FUEL CELL ELECTRICAL POWER GENERATING SYSTEM DYNAMIC RESPONSE AND PERFOMANCE CHARACTERIZATION TEST RESULTS

SSI REPORT No. 518-01

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1.0 INTRODUCTION

1.1 PURPOSE AND BACKGROUND

In order to determine the ability of a fuel cell based electrical power generating system to meet the requirements of an equivalent shipboard propulsion or ship's service electrical power generating system, a set of test protocols will be developed that simulate the shipboard operating environment. The response and performance standards utilized for this equipment when utilized aboard ships are established by any one of a number of regulatory agencies such as the ABS, Dn V, Lloyds or U.S.C.G. In general, most of these agencies will accept the standards of another so that testing for the ABS will suffice for Dn V, etc. To accomplish the proposed fuel cell response and performance characterization tests, the standards of the **ABS RULES FOR BUILDING AND CLASSING STEEL VESSELS - 2001** and **IEEE 45-1998 RECCOMENDED PRACTICE FOR SHIPBOARD ELECTRICAL INSTALLATIONS** as well others will be reviewed and employed. These standards provide the minimum performance criteria that shipboard electrical power generating equipment and systems must meet to be deemed suitable for use in shipboard applications.

Fuel cells are not presently addressed by ABS or IEEE 45 rules and standards. Shipboard electrical power generators whether they are driven by a diesel engine, steam or gas turbine are separated into their two main components; the prime mover and the generator/alternator and are addressed in this manner by current marine regulations. Because the fuel cell combines the prime mover and the generator into a single unit, the standards that would most likely apply would be a combination of these requirements.

On March 12 through March 15, 2002 a series of tests were performed in Framingham, Massachusetts for the purpose of determining the ability of the Sure Power™ power management system to meet existing regulatory bodies requirements for power systems installed on aboard an ocean going vessel.

In attendance for all or part of the tests were:

Mr. William Cratty	Sure Power™	Exe. Vice President
Mr. Steve Fairfax	M Technology	President
Mr. Neal Dowling	M Technology	Senior Engineer
Mr. Eric Taylor	M Technology	Mechanical Engineer
Mr. Michael Perelstein	Strategic Facilities	Associate
Mr. Brian Norton	Seaworthy Systems	Senior Engineer

M Technology personnel as operators of the system, performed all tests. Mr. Perelstein from Strategic Facilities acted as a non-interested third party to record the data. Mr. Norton was present to insure that test protocol was adhered to and to provide guidance when necessary.

1.2 APPLICABLE REGULATORY STANDARDS

To determine the suitability of the Sure Power™ system for shipboard use it was decided to conform to existing **ABS – Steel Vessels 2001, IEEE Std 45-1998** and **U.S.C.G. CFR** standards and regulations as they apply to shipboard generators. This decision was driven by the aspiration of installing this system on an U.S. flagged vessel

1.3 SCOPE AND APPROACH

From these publications the following regulations were determined to be applicable: **ABS - Rules for Building and Classing Steel Vessels 2001, 4-8-3/3.13.2 (b, c, and d), 4-2-1/13.9.3(*i* and *ii*), 4-2-1/7.5.1(a)*ii*) and 4-2-1/7.5.2, IEEE Std 45-1998 5.6, 5.4.1, 5.4.2.1 and 5.5.1 and U.S.C.G. 46 CFR 112.3-7**. A regulation was deemed applicable if any section of with it dealt with electrical output parameters regardless of whether this parameter was simply an indicator of the prime mover's ability to meet test conditions. All cited regulations are contained in Appendix B under references and at the end of the individual test plans.

After applicable regulations were identified and abstracted they were developed into test plans.

The above regulations are designed for conventional rotating generators, typically with a diesel engine for a prime mover. Due to the configuration of the Sure Power™ system these regulations on shipboard generators and prime movers are not always directly applicable to performance parameters and operation of the system. Individual test plans were developed to demonstrate the ability of the Sure Power™ system to meet these regulations regardless of applicability of the regulations to the system. The test plans (Appendix B) were divided into four sections. Each section is formatted similarly, with a statement of purpose for the section, an individual test that states its purpose, what regulations it satisfies, starting conditions and a detailed set of instructions for carrying out that test. At the end of each test plan are the specific regulations cited in the test plans.
These test plans are in Appendix B.

Data sheets for each test plan were developed to compliment the test plans and allow for an easy determination of the performance of the Sure Power™ system during the test procedure. Completed data sheets may be found in Appendix A.

In order to verify that the Sure Power™ system met the requirements as set out in the test plans, a third party testing company (Strategic Facilities) measured, collected and recorded output bus operating parameters on the data sheets (Appendix C).

2.0 SYSTEM DECRIPTION

2.1 INTRODUCTION

The Sure Power™ system as it is designed can use any source (s) of power. Voltage type (AC or DC), voltage level and frequency levels of most commercially available generator/alternator can be accommodated. These parameters may vary from each other in the case of multiple sources. At the end of this section is Figure 2.1, a one-line diagram of the system tested in Framingham, Ma. The following paragraphs the drawing briefly describe the system components, functions and operational characteristics.

2.2 Fuel cell

In the Framingham, Ma. test bed system two United Technology phosphoric acid fuel cells were used to supply approximately 160 kWe net each. For a total of 320 kWe net of power. These units deliver this power at 480 vac, 3 phase at the unit outlet.

2.3 DC BUS

In the Sure Power™ system this output is inverted to 550 vdc using one Robcon inverter per cell.

2.4 POWER BRIDGE

This 550 vdc can then go to either feed the "Power Bridge" or to the "Uniblock", both manufactured by Piller. In the power bridge, power from the "Uniblock" drives a pony motor to initiate and maintain flywheel charge. The power bridge discharges to "bridge " over a load increase until the fuel cells can increase their output.

2.5 Dual Path Rotary UPS – "Uniblock"

As the power enters the dual path rotary ups at 550 vdc it is inverted to 480 vac 3 phase. This powers a motor generator set (m-g set) to produce "clean" 480 vac, 3 phase power. The m-g set may be fed from three sources. It may either be powered from the fuel cells or from the grid via the "static switch", or through a rectifier/inverter also from the grid path.

2.6 Final Bus

The final bus provides 480 vac, 60 Hz, 3 phase power.

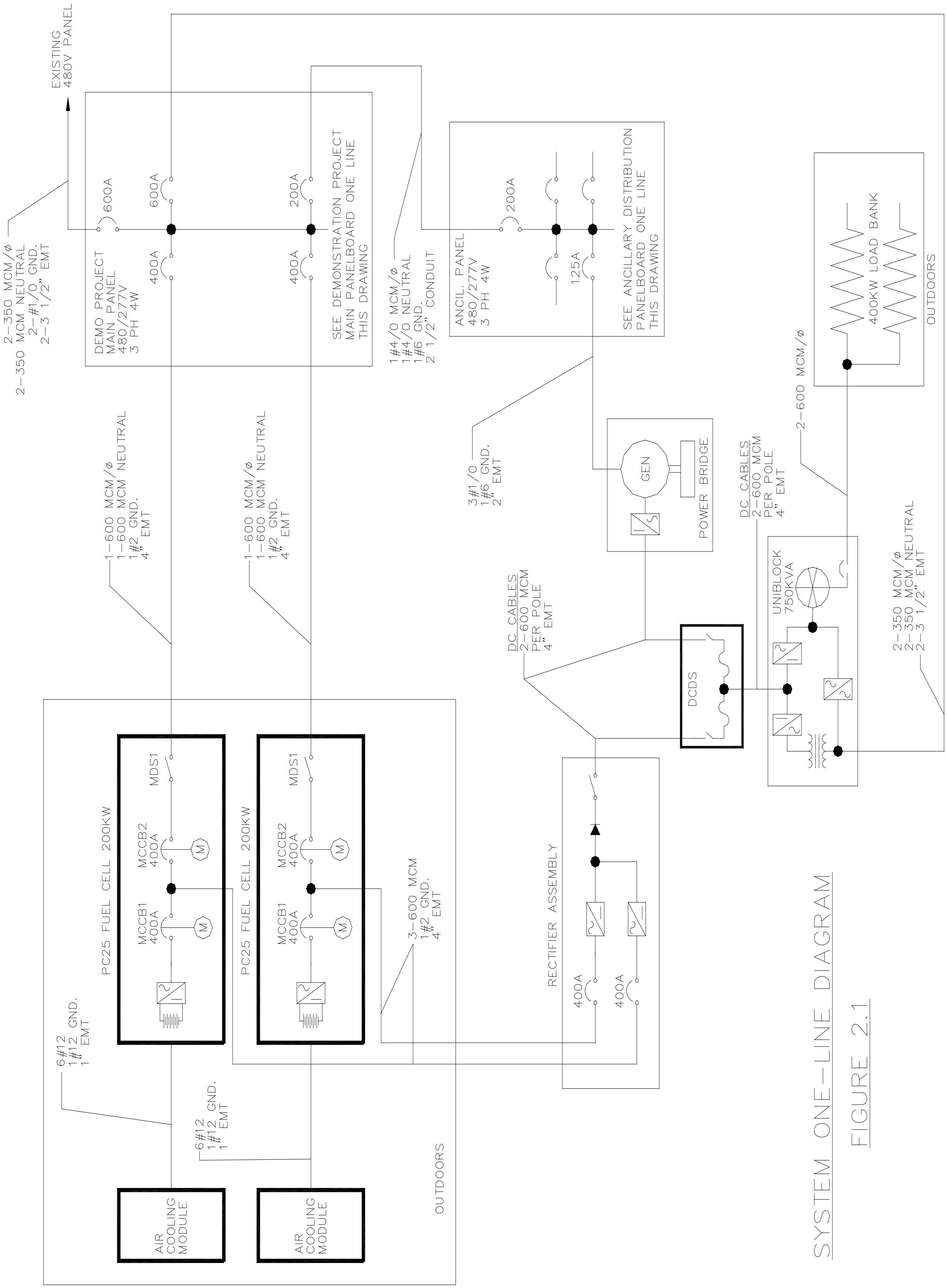
EXISTING 480V PANEL
2-350 MCM/φ
2-350 MCM NEUTRAL
2-#1/0 GND.
2-3 1/2" EMT
600A
DEMO PROJECT
MAIN PANEL
480/277V
3 PH 4W
600A
400A
200A
400A
SEE DEMONSTRATION PROJECT
MAIN PANELBOARD ONE LINE
THIS DRAWING
1#4/0 MCM/φ
1#4/0 NEUTRAL
1#6 GND.
2 1/2" CONDUIT
ANCIL. PANEL
480/277V
3 PH 4W
200A
125A
SEE ANCILLARY DISTRIBUTION
PANELBOARD ONE LINE
THIS DRAWING
400KW LOAD BANK
OUTDOORS
2-600 MCM/φ
1-600 MCM/φ
1-600 MCM NEUTRAL
1#2 GND.
4" EMT
3#1/0
1#6 GND.
2" EMT
GEN
POWER BRIDGE
DC CABLES
2-600 MCM
PER POLE
4" EMT
UNIBLOCK
750KVA
2-350 MCM/φ
2-350 MCM NEUTRAL
2-3 1/2" EMT
DCDS
PC25 FUEL CELL 200KW
MDS1
MCCB2
400A
MCCB1
400A
M
3-600 MCM
1#2 GND.
4" EMT
RECTIFIER ASSEMBLY
400A
6#12
1#12 GND.
1" EMT
AIR
COOLING
MODULE
OUTDOORS
SYSTEM ONE-LINE DIAGRAM
FIGURE 2.1

FIGURE 2-1

3.0 TEST PROTOCOL AND PROCEDURES

3.1 TEST PROTOCOLS

Test protocols and procedures were developed from existing ABS – Steel Vessels 2001, IEEE Std 45-1998 and U.S.C.G. CFR publications. These regulations, specifically ABS - Rules for Building and Classing Steel Vessels 2001, 4-8-3/3.13.2 (b, c, and d), 4-2-1/13.9.3(*i* and *ii*), 4-2-1/7.5.1(a)*ii*) and 4-2-1/7.5.2, IEEE Std 45-1998 5.6, 5.4.1, 5.4.2.1 and 5.5.1 and U.S.C.G. 46 CFR 112.3-7, were used to develop test plans. The test plans were split into four test plan groups. Group 1 consisted of all tests addressing sustained operation. Group 2 contained all the plans dealing with voltage regulation. Group 3 contained all the plans concerning frequency regulation, and Group 4 contained the plan that dealt with parallel operation. These plans are abstracted below, complete test plans are in Appendix A.

Test plan **No. 1** concerns sustained full power ability. Test **1.1** is designed to determine the ability of the Sure Power ™system to deliver and maintain full power output for an extended period of time (not less than 60 min). See ABS - 4-2-1/13.9.3(*i*). Test **1.2** is designed to determine the ability of the Sure Power™ system to deliver 110% (352 kWe) of full power at rated voltage and frequency for at least 30 minutes. See ABS - 4-2-1/13.9.3(*ii*). Test **1.3** is designed to demonstrate system performance over a range of load and operating conditions for at least four hours. See ABS - 4-2-1/15.7.

Test plan **No. 2** deals with voltage regulation. Test **2.1** was designed to determine the ability of the Sure Power™ system to maintain voltage stability (+/-2.5% of rated voltage) through out the rated load range (0 - 100%, 0 - 320kw). See ABS – 4-8-3/3.13.2(*b*), 4.2.1/7.5.1(*d*). and IEEE - 5.4.1. Test **2.2** was designed to determine the ability of the Sure Power™ system to accept a large starting load (150% of rated current) and still maintain a steady state condition voltage. See ABS – 4-8-3/3.13.2(*c*) and IEEE-5.4.2.1 Test **2.3** is designed to determine the ability of the Sure Power™ system to deliver power with proper voltage (480 v) during a momentary (2 sec.) overload (300% of rated capacity) (960 kWe). See ABS – 4-8-3/3.13.2(*d*) and IEEE - 5.4.1.

Test plan **No. 3** reviews voltage frequency regulation. Test **3.1** is designed to determine the ability of the Sure Power™ system to handle frequency regulation during load changes. See ABS - 4-2-1/7.5.1(a)*i*), 4-2-1/7.5.1(a)*ii*). Test **3.2** is designed to determine the ability of the Sure Power™ system to handle frequency regulation during load changes. See IEEE STD 45-1998, 5.6.

Test plan **No. 4** concerns fuel cell parallel operation. Test **4.1** is designed to determine the ability of the Sure Power™ system to demonstrate load sharing stability (+/-15% of combined rated power of the generators) through out the combined rated load range (20-100%, 32 - 320kw). See ABS – 4-2-1/7.5.2. and IEEE - 5.5.1.

Mr. Neal Dowling and Mr. Eric Taylor, of M Technology, operated the system for all the tests. In addition they collected additional data beyond what is called for existing regulations. This data was incorporated into the test results and gives a broader view of the system's performance during the tests.

Mr. Brian Norton, Seaworthy Systems, observed the testing to ascertain that all protocol was being followed and that the necessary data was being collected and recorded.

Mr. Michael Perelstein, Strategic Facilities, as a disinterested third party measured, collected and recorded the necessary data.

3.2 TEST FACILITY AND EQUIPMENT

The test facility in Framingham, Massachusetts consisted of the equipment described in Section 2.0, System Description. Full access to all points in the system was given. After analyzing the regulations, it was decided that the majority of the readings should be taken at the outlet bus. The conditions recorded there would be what machinery would be "seeing." Additional readings were taken at the fuel cell stack output and the fuel cell output connection.

Measuring and recording systems were supplied by Strategic Facilities for all primary measuring points and by M Technology for all secondary points. All measuring equipment was certified as being in calibration.

4.0 TEST RESULTS

4.1 SUMMARRY OF TEST RESULTS

The test results are shown below in tabulated form with additional details concerning tests and results in the following paragraphs. Completed data sheets can be found in Appendix B.

TEST No.	TEST DESCRIPTION	REGULARTORY REFERENCE	TEST RESULT
1.1	**Operation, 60min, 100% Load**	**ABS - 4-2-1/13.9.3.(*I*)**	**SAT**
1.2	**Operation, 30min, 110% Load**	**ABS - 4-2-1/13.9.3(*ii*)**	**SAT**
1.3	**Operation, 4 hr, Various Loads**	**ABS - 4-2-1/15.7**	**SAT**
2.1	**Voltage, +/-2.5% vac of Rated Voltage, 0-100% Load**	**ABS - 4-8-3/3.13.2(*b*)** **ABS - 4-2-1/7.5.1(*d*)** **IEEE - 5.4.1**	**SAT**
2.2	**Voltage, 150% Load**	**ABS - 4-8-3/1.13.2(*c*)** **IEEE - 5.4.2.1**	**SAT**
2.3	**Voltage, 300% Overload**	**ABS - 4-8-3/3.13.2(*d*)** **IEEE - 5.4.1**	**UNSAT**
3.1	**Frequency - 100% - 0% - 50% - 100%**	**ABS - 4-2-1/7.5.1(*a*)*ii*)**	**SAT**
3.2	**Frequency - 0% - 75% - 100% - 25% - 0%**	**IEEE - 5.6**	**SAT**
4.1	**Parallel Operation**	**ABS - 4-2-1/7.5.2** **IEEE - 5.5.1**	**SAT**

SUMMARY OF TEST RESULTS
TABLE 4-1

TEST 1.1 - Test 1.1 is designed to demonstrate the ability of the Sure Power ™system to deliver and maintain full power output for an extended period of time (not less than 60 min). See ABS - 4-2-1/13.9.3(*i*).

During this timed test both the system output voltage remained steady and bus frequency changed a maximum of 0.03 % (0.02 Hz). The unit ran well with no difficulties.

The system complied with this regulation.

TEST 1.2 - Test 1.2 is designed to demonstrate the ability of the Sure Power™ system to deliver 110% (352 kWe) of full power at rated voltage and frequency for at least 30 minutes. See ABS - 4-2-1/13.9.3(*ii*).

During this timed test both the system output voltage remained steady and bus frequency changed a maximum of 0.07 % (0.04 Hz). The unit ran well with no difficulties.

The system complied with this regulation

4.0 TEST RESULTS

TEST 1.3 - Test 1.3 is designed to demonstrate the ability of the Sure Power™ system to deliver power at rated voltage and frequency under various load conditions for at least 4 hours. See ABS - 4-2-1/15.7.

During this timed test, conducted simultaneously with the other testing, both the system output voltage and bus frequency remained steady and at acceptable limits. The unit ran well with no difficulties.

The system complied with this regulation.

TEST 2.1 - Test 2.1 was designed to demonstrate the ability of the Sure Power™ system to maintain voltage stability (+/-2.5% of rated voltage) throughout the rated load range (0 - 100%, 0 - 320kw). See ABS – 4-8-3/3.13.2(*b*), 4.2.1/7.5.1(*d*). and IEEE - 5.4.1.

Maximum deviation was -1 volt or 0.36% of the rated voltage (277 volts). This is below the allowable deviation of +/-7 volts or +/-2.5% of rated voltage.

The fuel cells' voltage was also stable. Fuel cell No. 1 maximum deviation was –1.08%. The No. 2 fuel cell's maximum deviation was –1.44%.

Both the fuel cells and the system are in compliance with this regulation.

TEST 2.2 - Test 2.2 was designed to demonstrate the ability of the Sure Power™ system to accept a large starting load (150% of rated current) and still maintain a steady state condition voltage. See ABS – 4-8-3/3.13.2(*c*) and IEEE-5.4.2.1.

There was no deviation from the rated voltage for the system or the individual cells.

Both the fuel cells and the system are in compliance with these regulations.

TEST 2.3 – Test 2.3 is designed to demonstrate the ability of the Sure Power™ system to deliver power with proper voltage (480 v) during a momentary (2 sec.) overload (300% of rated capacity) (960 kWe). See ABS – 4-8-3/3.13.2(*d*) and IEEE - 5.4.1.

This test was unable to be completed on Thursday March 14 due to the necessity of adjustments to the frequency trip tolerance. The data submitted for this test comes from M Technology.

The three graphs submitted (see Appendix B) show current at the bus, at the power bridge and voltage at the bus. The graphs show a maximum current of 1000 amps at the bus and 1000 amp current at the power bridge. As the transducers saturate at 1000 amps, it is unknown if the system delivered 300% of its rated capacity (960 kWe).

The bus voltage standard deviation for the first two (2) seconds of the saturation level of the test equipment was 58.7 volts.

This would appear not to be in compliance with regulations.

4.0 TEST RESULTS

TEST 3.1 - Test 3.1 is designed to demonstrate the ability of the Sure Power™ system to handle frequency regulation during load changes. See ABS - 4-2-1/7.5.1(a)*i*), 4-2-1/7.5.1(a)*ii*)

As different loads were applied readings were taken at the prescribed times. The bus frequency had a maximum deviation of 0.13% (0.08 Hz) and always to returned to within 0.03% (0.02 Hz) after five (5) seconds.

The system complied with this regulation.

TEST 3.2 - Test 3.2 is designed to demonstrate the ability of the Sure Power™ system to handle frequency regulation during load changes. See IEEE STD 45-1998, 5.6.

As different loads were applied readings were taken at the prescribed times. The bus frequency had a maximum deviation of 0.6% (0.36 Hz) and always to returned to within 0.08% (0.05 Hz) after two (2) seconds.

The system complied with this regulation.

TEST 4.1 - Test 3.1 is designed to demonstrate the ability of the Sure Power™ system's load sharing stability (+/-15% of combined rated power of the generators) throughout the combined rated load range (20 - 100%, 32 - 320kw). See ABS – 4-2-1/7.5.2. and IEEE - 5.5.1.

Throughout all the above tests data was gathered on both fuel cells as well as the system. The fuel cells performed within tolerance on all tests that pertain to this regulation.

The system complied with this regulation.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The Sure Power™ system tested, utilizing two fuel cells met all regulations as they apply to rotating alternating and direct current generators, with the exception of the three hundred percent (300%) overload test (test 2.3).

This test is designed to provide design current/voltage during a massive short circuit in order to show that the system can maintain its physical integrity until it can operate breakers and restore the load to its rated capacity. The first test of this capability failed to reach the time limits as specified in the test plan and as measured and recorded by Mr. M. Perelstein, Strategic Facilities. Later results submitted by M Technology indicate that the test had been performed for the necessary time. The data and graphs show a maximum current of 1000 amps at the bus and 1000 amp current at the power bridge. As the transducers saturate at 1000 amps, the true values and variations were not measured. Therefore it is not known if the system was subjected to a 300% overload.

To clarify this issue, test 2.3 should be performed again. A disinterested third party should make the measurements with equipment of sufficient sensitivity and range to confirm of the system's capability to meet this requirement. Additionally it appears that the systems frequency control, normally configured to provide clean power to sensitive equipment was too restrictive for a typical ship's service electrical power application.

Before adjustments, the sensitivity of the control loop should be revised to provide a broader range of frequency response deviations. However, this should take into account its impact on other frequency tests (i.e.Test Plan No. 3).

This adjustment should be made prior to presenting the system for regulatory acceptance. When the power system is presented to the regulatory bodies, it must operate "seamlessly". While adjustments between tests are accepted, so that all settings may be tuned for optimal system performance, it will not be allowed when the system is presented to regulatory agency for type approval. Once all settings used during the testing are established, they should be retained so that they may be reprogrammed before presentation to a regulatory agency.

Regulations for fuel cells are only now beginning to be published for land based applications. It will most likely be a few years before marine regulations are written. By that time, it is certain that fuel cell orientated marine regulations will have evolved far beyond the current ones. However, the fuel cells, when combined with the rest of the Sure Power™ system appear to be able to comply with existing shipboard electrical regulations, codes and standards.

The Sure Power™ system, utilizing fuel cells, provides environmentally clean power. In addition, it allows enhanced interchangeability of generators. It also provides a stable "clean" source of AC power. It can also provide an equally stable source of DC power. With its power bridge it can maintain an uninterruptible source of power until standby generators can start and be brought on line.

The Sure Power™ system allows integration of generators with different characteristics (voltage, hertz and motive source) on a common power bus by the elimination of paralleling issues. Use of this system would allow a vessel to configure its generating equipment for the most efficient operation, while maintaining a high degree of reliability.

The high quality, purity and dependability of the alternating current bus of this system make it most suitable to vessels that require clean power with high reliability. Typically these vessels include cruise ships, military ships and research ships. Any of these types of vessels would make an excellent platform for future demonstrations.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The use of a direct current bus in a ladder type configuration with this system is extremely promising. Direct current also offers many system advantages such as speed control and starting torque.

Using the Sure Power™ system's power bridge, generators' ratings may be revised as starting loads are absorbed by the flywheel. The greatest benefit in safety is that the emergency bus would be able to maintain constant power and provide an uninterruptible power supply. This would allow key machinery and navigational aids to continue to function during the transition to the stand-by or emergency generator upon the loss of an on line generator.

APPENDIX A

TEST PLANS

TEST PLAN No. 1
SURE POWER™ SYSTEM FREQUENCY REGULATION
AND
REGULATORY ABSTRACTS

The purpose of Test Plan No. 1 is to demonstrate that the Sure Power system can meet ABS and IEEE regulations as they currently apply to A/C generating sets' sustained full power output. Although the regulatory sections quoted are for diesel prime movers, the requirements for other prime movers are identical. This test plan comprises three (3) tests as listed below. At the end of this test plan are the relevant regulations in full detail. All testing should be conducted while maintaining a 0.8 lagging power factor except as noted. Data to be collected and recorded as directed.

TEST - 1.1

PURPOSE:	Test 1.1 is designed to determine the ability of the Sure Power™ system to deliver full power output for an extended amount of time not less than sixty (60) minutes.
SATISFIES:	ABS - 4-2-1/13.9.3(*i*)
STARTING CONDITIONS:	System connected to bus at 75% of system rated output (280 kw).

1) Increase load until it is at 100% of system's rated power (320 kw). After steady state conditions have been reached run for at least 60 minutes. Collect a full set of data every 15 minutes.

TEST - 1.2

PURPOSE:	Test 1.2 is designed to determine the ability of the Sure Power™ system to deliver 110% (352 kw) of full power at rated voltage and frequency for at least thirty (30) minutes.
SATISFIES:	ABS - 4-2-1/13.9.3(*ii*)
STARTING CONDITIONS:	Test No. 1.1 completed, system connected to bus at 100%.

1) Increase load until system is at 110% of rated power (352 kw). After steady state conditions have been reached, run for at least 30 minutes. Collect a full set of data every 15 minutes.

TEST - 1.3

PURPOSE:	Test 1.3 is designed to determine the ability of the Sure Power™ system to deliver power at rated voltage and frequency for at least four hours (4 hrs). This can be carried out while other testing, specifically frequency control, is underway.
SATISFIES:	ABS - 4-2-1/15.7
STARTING CONDITIONS:	Testing underway

1) Collect and record data for all other tests and record any unusual operational characteristics.

REFERENCES

ABS - STEEL VESSELS 2001, 4-2-1/

13.9 Shop Tests of Each Produced Diesel Engine

13.9.3 Engines Driving Electric Propulsion Generators

For engines intended for driving electric propulsion generators the tests are to be performed at rated speed with a constant governor setting under the following conditions:
i) 100% rated power for at least 60 min., after having reached steady conditions.
ii) 110% of rated power for 30 min., after having reached steady conditions.
iii) After running on the test bed, the fuel delivery system of the engine is to be adjusted so that an overload power of 110% of the rated power can be supplied. Due regard being given to service conditions after installation on board and to the governor characteristics including the activation of generator protective devices. See also 4-2-1/7.5.1(b) for governor characteristics associated with power management systems.
iv) 75%, 50% and 25% of rated power and idle run.
v) Start-up tests.
vi) Testing of governor and independent overspeed protective device.
vii) Testing of shutdown device.

13.9.4 Engines Driving Other Generators and Machinery

Engines intended for driving vessel service generators, emergency generators, or other essential machinery are to be tested as specified in 4-2-1/13.9.3. After running on the test bed, the fuel delivery system of the engine is to be adjusted so that an overload power of 110% of the rated power can be supplied. Due regard being given to service conditions after installation on board and to the governor characteristics including the activation of generator protective devices. See also 4-2-1/7.5.1(b) for governor characteristics associated with power management systems.

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15.7 Engines Driving Generators
For engines driving generators for essential services other than propulsion generators, an operation test at rated power for an extended period is to be carried out. For main service generators, the duration of test is to be at least four hours. Governor characteristics associated with power management systems in 4-2-1/7.5.1ii) are to be demonstrated during the vessel's trial.

7.5.1 Speed Governing

Diesel engines driving propulsion, auxiliary or emergency electric generators are to be fitted with an operating governor which is capable of automatically maintaining the speed within the following limits:

ABS - STEEL VESSELS 2001 (cont'd)

7.5.1(a) The momentary speed variations when running at the indicated load is to be within 10% of the rated speed when:

i) running at full load (equal to rated output) of the generator and the full load of the generator is suddenly thrown off;

ii) running at no load and 50% of the full load of the generator is suddenly thrown on, followed by the remaining 50% after an interval sufficient to restore the speed to steady state.

In both cases, the speed is to return to within 1% of the final steady state speed in no more than 5 seconds.

7.5.1(b) Where the electrical power system is fitted with a power management system and sequential starting arrangements, the application of loads in multiple steps of less than 50% of rated load in 4-2-1/7.5.1(a)i) above may be permitted provided it is in accordance with 4-2-1/Figure 5. The details of the power management system and sequential starting arrangements are to be submitted and its satisfactory operation is to be demonstrated to the Surveyor.

7.5.1(c) For diesel engines driving emergency generators, the requirements of 4-2-1/7.5.1(a)i) and, where applicable, 4-2-1/7.5.1(a)ii) above are to be met. In addition, if the sum of the emergency load that can be automatically connected is more than: in the case of 4-2-1/7.5.1(a)i), 50 % of the full load of the generator, or in the case of 4-2-1/7.5.1(a)ii), the first applied load permitted by 4-2-1/Figure 5, the sum of the emergency loads is to be used as the first applied load.

7.5.1(d) The permanent speed variation is to be within 5% of the rated speed at any load between no load and the full load.

4-8-3/3.13 Generator Control

3.13.1 Operating Governors

An operating governor is to be fitted to each prime mover driving main or emergency generator and is to be capable of automatically maintaining the speed within the following limits.

*3.13.1(a) Steam or gas turbine prime mover*s:

i) The momentary speed variations when running at full load (equal to rated output) is to be within 10% of the rated speed when:

- the full load of the generator is suddenly thrown off;
- 50% of the full load of the generator is suddenly thrown on, and
- followed by the remaining 50% after an interval sufficient to restore the speed to steady state.

In all three cases, the speed is to return to within 1% of the final steady state speed in no more than 5 seconds.

ii) The steady state speed variation is to be within 5% of the rated speed at any load between no load and the full load.

TEST PLAN No. 2
SURE POWER™ SYSTEM VOLTAGE REGULATION
AND
REGULATORY ABSTRACTS

The purpose of Test Plan No. 2 is to demonstrate that the Sure Power™ system can meet ABS and IEEE regulations as they currently apply to A/C generating sets' voltage regulation on ships. Test plan 1 is comprised of three (3) tests as listed below. At the end of this test plan are the relevant regulations in full detail. All testing should be conducted while maintaining a 0.8 lagging power factor except as noted. Voltage and time is to be recorded immediately upon load application and after a stabile state has been reached.

TEST - 2.1

PURPOSE:	Test 2.1 is designed to determine the ability of the Sure Power™ system to maintain voltage stability (+/-2.5% of rated voltage) through out the rated load range (0 - 100%, 0 - 320kw).
SATISFIES:	ABS – 4-8-3/3.13.2(*b*), 4-2-1/7.5.1(*d*), and IEEE - 5.4.1
STARTING CONDITIONS:	System at idle (0 kw) connected to bus.

1) With system at no load , record voltage and frequency for listed locations.

2) Increase load to 10% (32 kw) and record voltage and time immediately upon application of load and after steady state has been reached.

3) Continue increasing load in 10% (32 kw) increments until 100% (320 kw) of rated load is reached. Record as above.

TEST - 2.2

PURPOSE:	Test 2.2 is designed to determine the ability of the Sure Power™ system to accept a large starting load (150% of rated current) and still maintain a steady state condition voltage.
SATISFIES:	ABS – 4-8-3/3.13.2(*c*) and IEEE - 5.4.2.1
STARTING CONDITIONS:	System connected to bus at no load (0 kw).

1) With the system at no load output apply a load of 150% (720 amps) of rated current (480 amps) at a 0.4 lagging power factor. Record voltage just prior to application of load and 1.5 seconds after load is applied.

2) After system has stabilized at the above loading condition, record voltage. Remove all load and record voltage again 1.5 seconds after the load has been removed.

TEST PLAN No. 2
SURE POWER™ SYSTEM VOLTAGE REGULATION
AND
REGULATORY ABSTRACTS

TEST - 2.3

PURPOSE:	Test 2.3 is designed to determine the ability of the Sure Power™ system to deliver power with proper voltage (480 v) during a momentary (2 sec.) overload (300% of rated capacity) (960 kw).
SATISFIES:	ABS – 4-8-3/3.13.2(*d*) and IEEE - 5.4.1.
STARTING CONDITIONS:	System connected to bus with 100 kw load.

1) Increase load to 300% (960kw) of system's output for two (2) seconds. Record voltage and amperage at application of load and at a two (2) second limit.

TEST PLAN No. 2
SURE POWER™ SYSTEM VOLTAGE REGULATION
AND
REGULATORY ABSTRACTS

REFERENCES

ABS - STEEL VESSELS 2001, 4-8-3/

3.13.2 Automatic Voltage Regulation System
The following requirements are for AC generators. For DC generators, refer to IEC Publications 60092-202 and -301.

*3.13.2(a) Genera*l. An automatic voltage regulator is to be fitted for each generator. Excitation current for generators is to be provided by attached rotating exciters or by static exciters deriving their source of power from the machines being controlled.

*3.13.2(b) Variation from rated voltage – steady stat*e. The automatic voltage regulator is to be capable of maintaining the voltage under steady conditions within ±2.5% of the rated voltage for all loads between zero and rated load at rated power factor, taking the governor characteristics of generator prime movers into account. These limits may be increased to ±3.5% for generators for emergency services.

*3.13.2(c) Variation from rated voltage – transien*t. Momentary voltage variations are to be within the range of -15% to +20% of the rated voltage, and the voltage is to be restored to within ±3% of the rated voltage in not more than 1.5 seconds when:
a load equals to the starting current of the largest motor or a group of motors, but in any case, at least 60% of the rated current of the generator, and power factor of 0.4 lagging or less, is suddenly thrown on with the generator running at no load; and
a load equal to the above is suddenly thrown off.

*3.13.2(d) Short circuit conditio*n. Under short circuit conditions, the excitation system is to be capable of maintaining a steady-state short circuit current for 2 seconds or for such magnitude and duration as required to properly actuating the electrical protective devices. See 4-8-3/3.9.

3.9 *Short Circuit Capability* Short circuit capabilities of generators are to be in accordance with IEC Publication 60034-1. Under short circuit conditions, generators are to be capable of withstanding the mechanical and thermal stresses induced by short circuit current of at least three times the full load current for at least 2 seconds.

4.2.1/7.5.1(d) The permanent speed variation is to be within 5% of the rated speed at any load between no load and the full load.

IEEE Std 45-1998

5.4.1 General

Separate voltage regulators should be provided for each generator. Voltage regulation should be automatic and should function under steady-state load conditions between 0% and 100% load at all power factors that can occur in normal use. Voltage regulators should be capable of maintaining the voltage within the range of 97.5% to 102.5% of the rated voltage. A means of adjustment should be provided for the voltage regulator circuit. Voltage regulators should be capable of withstanding shipboard conditions and should be designed to be unaffected by normal machinery space vibration. Under overload or short circuit conditions, the generator and voltage regulator together with the prime mover and excitation system should be capable of maintaining a current of such magnitude and duration as required to properly actuate the associated electrical protective devices, with a value of not less than 300% of generator full-load current for a duration of 2 s, or of such additional magnitude and duration as required to properly actuate the associated protective circuit breakers.

5.4.2.1 Main or ship service generators

For single-generator operation (no reactive droop compensation), the steady-state voltage for any increasing or decreasing load between zero and full load at rated power factor under steady-state operation should not vary at any point more than ±2.5% of rated generator voltage.
Under transient conditions, when the generator is driven at rated speed at its rated voltage, and is subjected to a sudden change of symmetrical load within the limits of specified current and power factor, the voltage should not fall below 88% nor exceed 112% of the rated voltage. The voltage should then be restored to within ±2.5% of the rated voltage in not more than 1.5 s. In the absence of precise information concerning the maximum values of the sudden loads, the following conditions should be assumed: 150% of rated current with a power factor of between 0.4 lagging and zero to be applied with the generator running at no-load, and then removed after steady-state conditions have been reached.

TEST PLAN No. 3
SURE POWER™ SYSTEM FREQUENCY REGULATION
AND
REGULATORY ABSTRACTS

The purpose of Test Plan No. 3 is to demonstrate that the Sure Power system can meet ABS and IEEE regulations as they currently apply to A/C generating sets' frequency response and regulation on ships. Although the regulatory sections quoted are for diesel prime movers, the requirements for other prime movers are identical. The test plan is comprised of two (2) tests as listed below. At the end of this test plan are the relevant regulations in full detail. All testing should be conducted while maintaining a 0.8 lagging power factor except as noted. Frequency and time is to be recorded immediately upon load application and after a steady state condition has been reached.

TEST - 3.1

PURPOSE: Test 3.1 is designed to determine the ability of the Sure Power™ system handle frequency regulation during load changes.

SATISFIES: ABS - 4-2-1/7.5.1(a)*i*), 4-2-1/7.5.1(a)*ii*)

STARTING CONDITIONS: System at 100% output on bus.

1) With system at 100% of rated power (320 kw), remove all load. Record maximum frequency deviation. After 5 seconds record frequency again.

2) With system at idle (0 kw) but connected to the bus apply 50% (160 kw) of the rated full load capacity of the system. Record maximum frequency deviation. After 5 seconds record frequency again.

3) After frequency and system has reached a steady state condition from application of above load (160 kw) apply the remaining 50% (160 kw) of rated full load capacity. Record maximum frequency deviation. After 5 seconds record frequency again.

TEST - 3.2

PURPOSE: Test 3.2 is designed to determine the ability of the Sure Power™ system to handle frequency regulation during load changes.

SATISFIES: IEEE STD 45-1998, 5.6

STARTING CONDITIONS: System connected to bus at 0% (0 kw) load.

1) With the system at idle 0% (0 kw) but connected to the bus apply 75% (240 kw) of the rated full load capacity of the system. Record maximum frequency deviation. After 2 seconds record frequency again.

2) After frequency and system have reached a steady state from application of above load apply the remaining 25% (80 kw) of rated full load capacity. Record maximum frequency deviation. After 5 seconds record frequency again.

TEST - 3.2 (continued)

3) After bus frequency and system have reached a steady state condition, remove 75% (240 kw) of rated full load capacity. Record maximum frequency deviation. After 2 seconds record frequency again.

4) After frequency and system has reached a steady state from application of above load remove the remaining 25% (80 kw) of rated full load capacity. Record maximum frequency deviation. After 5 seconds record frequency a gain.

REFERENCES

ABS - STEEL VESSELS 2001, 4-2-1/

7.5.1 Speed Governing

Diesel engines driving propulsion, auxiliary or emergency electric generators are to be fitted with an operating governor which is capable of automatically maintaining the speed within the following limits:

7.5.1(a) The momentary speed variations when running at the indicated load is to be within 10% of the rated speed when:

i) running at full load (equal to rated output) of the generator and the full load of the generator is suddenly thrown off;

ii) running at no load and 50% of the full load of the generator is suddenly thrown on, followed by the remaining 50% after an interval sufficient to restore the speed to steady state.

In both cases, the speed is to return to within 1% of the final steady state speed in no more than 5 seconds.

7.5.1(b) Where the electrical power system is fitted with a power management system and sequential starting arrangements, the application of loads in multiple steps of less than 50% of rated load in 4-2-1/7.5.1(a)i) above may be permitted provided it is in accordance with 4-2-1/Figure 5. The details of the power management system and sequential starting arrangements are to be submitted and its satisfactory operation is to be demonstrated to the Surveyor.

7.5.1(c) For diesel engines driving emergency generators, the requirements of 4-2-1/7.5.1(a)i) and, where applicable, 4-2-1/7.5.1(a)ii) above are to be met. In addition, if the sum of the emergency load that can be automatically connected is more than: in the case of 4-2-1/7.5.1(a)i), 50 % of the full load of the generator, or in the case of 4-2-1/7.5.1(a)ii), the first applied load permitted by 4-2-1/Figure 5, the sum of the emergency loads is to be used as the first applied load.

7.5.1(d) The permanent speed variation is to be within 5% of the rated speed at any load between no load and the full load.

ABS - STEEL VESSELS 2001 (cont'd)

4-8-3/3.13 Generator Control

3.13.1 Operating Governors

An operating governor is to be fitted to each prime mover driving main or emergency generator and is to be capable of automatically maintaining the speed within the following limits.

*3.13.1(a) Steam or gas turbine prime mover*s:

i) The momentary speed variations when running at full load (equal to rated output) is to be within 10% of the rated speed when:

- the full load of the generator is suddenly thrown off;
- 50% of the full load of the generator is suddenly thrown on, and
- followed by the remaining 50% after an interval sufficient to restore the speed to steady state.

In all three cases, the speed is to return to within 1% of the final steady state speed in no more than 5 seconds.

ii) The steady state speed variation is to be within 5% of the rated speed at any load between no load and the full load.

iii) For emergency generators, the requirements of 4-8-3/3.13.1(a)i) and 4-8-3/3.13.1(a)ii) above are to be met. However, for purpose of 4-8-3/3.13.1(a)i), where the sum of all loads that can be automatically connected is larger than 50 % of the full load of the emergency generator, the sum of these loads is to be used.

*3.13.1(b) Diesel engine prime move*r:

i) The momentary speed variations when running at full load (equal to rated output) is to be within 10% of the rated speed when:

- the full load of the generator is suddenly thrown off;
- 50% of the full load of the generator is suddenly thrown on, and
- followed by the remaining 50% after an interval sufficient to restore the speed to steady state.

In all three cases, the speed is to return to within 1% of the final steady state speed in no more than 5 seconds. Considerations can be given to alternative method of load application as provided in 4-2-1/7.5.1ii) for electrical systems fitted with power management systems and sequential starting arrangements.

ii) The steady speed variation is to be within 5% of the rated speed at any load between no load and the full load.

iii) For emergency generators, the requirements of 4-8-3/3.13.1(b)i) and 4-8-3/3.13.1(b)ii) above are to be met. However, for purpose of 4-8-3/3.13.1(b)i), where the sum of all loads that can be automatically connected is larger than 50 % of the full load of the emergency generator, the sum of these loads is to be used.

TEST PLAN No. 3
SURE POWER™ SYSTEM FREQUENCY REGULATION
AND
REGULATORY ABSTRACTS

IEEE STD 45-1998

5.6 Prime movers

Each prime mover should be fitted with an efficient speed regulating governor as well as an automatic overspeed trip. The automatic overspeed trip should function to shut down the unit automatically when the speed exceeds the designed maximum service speed by more than 15%. The overspeed trip should also be equipped with a means for manual tripping. Each prime mover should, in addition, be under control of an efficient operating governor capable of limiting the speed, when full load is suddenly removed, to at least 5% less than that of the overspeed trip setting. The prime mover and regulating governor should also limit the momentary speed variation to 5.5% of the rated speed when 75% of the rated load of the generator is suddenly applied followed by the remaining 25% after an interval sufficient to restore the speed to steady state. The speed should return to within 1% of the final steady-state speed as follows:

IEEE STD 45-1998 (continued)

5.6 Prime movers

Load Response	Time	Speed Deviation
±75%	2.0 s	5.5%
±100%	5.0 s	7.5%

Emergency generator sets should accept 100% rated kilowatt load in one step. All sets of 100 kW capacity and above should be provided with a coupling fitted to the rotor or armature shaft. Each generator should be driven by a separate prime mover that, if used to drive other auxiliary loads, should have sufficient capacity for the total load, unless it is not possible to use the generator and the other auxiliary load simultaneously. Generating sets that operate in parallel should be provided with a switch that trips the generator circuit breaker when the overspeed device is actuated.

Table 4-1–Alternating current (ac) power characteristics (low-voltage systems)

Characteristics Limits	Frequency
a) Nominal frequency	50/60 Hz
b) Frequency tolerances	±3%
c) Frequency modulation	½%
d) Frequency transient:	
1) Tolerance	±4%
2) Recovery time	2 s
e) The worst-case frequency excursion from nominal frequency resulting from b), c), and d)1) combined, except under emergency conditions.	±5 ½%

TEST PLAN No. 3
SURE POWER™ SYSTEM FREQUENCY REGULATION
AND
REGULATORY ABSTRACTS

Voltage	
a) User voltage tolerance:	
1) Average of the three line-to-line voltages	±5%
2) Any one line-to-line voltage, including a)1) and line voltages unbalances b)	±7%
b) Line voltage unbalance	3%
c) Voltage modulation	5%
d) Voltage transient:	
1) Voltage transient tolerances	±16%
2) Voltage transient recovery time	2 s
e) Voltage spike (peak value includes fundamental)	±2500 V (380–600 V) system; 1000 V (120–240 V) system.
f) The maximum departure voltage resulting from a)1) and d) combined, except under transient or emergency conditions.	±6%
g) The worst case voltage excursion from nominal user voltage resulting from a)1), a)2), and d)1) combined, except under emergency conditions.	±20%
Waveform voltage distortion	
a) Maximum total harmonic distortion	5%
b) Maximum single harmonic	3%
c) Maximum deviation factor	5%
Emergency conditions	
a) Frequency excursion	–100 to +12%
b) Duration of frequency excursion	Up to 2 min
c) Voltage excursion	–100 to +35%
d) Duration of voltage excursion:	
1) Lower limits (–100%)	Up to 2 min
2) Upper limit (+35%)	2 min

TEST PLAN No. 4
FUEL CELL PARALLEL OPERATION REGULATION

The purpose of Test Plan No. 4 is to demonstrate that the Sure Power™ system can meet ABS and IEEE regulations as they currently apply to A/C generating sets' parallel operation regulation on ships. Although the regulatory sections quoted are for diesel prime movers, the requirements for other prime movers are identical. The test plan is comprised of one (1) test as listed below. At the end of this test plan are the relevant regulations in full detail. All testing should be conducted while maintaining a 0.8 lagging power factor except as noted. Frequency and time is to be recorded immediately upon load application and after a steady state condition has been reached.

TEST - 4.1

PURPOSE:	Test 4.1 is designed to determine the ability of the Sure Power™ system to demonstrate load sharing stability (+/-15% of combined rated power of the generators) through out the combined rated load range (20 - 100%, 32 - 320kw).
SATISFIES:	ABS – 4-2-1/7.5.2 and IEEE - 5.5.1
STARTING CONDITIONS:	Both cells and paralleling source connected to bus at 75% of combined rated load.

1) Using Test Plan Data Sheet 4.1 and system at above load record kilowatts, voltage and amperage of both the system and the paralleling source generators.

2) Decrease load to 20% of combined power output and record kilowatts, voltage, and amperage of both the sure power system and the paralleling source.

3) Increase load by 10% of combined power output and record voltage and time immediately upon application of load after steady state has been reached for both the Sure Power system and the paralleling source.

4) Keep increasing load by 10% increments until 100% of the combined rating is reached. Record as above.

TEST PLAN No. 4
FUEL CELL PARALLEL OPERATION REGULATION

REFERENCES

ABS STEEL VESSELS 2001, 4-2-1/

7.5.2 Generators in Parallel
For diesel engines driving AC generators that operate in parallel, the governor's characteristics are to be such that in the range between 20% and 100% of the combined rated load of all generators, the load on any individual generator will not differ from its proportionate share of the total combined load by more than 15% of the rated power of the largest generator or 25% of the individual generator, whichever is less. Provisions are to be made to adjust the governors sufficiently fine in order to permit a load adjustment within the limits of 5% of the rated load at normal frequency.

IEEE STD 45-1998

5.4.2.1 Main or ship service generators

For single-generator operation (no reactive droop compensation), the steady-state voltage for any increasing or decreasing load between zero and full load at rated power factor under steady-state operation should not vary at any point more than ±2.5% of rated generator voltage.

Under transient conditions, when the generator is driven at rated speed at its rated voltage, and is subjected to a sudden change of symmetrical load within the limits of specified current and power factor, the voltage should not fall below 88% nor exceed 112% of the rated voltage. The voltage should then be restored to within ±2.5% of the rated voltage in not more than 1.5 s. In the absence of precise information concerning the maximum values of the sudden loads, the following conditions should be assumed: 150% of rated current with a power factor of between 0.4 lagging and zero to be applied with the generator running at no-load, and then removed after steady-state conditions have been reached.

For two or more generators with reactive droop compensation, the reactive droop compensation should be adjusted for a voltage droop of no more than 4% of rated voltage for a generator. The system performance should then be such that the average curve drawn through a plot of the steady-state voltage vs. load for any increasing or decreasing load between zero and full load at rated power factor, droops no more than 4% of rated voltage and no recorded point varies more than ±1% of rated generator voltage from the average curve.

Isochronous operation of a single generator operating alone is acceptable. However, where two or more generators are arranged to operate in parallel, only one machine should be operating in the isochronous mode unless voltage regulation with isochronous cross-current compensation reactive load-sharing capabilities are provided. Care should be taken when operating machines in parallel in the droop/isochronous modes to ensure that the system minimum load does not decrease below the output set point of the droop machine(s), as this may cause a frequency change in the system and the machine operating in the isochronous mode to motor.

5.5 Parallel operation

5.5.1 General

Generating sets should be capable of operating successfully in parallel. Successful parallel operation is attained if the load on any generator does not differ by more than ±15% of its proportionate share of the combined kilowatt load, based on generator ratings, for any steady-state condition of the combined load
IEEE 5.5.1 (continued)

between 20% and 100% of the sum of the rated loads of all the generators. The starting point for determination of the foregoing load distribution requirements should be at 75% load with each generator carrying its proportionate share.

When tests are made to determine if successful parallel operation of dc generating sets is obtained, the following should be met:

a) The generators should be at normal operating temperatures.
b) The speed of the generators should be constant or slightly decreasing with increase in load with the change in speed approximately proportional to load.
c) For compound-wound dc machines, series field equalizer connections should be provided.

The ratio of the resistance of the equalizer connections to the resistance of the series field and its connection, both to the point of paralleling, should be no more than 0.5. In no case should the cross-sectional area of the longest equalizer conductor from a generator be less than the cross-sectional area of the generator’s main power conductors.

APPENDIX B

TEST DATA RESULT

TEST PLAN DATA SHEET 1.1
100% LOAD - TIME TEST
FREQUENCY REGULATION

RATED OUTPUT CONDITIONS - ABS - 4-2-1/13.9.3*(i)*

TEST LOAD	SYSTEM			No. 1 Fuel Cell			No. 2 Fuel Cell		
OUTPUT	OUTPUT	OUTPUT	FREQUENCY	CELL STACK	OUTPUT	OUTPUT VOLTAGE	CELL STACK	OUTPUT	OUTPUT VOLTAGE
100% / (320kw)	AC Volts	Frequency (Hz)	% Deviation*	DC Volts	AC Volts	% Deviation*	DC Volts	AC Volts	% Deviation*
Start	278	60.00	0.00	164	276	-0.36	162	275	-0.72
15 Minutes	277	59.98	-0.03	170	276	-0.36	175	275	-0.72
30 Minutes	277	59.92	-0.13	170	275	-0.72	176	274	-1.08
45 Minutes	278	59.93	-0.12	165	277	0.00	175	277	0.00
60 Munites	278	60.00	0.00	168	276	-0.36	175	275	-0.72

* Deviation from 60 Hz

TEST PLAN DATA SHEET 1.2
110% LOAD TESTS
FREQUENCY REGULATION

OVERLOAD CONDITIONS - ABS - 4-2-1/13.9.3*(ii)*

TEST LOAD	SYSTEM			No. 1 Fuel Cell			No. 2 Fuel Cell		
OUTPUT	OUTPUT	OUTPUT	FREQUENCY	CELL STACK	OUTPUT	OUTPUT VOLTAGE	CELL STACK	OUTPUT	OUTPUT VOLTAGE
110% / (352kw)	AC Volts	Frequency (Hz)	% Deviation*	DC Volts	AC Volts	% Deviation*	DC Volts	AC Volts	% Deviation*
Start	276	59.96	-0.07	167	277	0.00	159	277	0.00
15 Minutes	278	60.03	0.05	166	277	0.00	159	277	0.00
30 Minutes	277	59.98	-0.03	165	276	-0.36	159	275	-0.72

* Deviation from 60 Hz

TEST PLAN DATA SHEET 2.1
VOLTAGE REGULATION
LOAD RANGE VOLTAGE DEVIATIONS

RATED LOAD RANGE - ABS - 4.8.3/3.13.2(*b*), 4.2.1/7.5.1(*d*) and IEEE - 5.4.1

LOAD SETTING % / (kWe)	SYSTEM		No. 1 Fuel Cell			No. 2 Fuel Cell		
	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*	CELL STACK DC Volts	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*	CELL STACK DC Volts	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*
IDLE	278	0.36	176.7	278	0.36	174	276	-0.36
10% / (32kw)	277	0.00	173.2	278	0.36	170.3	276	-0.36
20% / (64kw)	278	0.36	175.4	276	-0.36	168.9	275	-0.72
30% / (96kw)	278	0.36	175.1	275	-0.72	168.1	275	-0.72
40% / (128kw)	278	0.36	175.3	278	0.36	172.1	274	-1.08
50% / (160kw)	278	0.36	173.7	274	-1.08	171.8	275	-0.72
60% / (192kw)	278	0.36	172.9	277	0.00	169.8	276	-0.36
70% / (224kw)	278	0.36	171.2	276	-0.36	168.4	274	-1.08
80% / (256kw)	277	0.00	169.1	275	-0.72	166.5	277	0.00
90% / (288 kw)	277	0.00	167.2	280	1.08	168.8	276	-0.36
100% / (320kw)	278	0.36	168.4	274	-1.08	164.2	273	-1.44

* Deviation from rated voltage

TEST PLAN DATA SHEET 2.2
VOLTAGE REGULATION
TRANSIENT LOAD CONDITIONS

LARGE STARTING LOAD - ABS - 4.8.3/3.13.2(*c*) and IEEE - 5.4.2.1

SYSTEM				No. 1 Fuel Cell			No. 2 Fuel Cell		
OUTPUT Load kw	LOAD AMPS 0.4 Lagging PF	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*	CELL STACK DC Volts	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*	CELL STACK DC Volts	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*
0		278	0.36	175.9	278	0.36	174.5	277	0.00
+ 150% @ 1.5 Sec.	640KVA@.4 PF(550KVAR)	278	0.36	173.5	277	0.00		277	0.00
150% Stabilized		278	0.36	163	277	0.00		276	-0.36
0% @ 1.5 Sec.		278	0.36	178	277	0.00		277	0.00

* Deviation from rated voltage

TEST PLAN DATA SHEET 2.3
VOLTAGE REGULATION
OVERLOAD CONDITIONS

LARGE STARTING LOAD - ABS - 4.8.3/3.13.2(*d*) and IEEE - 5.4.1

SYSTEM				No. 1 Fuel Cell			No. 2 Fuel Cell		
OUTPUT Load kw	LOAD Amps	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*	CELL STACK DC Volts	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*	CELL STACK DC Volts	OUTPUT AC Volts	OUTPUT VOLTAGE % Deviation*
320 kw									
960kw @ 2 Sec.									

* Deviation from rated voltage

TEST PLAN DATA SHEET 3.1
LOAD CHANGES
FREQUENCY REGULATION

LOAD CHANGE - ABS - 4-2-1/75.5.1(a)*i*), 4-2-1/7.5.1(a)*ii*)

TEST LOAD	SYSTEM			No. 1 Fuel Cell			No. 2 Fuel Cell		
OUTPUT	OUTPUT	OUTPUT	FREQUENCY	CELL STACK	OUTPUT	OUTPUT VOLTAGE	CELL STACK	OUTPUT	OUTPUT VOLTAGE
Load kw	AC Volts	Frequency (Hz)	% Deviation*	DC Volts	AC Volts	% Deviation*	DC Volts	AC Volts	% Deviation*
100% / (320kw)	278	60.08	0.13		278	0.36	162.3	277	0.00
0 kw	278	60.06	0.10		277	0.00	175	276	-0.36
0 kw @ 5 Sec.	278	60.00	0.00		277	0.00	171.6	276	-0.36
0 kw	278	60.00	0.00		276	-0.36	177	276	-0.36
160kw	276	59.94	-0.10		275	-0.72	171	275	-0.72
160kw @ 5 Sec.	278	59.98	-0.03		276	-0.36	173	277	0.00
160kw	278	60.08	0.13		278	0.36	167	274	-1.08
320kw	276	59.98	-0.03		272	-1.81	167	272	-1.81
320kw @ 5 Sec.	278	60.03	0.05		277	0.00	162.5	274	-1.08

* Deviation from 60 Hz

TEST PLAN DATA SHEET 3.2
LOAD CHANGES
FREQUENCY REGULATION

LOAD CHANGE - IEEE STD 45-1998, 5.6

TEST LOAD	SYSTEM			No. 1 Fuel Cell			No. 2 Fuel Cell		
OUTPUT	**OUTPUT**	**OUTPUT**	**FREQUENCY**	**CELL STACK**	**OUTPUT**	**OUTPUT VOLTAGE**	**CELL STACK**	**OUTPUT**	**OUTPUT VOLTAGE**
Load kw	**AC Volts**	**Frequency (Hz)**	**% Deviation***	**DC Volts**	**AC Volts**	**% Deviation***	**DC Volts**	**AC Volts**	**% Deviation***
0	278	60.06	0.10	177	278	0.36	174.3	277	0.00
240 kW	277	60.36	0.60	160	277	0.00		276	-0.36
240 kw @ 2 Sec.	278	59.98	-0.03	174	275	-0.72		275	-0.72
320 kW	278	59.98	-0.03	170	277	0.00		276	-0.36
320 kw @ 5 Sec.	278	60.00	0.00	165	275	-0.72		276	-0.36
80kw	279	60.03	0.05	177	278	0.36		278	0.36
80 kw @ 2 Sec.	278	59.95	-0.08	181	278	0.36		277	0.00
0	279	60.20	0.33	183	275	-0.72		276	-0.36
0kw @ 5 Sec.	278	60.03	0.05	178	278	0.36		276	-0.36

* Deviation from 60 Hz