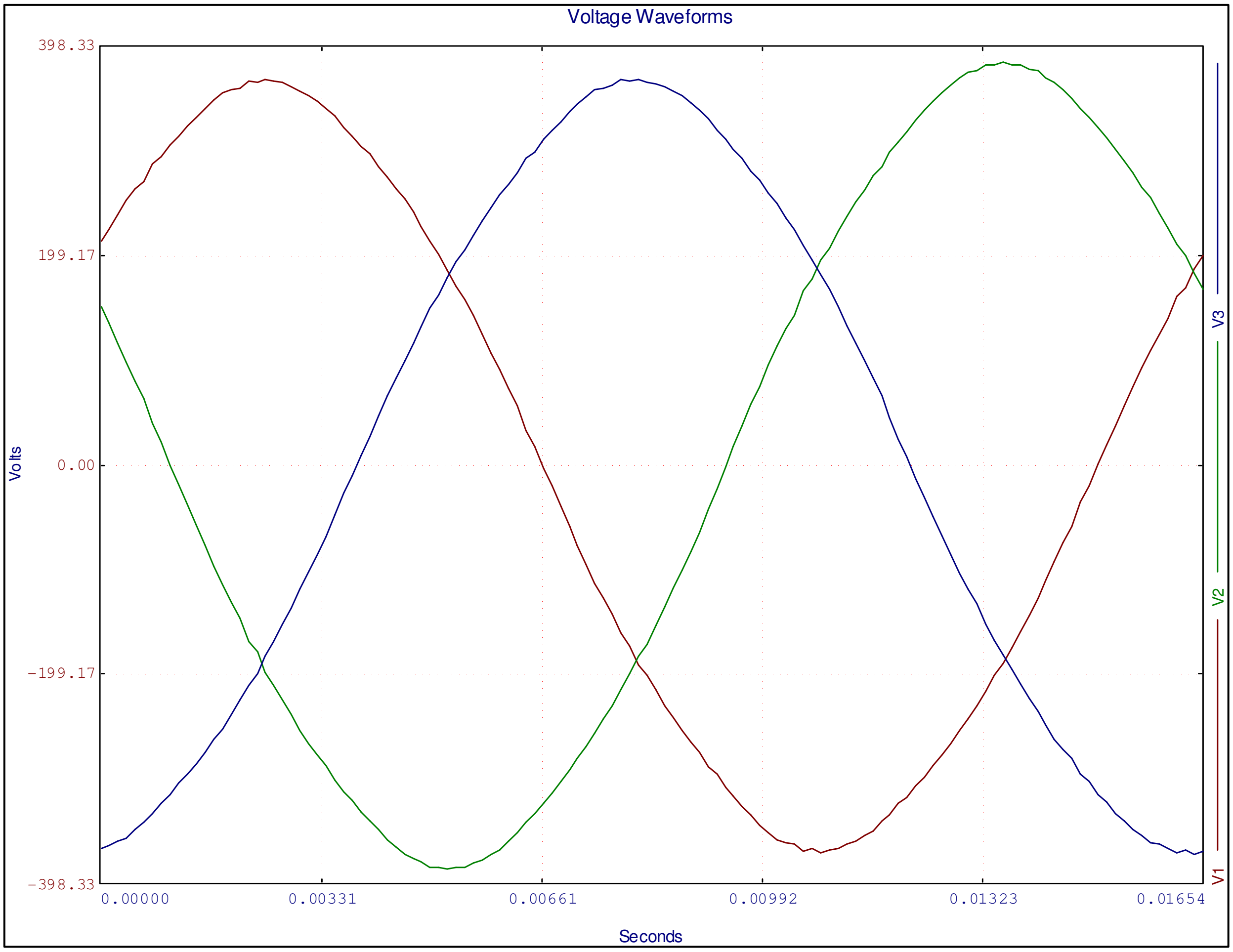

Figure 6 - Shore Tie Voltages, measured line-to-hull (ground) without induced ground fault

B. Shore tie transformer voltages measured: Phase A-Ground = 256V, Phase B-Hull = 268V, Phase C-Hull = 257V. The subsequent voltage imbalance measured 3%.

C. File ID: PS Shore WYE.dem, Shot 1.

D. ***Figure 7*** shows that with a ground applied to Phase C of the Shore Tie transformer, the Line-to-hull (ground) system voltages are displaced by the induced ground fault.

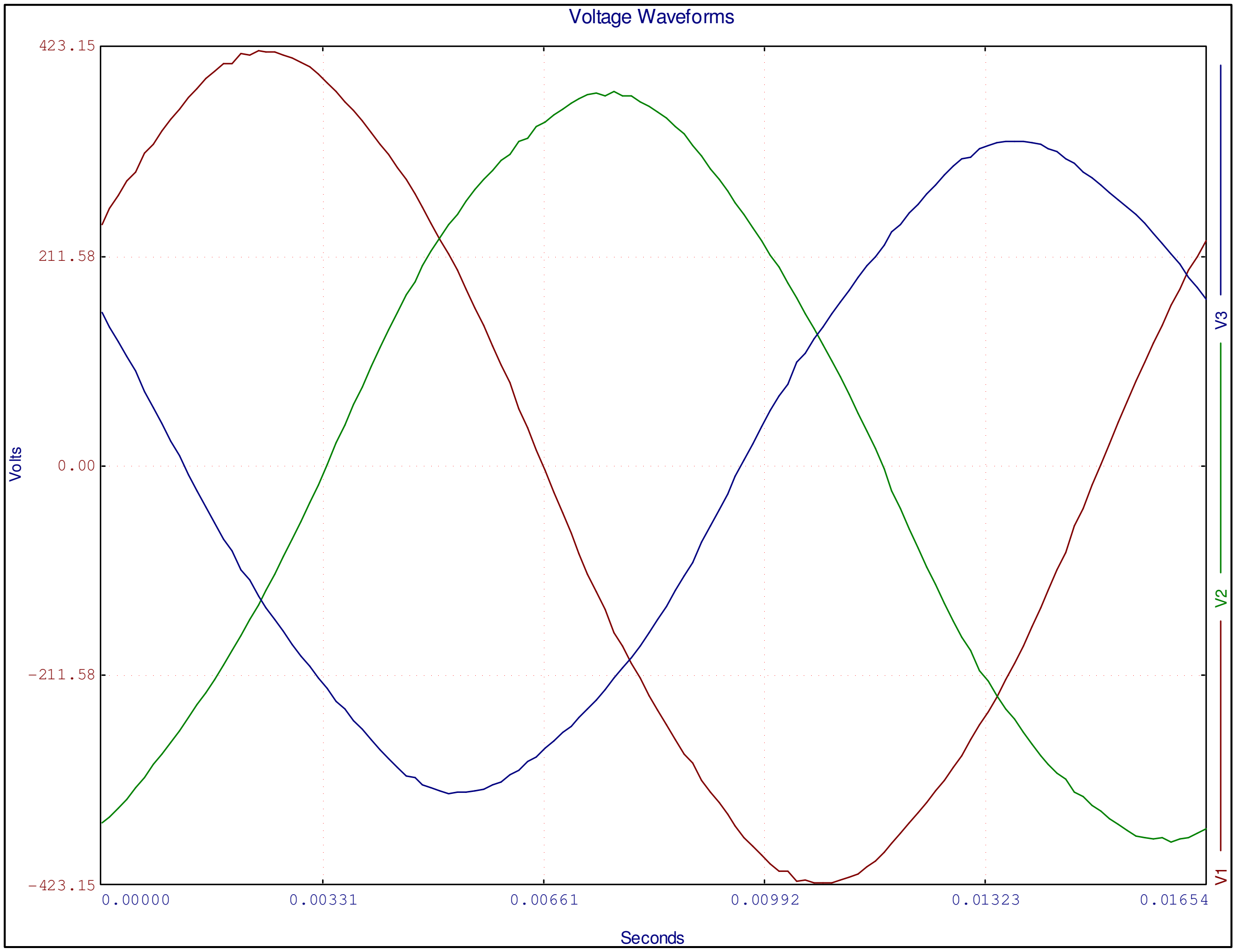

Figure 7 - Shore Tie Voltages, line-to-hull (ground) with an induced ground fault

E. Shore tie transformer voltages measured: Phase A-Hull = 294V, Phase B-Hull = 264V, Phase C-Hull = 229V. The subsequent voltage imbalance measured 13%.

F. File ID: PS Shore WYE.dem, Shot 31

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G. ***Figure 8*** shows that at the instant the ground fault was applied, the ungrounded phases surged to 686 volts peak.

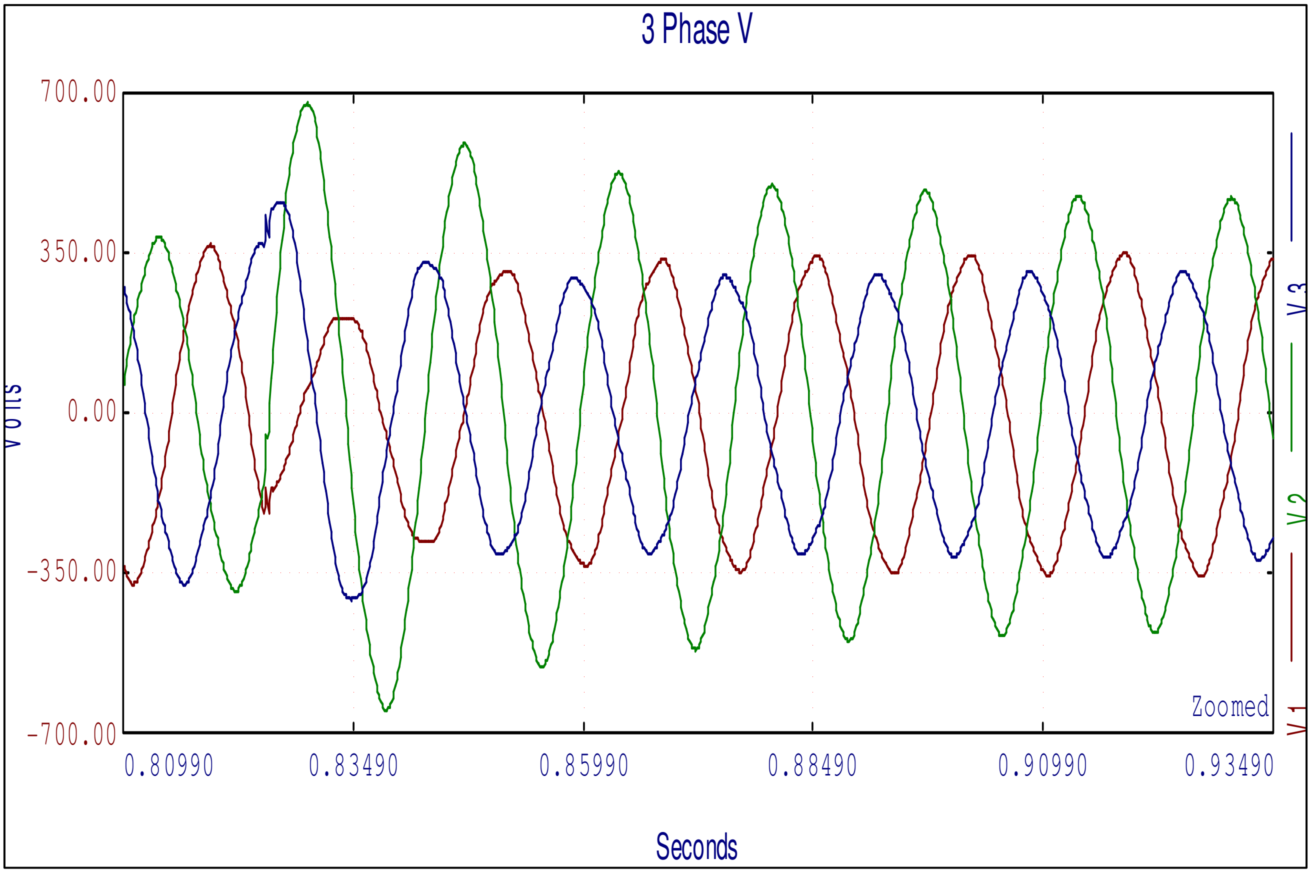

Figure 8 - Ground Fault on Shore Tie Service – Phase C, worst case recorded

H. File ID: PS Shore WYE.dem, Shot 78, autoscale off, range 0.810 – 0.935 sec, +/- 700 volts.

I. ***Figure 9*** shows the Shore Tie transformer with a ground applied to Phase C and the Phaseback unit energized. Phaseback reduced the Line-to-hull (ground) system voltage displacement during the induced ground fault.

J. Shore tie transformer voltages measured: Phase A-Hull = 265V, Phase B-Hull = 258V, Phase C-Hull = 276V. The subsequent voltage imbalance measured 3.6%.

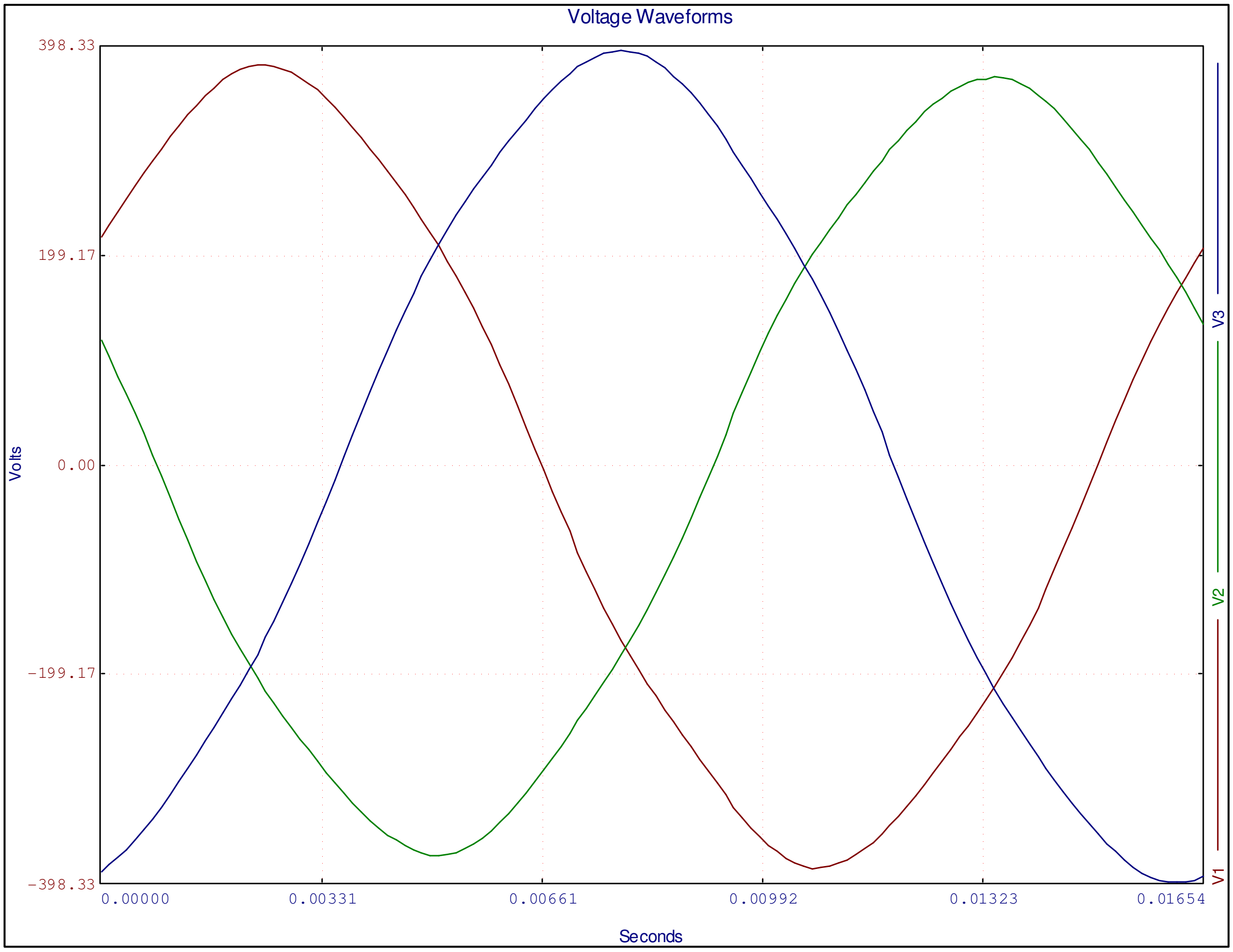

Figure 9 - Shore Tie Voltages, line-to-hull (ground) with an induced ground fault, with Phaseback energized

K. File ID: PS Shore WYE.dem, Shot 63

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L. ***Figure 10*** shows that at the instant the Phaseback unit was energized, there was an immediate reduction in the system voltage imbalance from 13% to 3.6%.

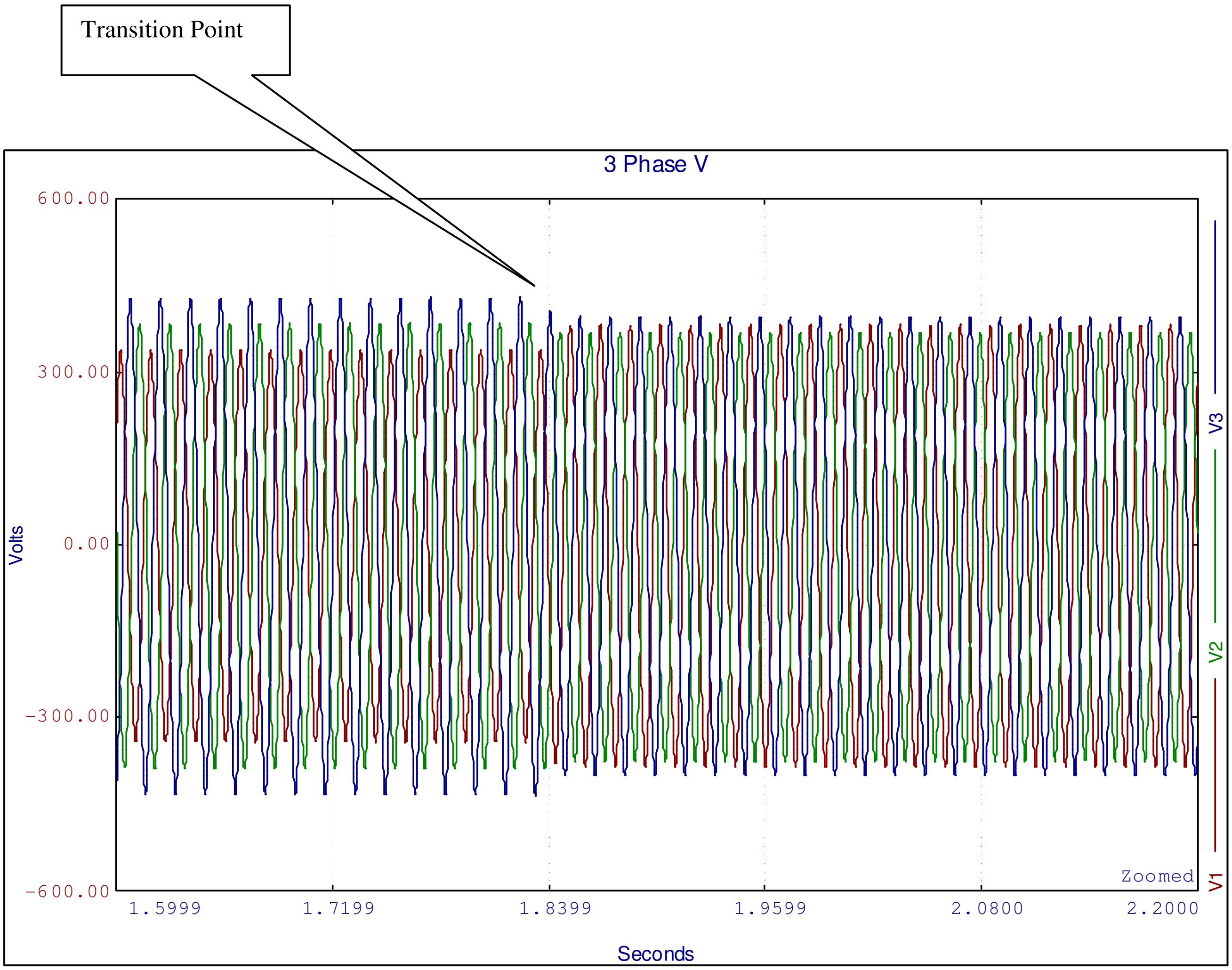

Figure 10 - Phaseback Energized during induced ground fault from Shore Tie

M. File ID: PS Shore WYE.dem, Shot 43, autoscale off, range 1.6 – 2.2 sec, +/- 600 volts.

VII. Line-to-Hull Fault Effects on ship service generators utilizing star wound alternators

A. Shipboard electrical service was shifted from the Shore Tie to the ship's generator. Polar Star generators are all "Star" WYE wound but do not have a grounded neutral (neutral conductor electrically bonded to ship's hull).

B. ***Figure 11*** shows the ungrounded ship's service voltage from the generator in line-to-hull (ground) measurement mode. The voltages measured were: Phase A-Hull = 253V; Phase B- Hull = 265V; and Phase C- Hull = 260V with a measured voltage imbalance of 2.5%.

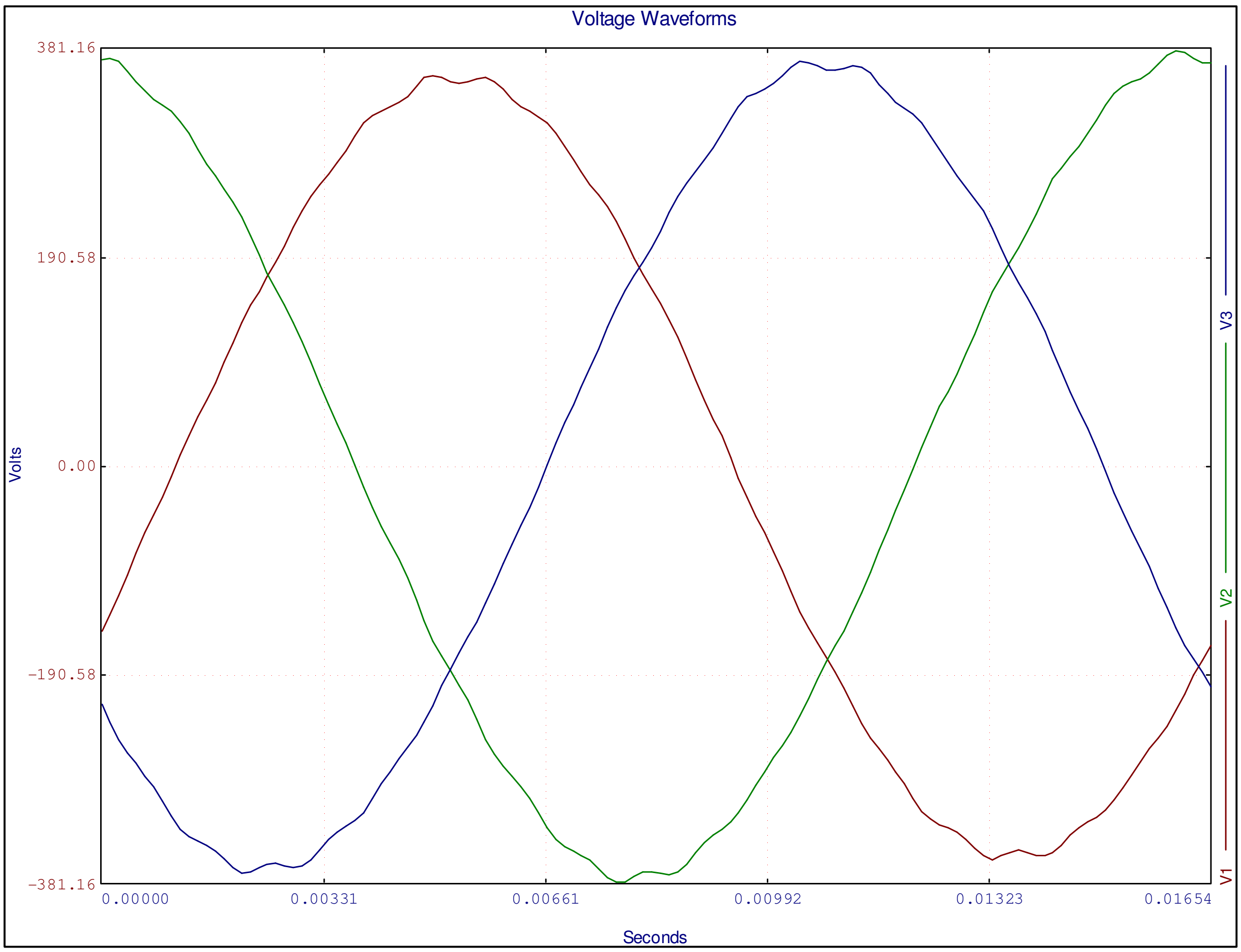

Figure 11 - Ship's generator system voltage in line-to-hull measurement mode.

C. File ID: PS Ship WYE.dem, shot 49.

D. ***Figure 12*** shows the ship's voltage with a ground applied to Phase A. The Line-to-hull (ground) system voltages are displaced by the induced ground fault.

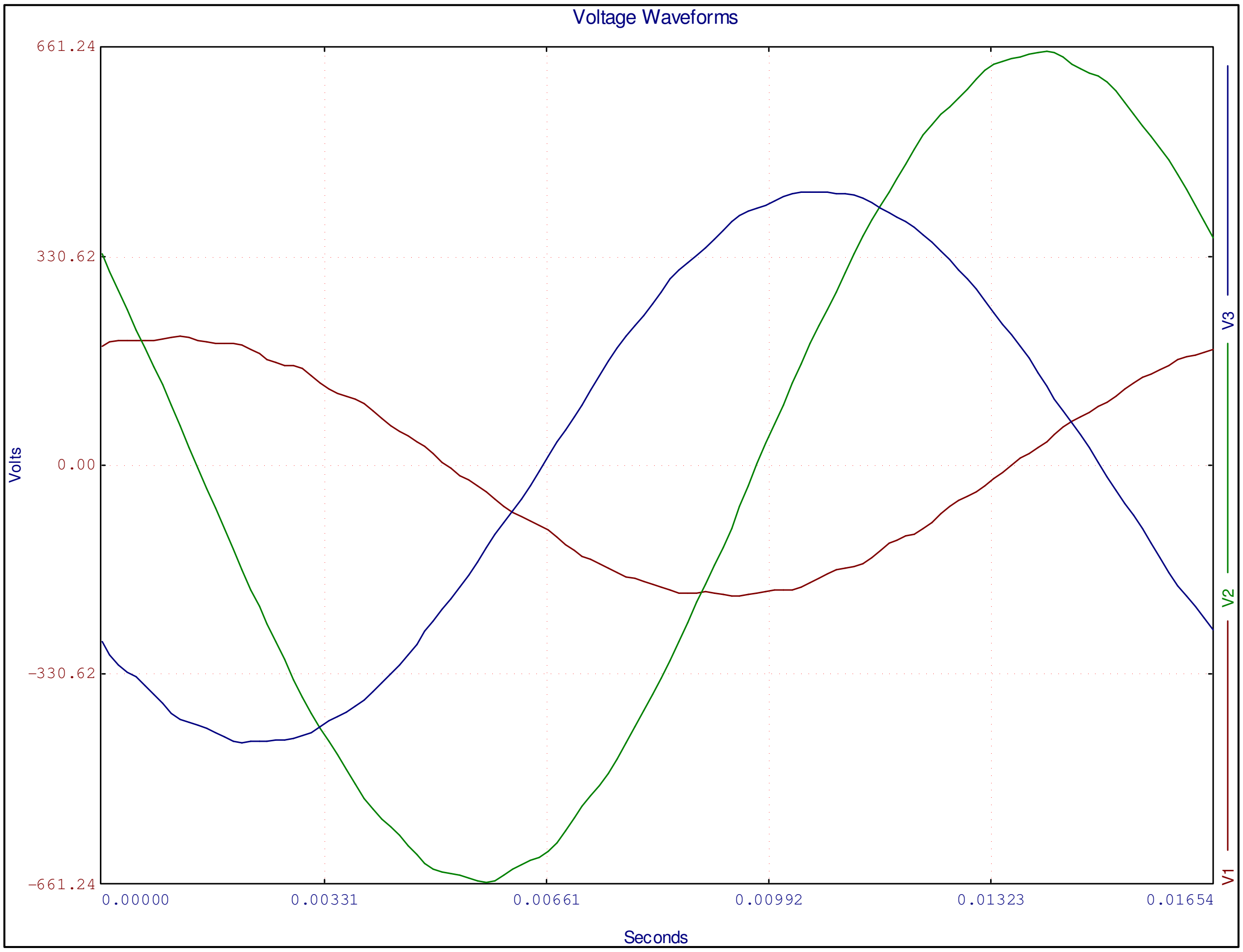

Figure 12 - Ship's voltages, measured line-to-hull (ground) with an induced ground fault

E. The ship's voltages measured: Phase A-Hull = 144V, Phase B-Hull = 462V, Phase C-Hull = 309V. The subsequent voltage imbalance measured 53%.

F. File ID: PS Ship WYE.dem, shot 50.

G. ***Figure 13*** shows that at the instant the ground fault was applied, the ungrounded phases surged to -684 volts peak.

H. File ID: PS Ship WYE.dem, shot 13, autoscale off, range 0.715 – 0.790, +/- 750v.

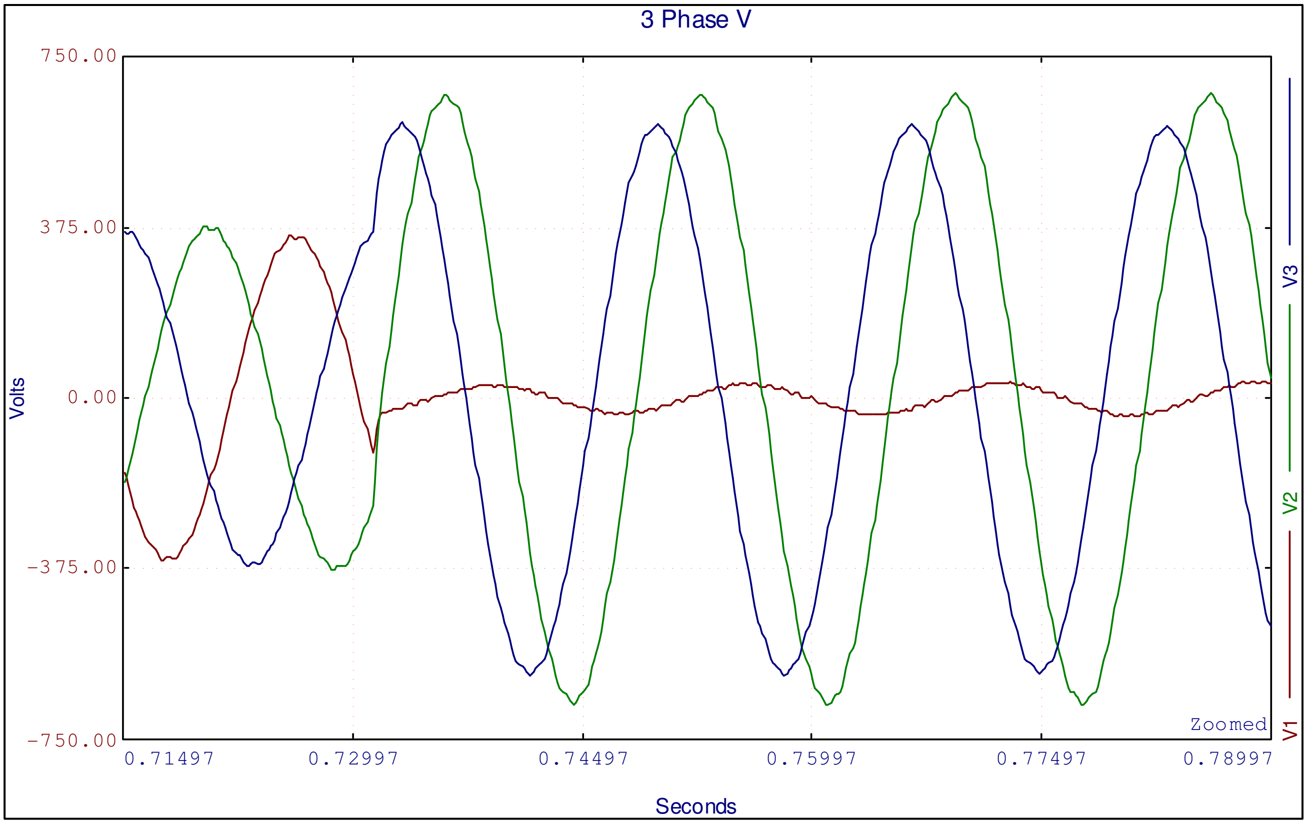

Figure 13 - Ground fault applied to ship's generator service.

G. ***Figure 14*** shows the ship's system with a ground applied to Phase C and the Phaseback unit energized. Phaseback reduced the Line-to-hull (ground) system voltage displacement during the induced ground fault.

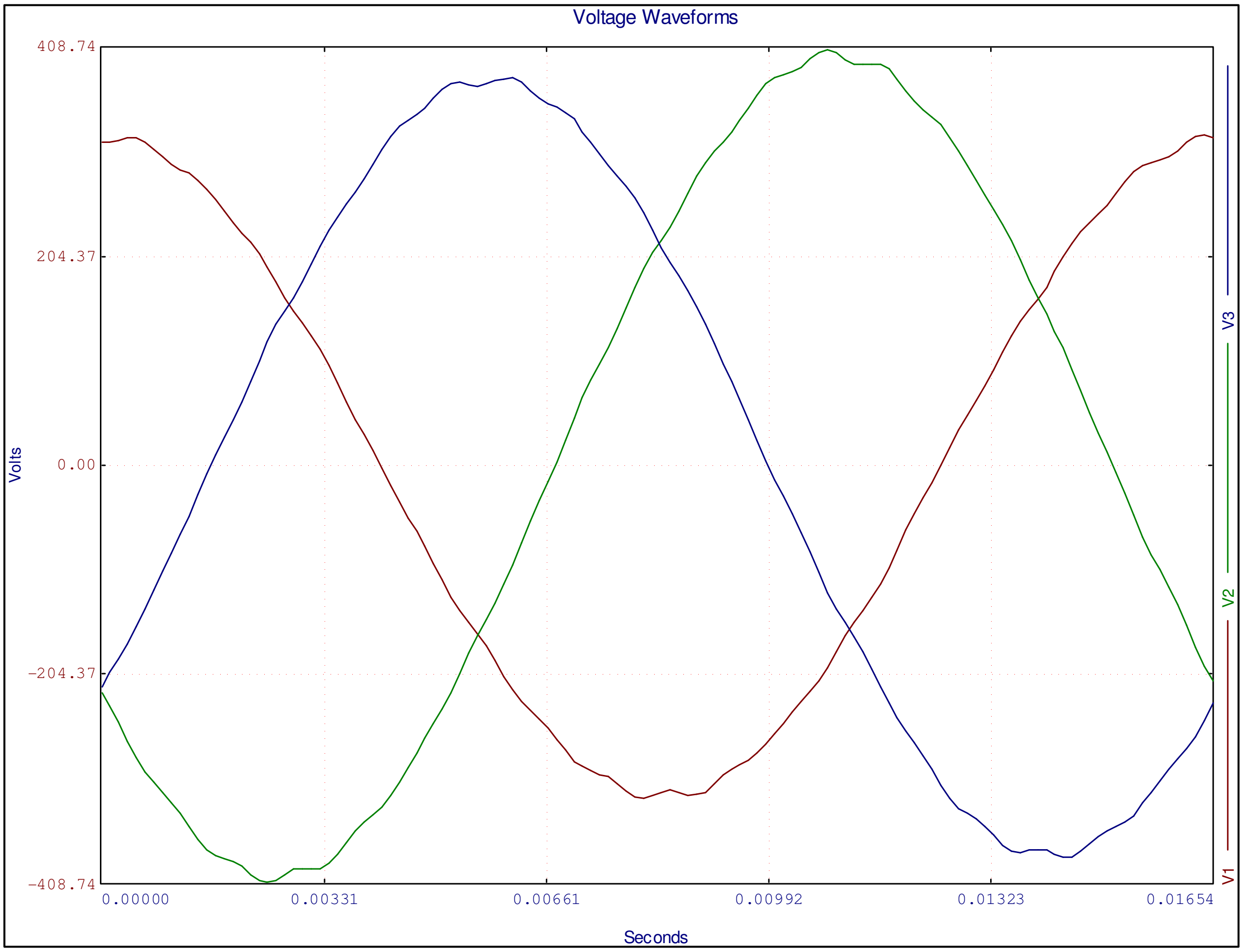

Figure 14 - Ship's system Voltages, measured line-to-hull (ground) with an induced ground fault, with Phaseback energized

H. The ship's voltages measured: Phase A-Hull = 229V, Phase B-Hull = 283V, Phase C-Hull = 268V. The subsequent voltage imbalance measured 12%.

I. File ID: PS Ship WYE.dem, shot 51.

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J. ***Figure 15*** shows that at the instant the Phaseback unit was energized in the presence of the induced ground fault, there was an immediate reduction in the system voltage imbalance from 53% to 12%.

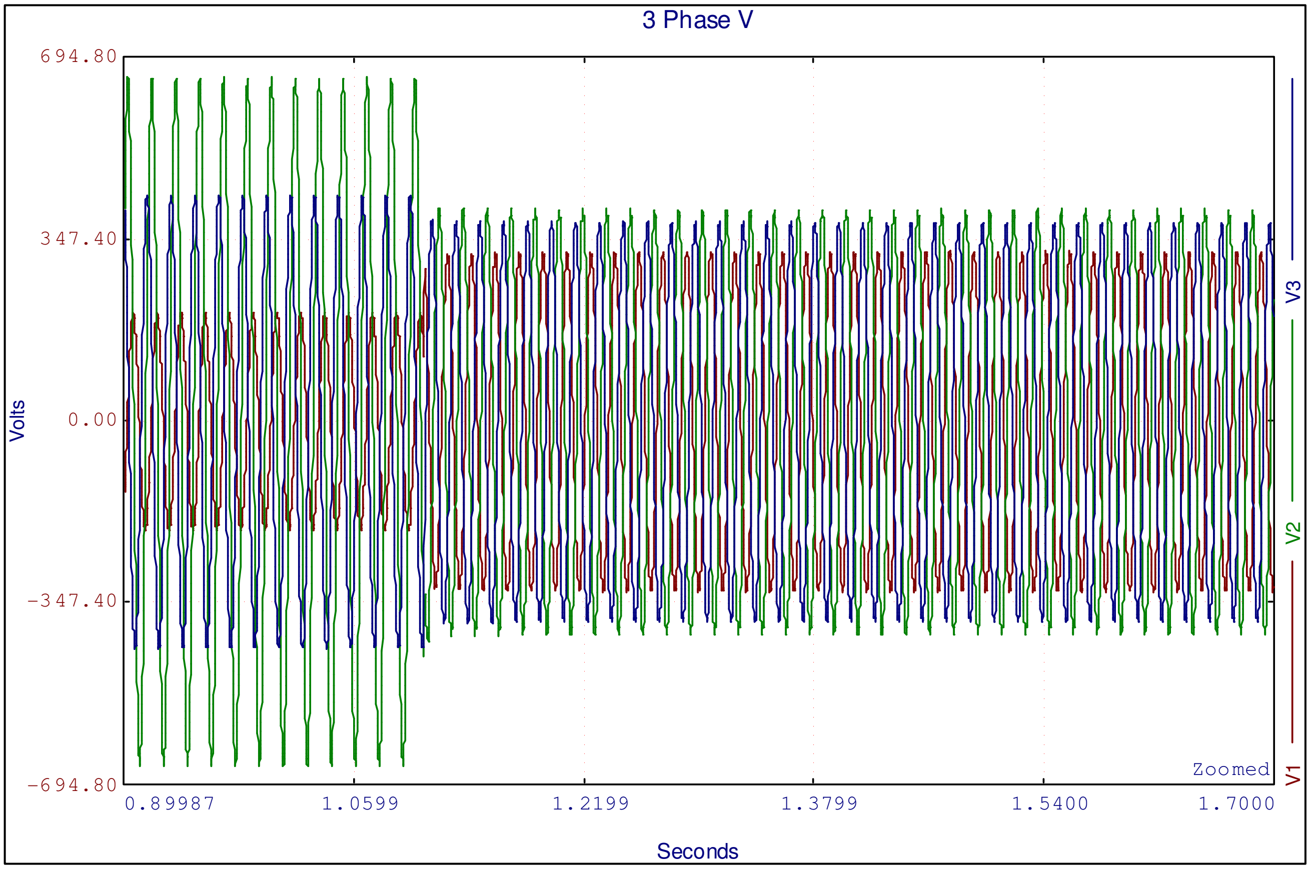

Figure 15 - Phaseback energized with induced ground fault on Ship's Generator

K. File ID: PS Ship WYE.dem, shot 20, autoscale OFF, range 0.9-1.7 seconds, +/- 700 volts.

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L. ***Figure 16*** shows the instant that the Phaseback unit was de-energized with the induced ground fault still present.

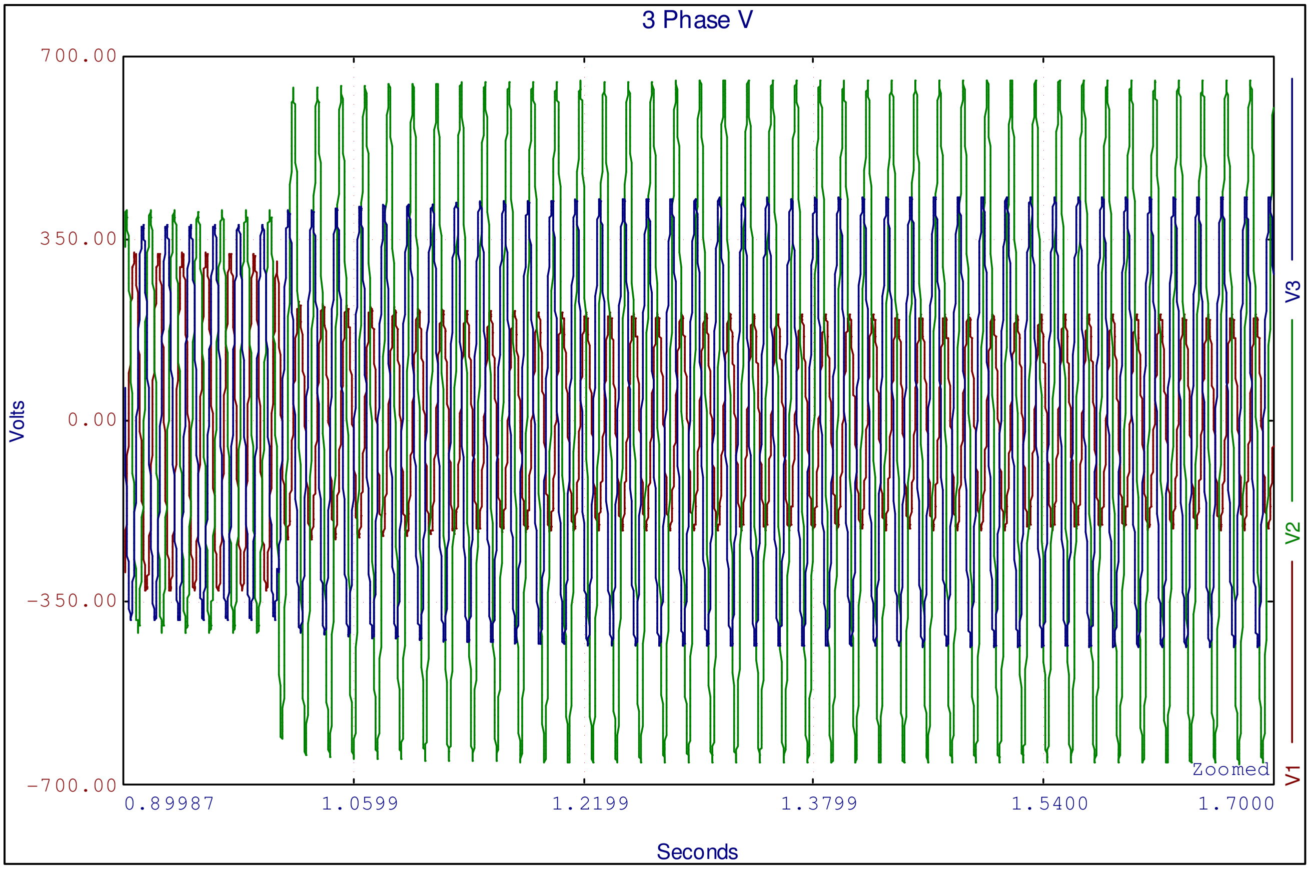

Figure 16 - Phaseback de-energized with induced ground fault on Ship's Generator

M. File ID: PS Ship WYE.dem, shot 27, autoscale OFF, range 0.9-1.7 seconds, +/- 700 volts.

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N. ***Figure 17*** shows the instant the induced ground fault was removed. The system voltages can be seen slowly recovering while the system parasitic capacitance balance is restored. The slow charging time indicates that the system parasitic capacitance is relatively low.

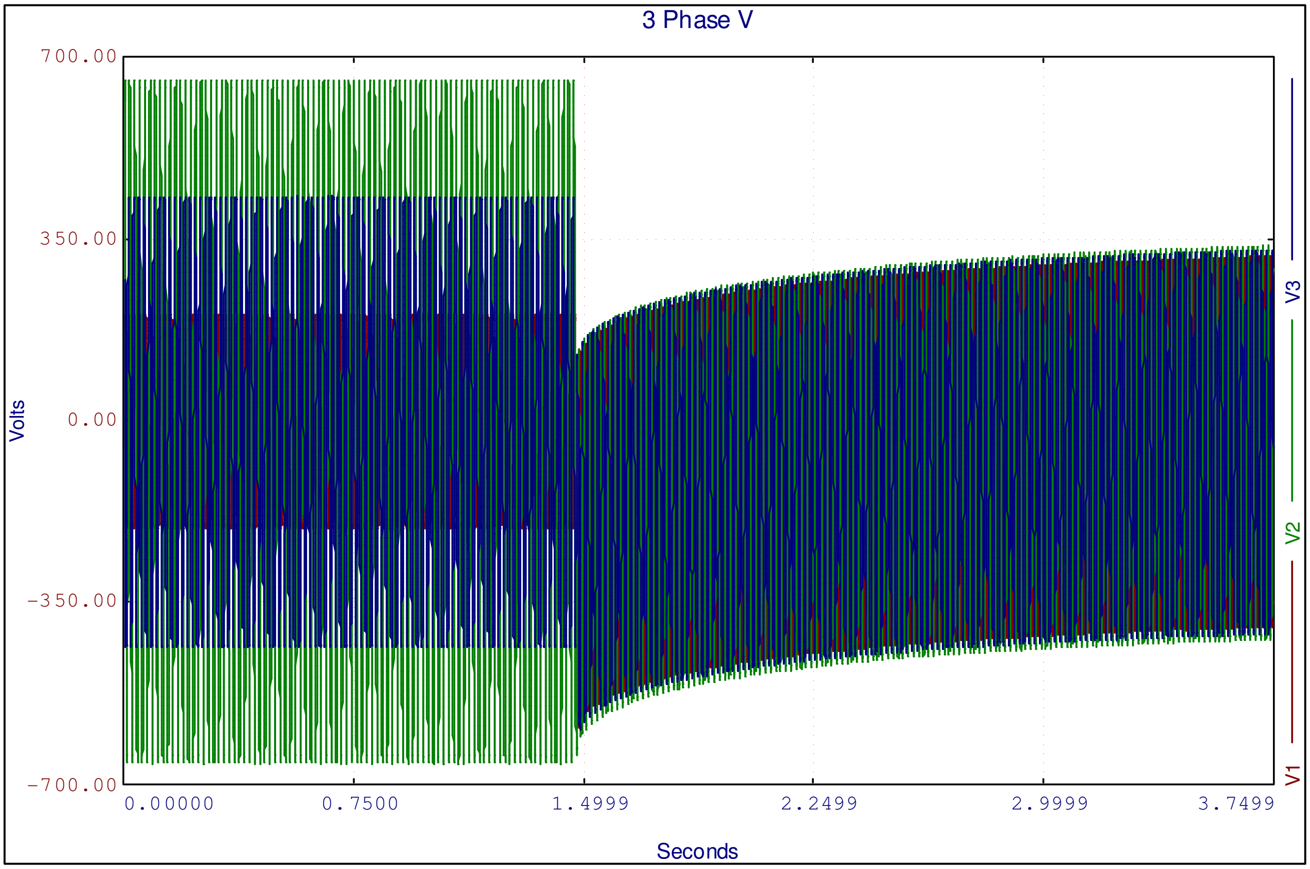

Figure 17 – Induced ground fault removed from Ship's Generator

N. File ID: PS Ship WYE.dem, shot 28

VIII. Shore Tie Test Data:

a. ***Table 1*** summarizes the test results.

Condition				System Voltages			Harmonic Data		Balance
Shot	Source	Ground Applied	Phaseback ON	Phase A Volts	Phase B Volts	Phase C Volts	Voltage (V_{thd}) AVG	% THD AVG	% V Balance AVG
1	Shore L-L*			463	464	453	11.5v	2.5%	1.6%
54	Shore L-L	X		465	464	454	13.3v	2.8%	1.6%
1	Shore L-H**			256	268	257	3.5v	1.4%	3%
31	Shore L-H	X		294	264	229	4.35v	1.7%	12.7%
63	Shore L-H	X	X	264	257	275	6v	2.25%	3.6%
49	Ship L-H***			253	265	260	2.8v	1.1%	2.5%
50	Ship L-H	X		144	462	309	2.8v	1.13%	52.7%
51	Ship L-H	X	X	229	283	268	3.0v	1.16%	12%

Shore L-L* File PS DELTA Shore.dem, Shore Tie Transformer, Line-to-Line voltage measurement
Shore L-H** File PS Shore WYE.dem, Shore Tie Transformer, Line-to-Hull (Ground) voltage measurement
Ship L-H*** File PS Ship WYE.dem, Ship Generator system, Line-to-Hull (Ground) voltage measurement

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IX. Test Result Summary:

A. Test Results of the USCG Polar Star WAGB-10 Phaseback tests, powered from the ISC Seattle, WA Shore Tie Transformer (450-volt, three-phase ungrounded DELTA). Voltage measurements were made **Line-to-Line.**

1. The system line-to-line voltages remained undisturbed while a phase-to-Hull (Ground) fault was inserted.

B. Test Results of the USCG Polar Star WAGB-10 Phaseback tests, powered from the ISC Seattle, WA **Shore Tie Transformer** (450-volt, three-phase ungrounded DELTA). Voltage measurements were made **Line-to-Hull (ground)**.

1. The system line-to-hull (ground) voltages were displaced during the insertion of a relatively benign ground fault on the shore tie system. The recorded displacement of the system voltages, see ***Figures 2*** and ***8***, was consistent with previously published data. [B-2, B-3]

2. Application of the ground fault resulted in a shift of the system voltage imbalance from 3% to 12.7%.

3. Connecting the Phaseback unit to the system in the presence of an induced ground fault reduced the system voltage imbalance from 12.7% to 3.6%.

C. Test Results of the USCG Polar Star WAGB-10 Phaseback tests, powered from the **ship's diesel generator** (450-volt, three-phase ungrounded WYE (STAR)). Voltage measurements were made **Line-to-Hull (ground).**

1. The system line-to-hull (ground) voltages were displaced during the insertion of a relatively benign ground fault on the ship's generator system. The recorded displacement of the system voltages, see ***Figures 2, 12,*** and ***13***, was again consistent with previously published data. [B-2, B-3]

2. Application of the ground fault resulted in an increase in the system voltage imbalance from 2.5% to 52.7%.

3. Connecting the Phaseback unit to the system during the ground fault reduced the system voltage imbalance from 52.7% to 12%.

D. Additional Observations:

1. The Phaseback unit contained a Ground fault indicator light. This light did not illuminate during any phase of the Polar Star tests. Subsequent discussion with the manufacturer indicated that the light was designed to illuminate under more severe ground fault conditions. During Polar Star testing, the Phaseback unit and the insertion point of the test ground fault was some distance from the voltage sources. Previous tests (USCG Kodiak 2005 and 2002) show more pronounced effects both in the system reaction to a test ground fault and the stabilizing effects of Phaseback when placed close to or at the voltage source. It is theorized that distribution cable impedances affect the system behavior during test conditions.

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2. The Phaseback unit also contained an AC Current Controller, p/n 700-880B, made by American Aerospace Controls, Inc. This was apparently set at mid range, (5 amps) but was not attached to any external indicating circuit.

3. The ship ground fault indicator lights did not indicate a ground during testing.

X. Conclusions:

A. Phaseback will stabilize the system voltage balance of an ungrounded voltage system in both DELTA or a WYE (Star) voltage sources. Although at first glace Phaseback appears to act similar to, and provide the benefits of, a high-resistance grounding (HRG) system for safety and operability, there are significant differences between Phaseback and HRG systems.

HRG systems are defined as "… grounded system(s) with a purposely inserted resistance that limits ground fault current such that the current can flow for an extended period without exacerbating damage."[1] Phaseback does not have a resistor in series with a ground fault current path and has not been observed to be a path for fault current.

1. Phaseback does not trip the service off as do commercially available HRGs. Unlike HRG systems, Phaseback is optimized to provide maximum stability of the voltage system in order to minimize process controller upsets, while HRG systems are designed to reduce fault currents and to minimize installation costs over grounded electrical systems.

2. During fault conditions, HRG systems may allow multiple amps of continuous hull (ground) current to flow. Phaseback tests on Polar Star showed currents of 0.017 amps with no ground fault, and 0.37 amps with an induced fault.

3. Unlike commercial HRG systems, Phaseback stabilizes system voltages thus preventing the flow of fault current. This is an ideal condition for the IT-rich environment aboard modern Navy and Coast Guard ships today and has very real potential for shore based IT systems. Reference (a) recommends a nearly identical circuit for CVN-class load centers.

B. Test results show that Phaseback can provide voltage stabilization for pier Shore Tie systems, thus providing protection against voltage surges originating from the local utility electrical system. Voltage surges on the Shore Tie system may cause distribution cable or connector failure that may endanger personnel. Phaseback will also improve the balance of Shore Tie electrical systems, thus reducing any circulating currents due to net current imbalances. This may help to reduce hull corrosion.

C. Another practical application for Phaseback may be as an added safety factor to stabilize the primary side of aircraft hangar power systems. Voltage surges on such systems may propagate through the hanger frequency inverters and damage any aircraft being powered from the hangar power system. Such voltage surges can damage the electronic flight control system electronics, thus endangering the flight crew.

D. Similar methods for stabilizing ungrounded power systems have been studied and recommended for ships by the Navy by reference (a) and [B-3].

XI. Recommendations:

A. The initial assessment of Phaseback is very positive. The device seems to offer a method of system voltage stabilization for ungrounded power systems that is not possible using any other means at this time. It is therefore recommended that the test and evaluation effort be continued and that the manufacturer be encouraged to modify the ground fault indicating system to provide operability with a pulsing DC ground fault detector. In addition, Phaseback indicating circuitry should be modified to approximate the capability of the Navy ground fault indicating light system, which shows relative phase balance and approximate severity of the ground.

B. Personnel involved in the testing aboard the Polar Star as well as representatives of shore facilities are in strong agreement that a means of indicating both the individual faulted phase and the relative magnitude is needed for the Phaseback unit. It is recommended that this issue be pursued in further testing and evaluation.

Bibliography

[B-1] S9086-KC-STM-010/CH-300R4, Naval Ship's Technical Manual, Chapter 300, Electric Plant – General

[B-2] "Electrical Systems Analysis and Design for Industrial Plants", Irwin Lazar, EE, MS. McGraw-Hill © 1980.

[B-3] "Grounding of Marine Electrical Power Systems: A True Perspective", The Society of Naval Architects and Marine Engineers, Spring Meeting STAR Symposium, Philadelphia, Pennsylvania 1987. D.D. Shipp, Westinghouse Electric Corp.; C.O. Crapps, US NAVY, Washington DC. T.M. Nolan, U.S. Coastguard, Washington DC.

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