AD-A164 742 TEST RESULTS FOR THE 25-KVA GROUND FAULT DETECTOR(U) 1/1
NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA L TUCKER
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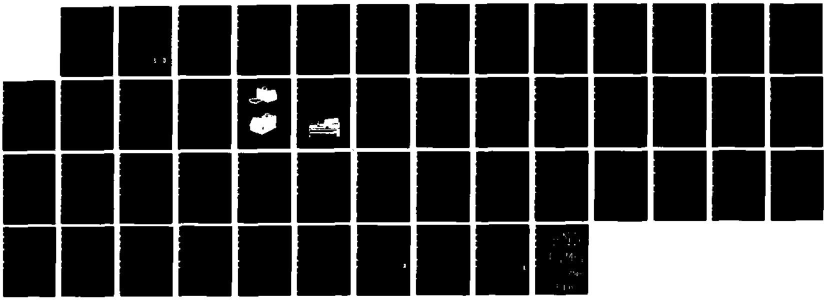

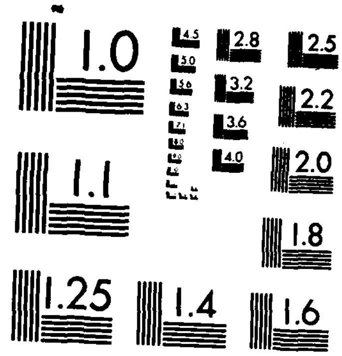
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N-1734R

NCEL Technical Note

January 1986
By L. Tucker
Sponsored By Naval Sea Systems Command

AD-A164 742

TEST RESULTS FOR THE 2.5-kVA GROUND FAULT DETECTOR

Divers using electrical equipment are exposed to shock hazards. The Naval Civil Engineering Laboratory (NCEL) tested commercially available ground fault protection devices designed for terrestrial use and found that none of them met Navy BUMED criteria for protection against electrical shock. The objective of this development was to meet the BUMED criteria using the most desirable features of current technology. NCEL developed a prototype system that detects low-level current (less than 5 mA) and terminates the current flow within 10 msec, a requirement inferred from the BUMED criteria.

This report replaces TN-1734.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

METRIC CONVERSION FACTORS

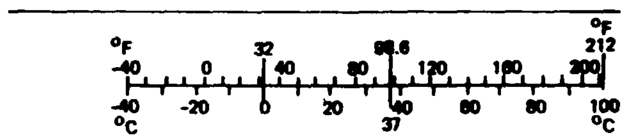
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Ground fault, GFI, electrical safety, electrical shock hazards, underwater electrical shock, diver electrical safety, diver safety, power transmission

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Divers using electrical equipment are exposed to shock hazards. The Naval Civil Engineering Laboratory (NCEL) tested commercially available ground fault protection devices designed for terrestrial use and found that none of them met Navy BUMED criteria for protection against electrical shock. The objective of this development was to meet the BUMED criteria using the most desirable features of current technology. NCEL developed a prototype system that detects low-level current (less than 5 mA) and terminates the current flow

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20. Continued

within 10 msec, a requirement inferred from the BUMED criteria.

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1. Ground fault   2. Electrical shock hazards   I. 43-064

Divers using electrical equipment are exposed to shock hazards. The Naval Civil Engineering Laboratory (NCEL) tested commercially available ground fault protection devices designed for terrestrial use and found that none of them met Navy BUMED criteria for protection against electrical shock. The objective of this development was to meet the BUMED criteria using the most desirable features of current technology. NCEL developed a prototype system that detects low-level current (less than 5 mA) and terminates the current flow within 10 msec, a requirement inferred from the BUMED criteria.

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CONTENTS

INTRODUCTION

Electrical power is being used by divers to provide lighting, vehicle propulsion, electric arc welding and, more recently, television and underwater inspection. Fortunately, reported accidents due to these uses have been limited to minor shocks; the number of such reports has been small when compared to diving accidents due to other causes. However, as the demand for use of electricity grows and the system power levels increase, the potential hazards of using electricity underwater must be addressed. This increased demand for electrical power can be met safely by the use of properly designed ground fault detection systems.

To help meet this need, the Naval Civil Engineering Laboratory (NCEL), under the sponsorship of the Naval Sea Systems Command and the Naval Facilities Engineering Command, conducted an extensive evaluation of commercially available ground fault detection devices. The basic criteria against which the devices were tested were established by the Navy Bureau of Medicine and Surgery (BUMED) and promulgated in ltr ser 0819023 of Aug 1980 (Subj: Underwater Electrical Safety). The ground fault devices tested were designed for terrestrial use and did not meet the established criteria for the protection of divers using submerged power systems. Therefore, the objective of this development was to meet the BUMED criteria using the most desirable features of current technology. The BUMED criteria for the maximum design limits to which personnel may be exposed while working in the underwater environment are as follows:

Direct Current:	30 mA for 50 msec
Alternating Current:	5 mA for 50 msec

The development of a prototype ground fault detection system continued under the sponsorship of the Naval Sea Systems Command. The NCEL prototype ground fault detection system was subjected to an extensive test and evaluation program. This report presents the results of the NCEL prototype development and the test and evaluation program.

PROTOTYPE DEVELOPMENT

Design Goals

The protection of a diver from electrical shock hazards in accordance with the BUMED criteria can be accomplished by several methods. One way is to limit the current output of the power supply to the maximum values set by BUMED (5 mA AC, 30 mA DC). A second method would restrict the maximum system voltage to a level that could not deliver a current through the diver's body greater than the BUMED limits based on a limb-to-limb impedance of 500 ohms. During the concept evaluation stage for the NCEL ground fault detection system, however, it was determined that both of these methods severely limit the development of useful power transmission systems (Ref 1). The concept selected for development allows the use of standard distribution system voltage levels, maximizes the use of off-the-shelf components, and protects the diver from electrical shock when working with equipment powered from the ground fault detection system.

A set of design goals was developed based upon the evaluation of a laboratory model of the 2.5-kVA ground fault detection system.

- Provide power for loads up to 2.5 kVA
- Initiate shutdown on ground fault currents of less than 5 mA AC and 30 mA DC
- Shut down power to the load in 10 msec or less
- Provide capability to detect the first ground fault on the load side of the system
- Electrically isolate the load voltage from the supply side
- Provide a path to dissipate stored energy from the system upon shutdown
- Include fail safe features in the electronic circuit design
- Eliminate nuisance tripping
- Provide system overload protection for load currents greater than 20 amperes for periods longer than 0.5 second

System Design

A contract was awarded to MODUMEND, Inc., West Lake Village, Calif., to design and build a prototype ground fault detection system based on the data from the NCEL 6.2 program. The schematic diagram (Figure 1) and Figures 2 and 3 show the prototype 2.5-kVA Single Phase Ground Fault Detector as delivered by the contractor. The system comprises five subsystems.

Power Control. To insure that the system can be turned off in less than 10 msec, a pair of solid state relays (SSR) was selected for the on/off power control. The SSRs are turned on by applying a 4- to 32-VDC signal to the control terminals. They turn off when the DC signal is removed and the load current passes through a zero crossing. The current in a 60-Hertz power system has a zero crossing every half cycle or 8.333 msec; therefore, the load can be turned off in less than 10 msec. Isolation of the supply voltage from the load side is achieved by the transformer T1.

Overload Control. To protect the system from excessive load currents, a transformer (T2) is connected to sense the current flow in the primary of the isolation transformer (T1). The output of T2 is rectified and fed to a voltage divider consisting of R6 and the potentiometer R5. When the load current exceeds 20 amperes, the output of the voltage divider turns on transistor Q6 and the control voltage to the SSRs is turned off. Under normal operating conditions the circuit is set to trip if the load current exceeds 20 amperes for longer than 0.5 second. The delay, set by the RC circuit of C2 and R7, allows loads such as electric motors, which draw five or six times their rated current during startup, to be operated without nuisance tripping.

VDC Power Supply. The primary of transformer T3 is connected to the supply side of the 120-VAC line. The output of T3 is rectified, filtered, and clamped at approximately 145 VDC by zener diode CR19. The negative side of the DC supply is connected to chassis ground and to the ground terminal of the power output plug. The positive side of the supply is connected to the electronic circuit common and indirectly to the load power lines. A comparator circuit consisting of the operational amplifier U2 and transistor Q8 monitor the output of the supply. If for any reason the supply voltage drops below 130 VDC, transistor Q8 is turned off, which turns off the control voltage to the SSRs and shuts down the system.

Ground Fault Detection. The positive side of the 145-VDC supply is connected to the load power lines through a network of resistors and diodes. The resistive network serves two purposes. First, if the ground fault is a direct short from one of the 120-VAC lines to seawater, resistors R11, R13, R14, or R16 would limit the DC current from the 145-VDC supply to a maximum of 4 mA. Second, resistors R12 and R15 combine with R11, R13, R14, and R16 to form a voltage divider. The output of the voltage divider is applied to the input of U1, a voltage comparator. The input signal to U1 is proportional to the resistance of the ground fault. If the signal exceeds the level set by potentiometer R29 (i.e., the ground fault resistance drops below a predetermined level), the output of U1 changes state and turns off transistors Q4 and Q5. When Q4 turns off, control voltage is removed from the SSRs and the system is shut down.

The diodes (CR13-CR16) are connected to form a full wave bridge rectifier that prevents the voltage comparator input from being reverse-biased by stray signals.

Triac Control. When a ground fault occurs and U1 changes state, transistor Q1 is turned off at the same time as Q4 and Q5. The relay (K1) powered through Q1 is delayed in turning off by capacitor C4 for approximately 12 msec. When the relay does drop out, the triac Q7 (a bidirectional solid state switch) turns on and shorts the 120-VAC lines. The short circuit provides a low resistance path for any stored energy in the load to be dissipated. If for any reason the SSRs do not open on command, the triac shorts the 120-VAC lines and fuse F1 will open and shut down the system.

Additional Circuit Operations. The ±15 VDC required for all of the electronic circuits is obtained from one power supply. If this supply should fail during normal use the system will shut down. If the supply does not come on when power is applied, the system will not turn on.

Should fuse F1 or F2 open, the system will not turn on.

After the system has been connected to a 120-VAC source and the power turned on, depressing the test switch (S3) will insert a 20 kΩ resistor between one line and ground. The system should trip off line; this is indicated by the loss of the "power on" light. The system can be reset using switch S2 (RESET).

PROTOTYPE TEST AND EVALUATION

During FY84, the prototype 2.5-kVA Single Phase Ground Fault Detector was tested and evaluated in the laboratory and in the harbor at Port Hueneme, Calif. The tests included measuring shutdown time, nuisance tripping, life cycle, and ocean operation as specified in the Test and Evaluation Master Plan (Ref 2). These tests were conducted to lend statistical confidence to analyses for reliability, maintainability, and availability. The test plan is included as Appendix A.

Shutdown Time Test

One of the stated design goals is for the ground fault detection system to shut down in less than 10 msec. To determine the value of ground fault resistance required to cause the system to trip, it was connected into a test circuit as shown in Figure 4. The test setup is shown in Figure 5. The ground fault resistance was simulated by connecting a decade resistance box to point A and setting it to 75 kΩ. The system was then turned on with the test switch open. The test switch was closed and the resistance dropped 1 kΩ per step until a trip occurred. The system tripped on the step from 52 to 51 kΩ. According to the manufacturer, the factory had set the trip point at 51 to 50 kΩ. The test was repeated two more times to verify the trip point.

During the tests to measure shutdown time, the system was loaded to 15 amperes by closing the appropriate switches. The decade resistance box was set to 15 kΩ. A storage type oscilloscope was set on single sweep with external trigger, 1 msec/cm horizontal, and 20 V/cm vertical. When the test switch was depressed the oscilloscope sweep was triggered and the 15-kΩ ground fault applied. The oscilloscope recorded and stored the system output voltage for 10 msec after the test switch was pushed. The time required to shut the system down was read from the oscilloscope trace and logged on Test Data Forms B and Bc. Copies of the data sheets are contained in Appendix B. This test was repeated 40 times each with the decade resistance box connected to point A (Figure 4) and point B. At the conclusion of the test, a record of the output voltage at shutdown was obtained by replacing the oscilloscope with an oscillograph recorder. A sample of the wave forms recorded is shown in Figure 6. Eighty-two shutdown times were observed or recorded without a nuisance trip. All trip times were less than the required 10 msec.

Nuisance Trip Test

Nuisance tripping of the ground fault detection system results in a loss of confidence in its protection capability and possible delays in completion of the task. This test was designed to determine the susceptibility of the system to tripping due to noise on the power line and to current surges in the load circuit. Again using the test circuit shown in Figure 4, the decade resistance box was connected to point A and set for 57 kΩ. The system was turned on and the load current adjusted to 10 amperes. A 1/2-hp electric drill motor was used as a variable load and a noise generator. The variable speed 1/2-hp electric drill motor was selected because of the high electrical noise level generated by the SCR speed control circuit and the motor brushes. When the drill motor was started, load current reached an amplitude of approximately 19 amperes with spikes to 26 amperes. It was started and stopped five times while observing the system for nuisance trips. If no trip occurred the decade box resistance was dropped 1 kΩ and the drill motor started and stopped five times again. This sequence was repeated until a system shutdown was observed. All information on the test was logged on a Test Data Form C and can be found in Appendix B.

No shutdown of the system occurred until the decade box resistance was lowered to 52 kΩ. This value is within the set-point tolerance for a normal trip due to low resistance to ground; therefore, no nuisance trips were observed.

Life Cycle Test

The purpose of this test was to determine operational reliability of the ground fault detection system. This was accomplished by operating the system under various load conditions and subjecting it to repeated ground faults. An automatic load cycling device was constructed that could turn on a load, initiate a ground fault, and reset the system. The test circuit is shown in Figure 7. Three load levels were automatically cycled through during the test. On the initial cycle, no load was applied (load current = 0 ampere) to the system and a 15-kΩ ground fault resistance was used to trip the system. When the automatic reset was initiated, a 3/4-hp electric motor came on for the second cycle (load current = 9 amperes). The third load consisted of the 3/4-hp motor plus two 500-watt resistance heater strips (load current = 17 amperes). The complete cycle through the three loads took approximately 3.5 minutes. A total of 3,000 system shutdowns was performed (1,000 complete test cycles).

Every 500 shutdowns during the test the storage oscilloscope was connected into the test circuit and the system shutdown time recorded. All of the shutdown times logged were less than 10 msec. During the 60 hours of the test no maintenance or adjustments on the system were required.

Ocean Operations

The ocean operations test was conducted off Pier 5 in the Port Hueneme Harbor, Port Hueneme, Calif. For this test, 1,000 feet of six-conductor SO type cable was deployed into the harbor along Piers 4 and 5. The 2.5-kVA Ground Fault Detector and control canister were connected as shown in Figure 8. The purpose of the control canister was to provide a dry location for the load resistors, indicator lights, and a relay. The relay can be remotely operated to insert or remove a 15-kΩ ground fault from one line to ground. The indicator lights provide for remote monitoring of the power system status.

When the system had been fully deployed, the power was turned on to check for proper operation. The indicator lights showed proper operation. The relay in the control canister was turned on and the system shut down. The relay was turned off and the system reset. This test was repeated 40 times without a malfunction. At the completion of the test the cable and control canister were recovered and returned to the laboratory with the system. All data were logged on Test Data Form D and are included in Appendix B.

INTEGRATED LOGISTICS SUPPORT

Reliability

A measurement of reliability is the mean time between failures (MTBF). The MTBF is the total functioning life of a population of a system during a specific measurement interval divided by the total number of failures within the population during the interval. The specific measurement interval in this case is the 68 hours of elapsed operating time for the prototype 2.5-kVA Ground Fault Detector (GFD) during the test and evaluation period. Unfortunately, for the purpose of estimating reliability, no failures occurred during the test. Per agreement in the Integrated Test and Evaluation Plan for Underwater Electrical Safety Devices (Ref 3), the minimum number of failures (one) was allowed to be assumed for the purpose of calculating an estimated MTBF. Based on this assumption of one failure for the test interval, the MTBF was calculated as follows:

$$\text{MTBF} = \frac{\text{Total Operating Hours}}{\text{Number of Failures}}$$

Therefore, the MTBF for the prototype GFD was 68 hours. The assumed failure was defined as an event that would have arisen from a characteristic inherent in the device and that would have prevented the device from performing its function. Temporary requirements for adjustment, calibration, or battery change were not counted as failures. It is expected that the MTBF will approach its mature predicted value of 7,553 hours for a production system as operational hours are accumulated on the system. The mean time between failures-inherent (MTBF-I) value of 7,553 hours was derived from component failure rate data on similar equipment used in a reliability math model for verification. Details of the model and input data used are contained in Reference 4.

Reliability is then estimated by the following:

$$\text{Reliability} = \exp\,(-\text{Mission Time}/\text{MTBF})$$

The mission time was assumed for the GFD to be 8 hours as specified in the program plan (Ref 5). The calculated reliability of the prototype 2.5-kVA ground fault detection system is 0.8898. This value is less than the value specified by Reference 5 (0.95), but it is based on an assumed failure at an elapsed test time of 68 hours, which was insufficient test time for the verification of the specified MTBF of the prototype system. Solving the above equation for a reliability value of 0.95 yields a MTBF value greater than 156 hours of testing to meet the sufficient test time requirement for verification of the specified reliability.

Maintainability

Maintainability is normally defined as a characteristic of design and installation. This characteristic is expressed as the probability that an item will be retained in, or restored to, a specified condition within a given period of time if prescribed procedures and resources are used. Mean time to repair (MTTR) is commonly used as the on-equipment measurement index. The MTTR considers active maintenance time only and is usually estimated as follows:

$$\text{MTTR} = \frac{\text{Total Repair Hours}}{\text{Number of Failures}}$$

Since no malfunctions occurred during the test program, the MTTR could not be calculated by this method. Therefore, a time-line analysis of the most probable repair requirements was conducted and a predicted value for on-equipment MTTR as well as off-equipment MTTR was calculated based on the time-line analysis of corrective task times weighted for inherent failure rate as defined in the Reliability Math Model developed and depicted in Reference 4. Details of the maintainability analysis are contained in Reference 6.

The block diagram of the system shown in Figure 9 was used to define the probable repair scenarios. The repairs are capable of being performed by a Construction Electrician with nominal Navy training. Support equipment, tools, and test equipment required for fault diagnostics and repair are standard Navy items (normal hand tools and a portable multimeter). Based on the most probable repair scenarios, the system on-equipment MTTR is 0.46 hour. See Reference 6 for details of the Maintainability Math Model and the input data used. The predicted value of 0.46 hour is well within the specified MTTR of 2.0 hours for the prototype GFD in Reference 5.

Availability

Availability is the parameter that translates system reliability and maintainability characteristics into an index of effectiveness. Availability is defined as a measure of the degree to which an item is in an operable and commitable state at the start of a mission when the mission is called for at a random point in time. The basic mathematical definition of availability is as follows:

$$\text{Availability} = \frac{\text{Uptime}}{\text{Total Time}} = \frac{\text{Uptime}}{\text{Uptime + Downtime}}$$

Reference 5 requires a calculation of operational availability (A_o) with a specified requirement for A_o to be at least equal to or greater than 0.90. Using the MTBF data of 68 hours of uptime and an assumed failure resulting in 0.46 hour of downtime from the time-line analysis depicted in Reference 6, the system availability is 0.993. This calculated value of 0.993 is well above the specified minimum of 0.90 for the prototype GFD in Reference 5. It can be realistically expected that this number will approach the specified value of 0.90 as more operational data and actual maintenance times are accumulated on the GFD system.

Logistic Supportability

Maintenance Concept. The GFD will be supported by a three-tiered maintenance concept consisting of system self-test performed at the organizational level, field maintenance performed at the intermediate level, and depot maintenance to be managed in accordance with the Ocean Facilities Program described in NAVFACINST 11261.5A (Ref 7) and CHESNAVFACENGCOMINST 4860.1A (Ref 8). Items determined by a Level of Repair Analysis (LORA) to be cost effective will be supported by depot level maintenance. Depot level repair may be accomplished by Navy in-house resources, contractor support, or returned to the original vendor for repair, as determined by the Single Item Manager consistent with the management policies described in NAVFACINST 11261.5A (Ref 7).

Organizational level is defined as the maintenance performed on the GFD by the Construction Electrician-Operator. The Construction Electrician-Operator has specific responsibilities toward maintaining the operational readiness of the training equipment.

Intermediate level is defined as the maintenance performed on the GFD by the Operator-Maintenance Technician. Organizational and intermediate levels will usually be performed by the same personnel.

Field maintenance diagnostics will be limited to resistance checks for grounds with a standard Navy multimeter. All internal repairs that would require adjustment/calibration of the GFD will be performed at the assigned depot repair activity.

Depot level repair will be accomplished on a cost-effective basis for boards and discrete devices exceeding field repair capability. Depot activities for the GFD will consist primarily of test and repair of the printed wiring board. An informal LORA and depot maintenance study (DMS) will further define the depot repair capabilities and test equipment. The contractor's production facility is currently projected as an interim repair activity.

Spares Provisioning. As part of the development effort, the contractor listed the types and quantities of spare parts that might be needed based on problems encountered during development and acceptance testing. The spare parts list was updated based on the operational experience gained during the evaluation program. The quantity and type of spare parts recommended are consistent with the Reliability Math Model of Reference 4 and the maintenance capabilities defined by the time-line analysis and the Maintainability Math Model detailed in Reference 6. The spare parts list is included in the operation and maintenance (O&M) manual (Appendix C).

Training. Operation of the 2.5-kVA GFD system requires no special training or skills. A brief review of the O&M manual provides the necessary information for correct operation of the front panel controls and interpretation of the indicator lights. Field maintenance is limited to bit/part/piece component replacement and resistance checks for grounds consistent with those functions that can normally be performed by a Construction Electrician. All internal repairs should be performed at a depot repair activity since the calibration of the GFD could be affected by the repair.

CONCLUSIONS AND RECOMMENDATIONS

1. The system met all operational goals during the test program. The system provides protection for operating personnel by detecting low level (less than 5 mA) ground fault currents and shutting down the system in 10 msec or less.

2. The test results show that the circuit design presented in this report detects ground faults in power systems being used in electrically hazardous locations and, in the event of a fault, secures power to the load, thus preventing operating personnel from receiving serious injury.

3. The electronic circuit presented in Figure 1 should be the main item considered for Approval for Procurement. The system shown in Figures 2 and 3 was the configuration developed for the prototype models of the GFD. This circuit can be incorporated into other systems to provide ground fault detection or packaged in any manner necessary to meet the operational requirements.

4. The BUMED criteria imply that the fault current not exceed 5 mA during any portion of the allowed 50-msec shutdown period. The system developed by NCEL does not limit the current during the initial 10-msec period of the fault before the shutdown devices activate. This interval is shorter than that provided by any other available product and is substantially shorter than the 50-msec period in the BUMED criteria.

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8. Naval Facilities Engineering Command, Chesapeake Division. CHESNAVFACENGCOM Instruction 4860.1A: Utilization policy for the ocean facilities program (OFP) ocean construction equipment inventory (OCEI); promulgation of. Washington, D.C., 14 May 1982.

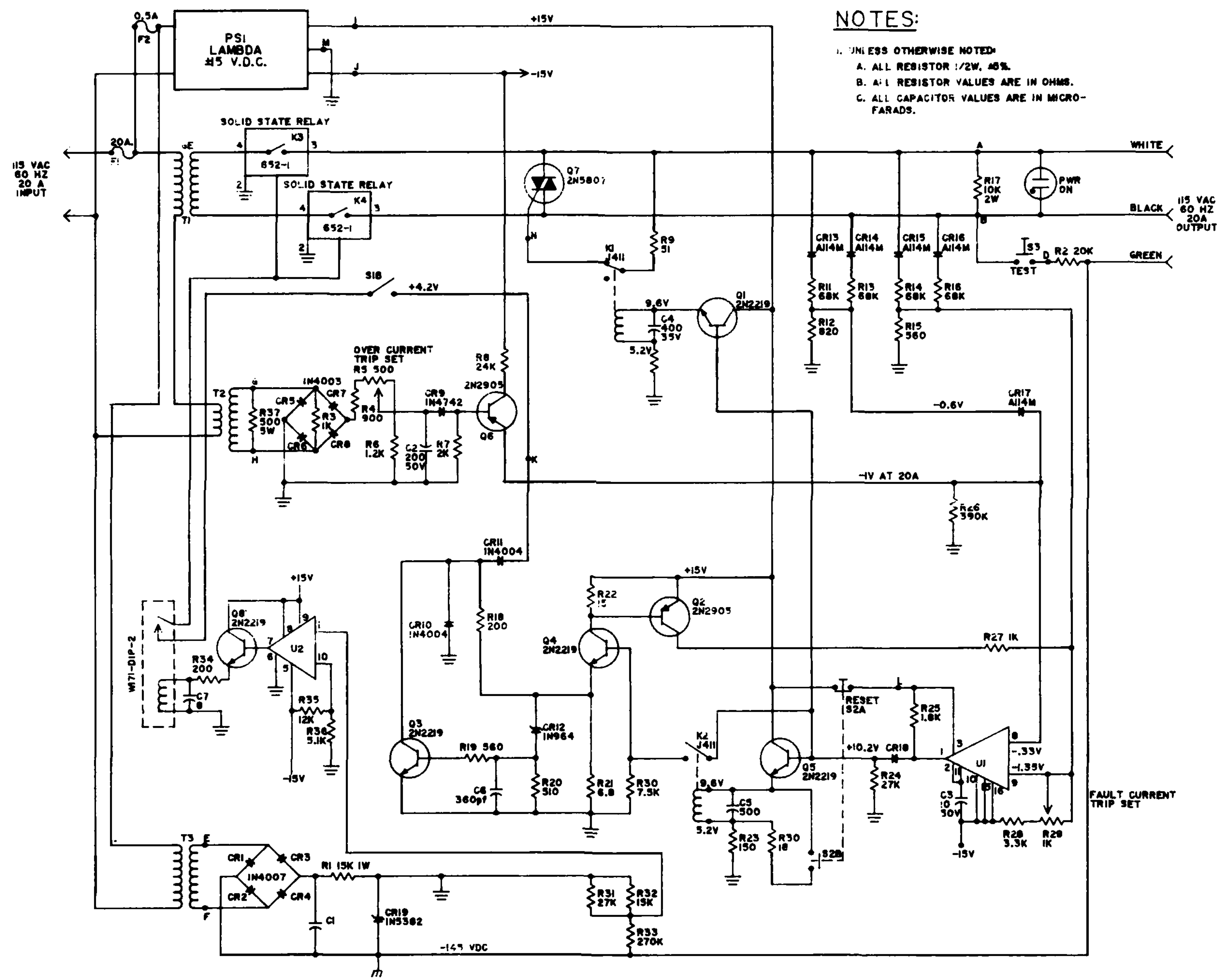

Figure 1. Schematic of 2.5-kVA ground fault detector.

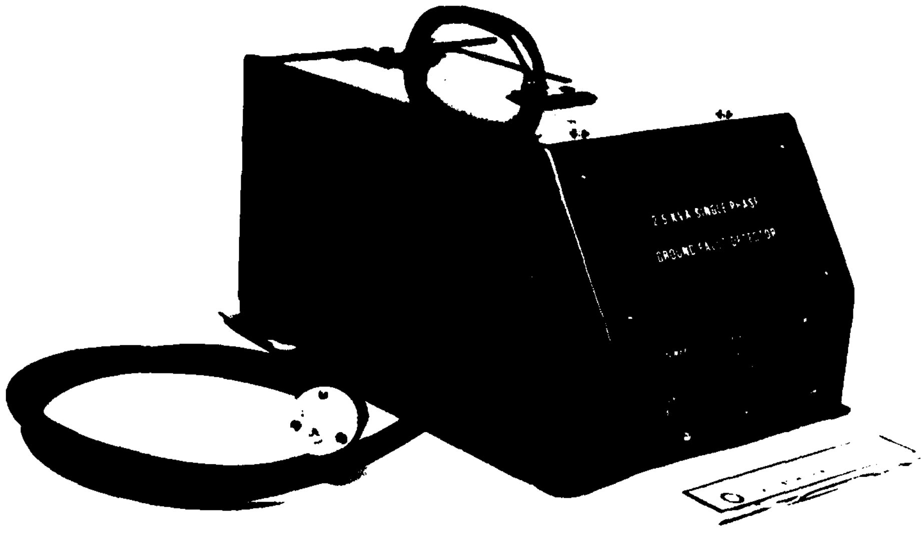

Figure 2. View of 2.5-kVA ground fault detector from left front.

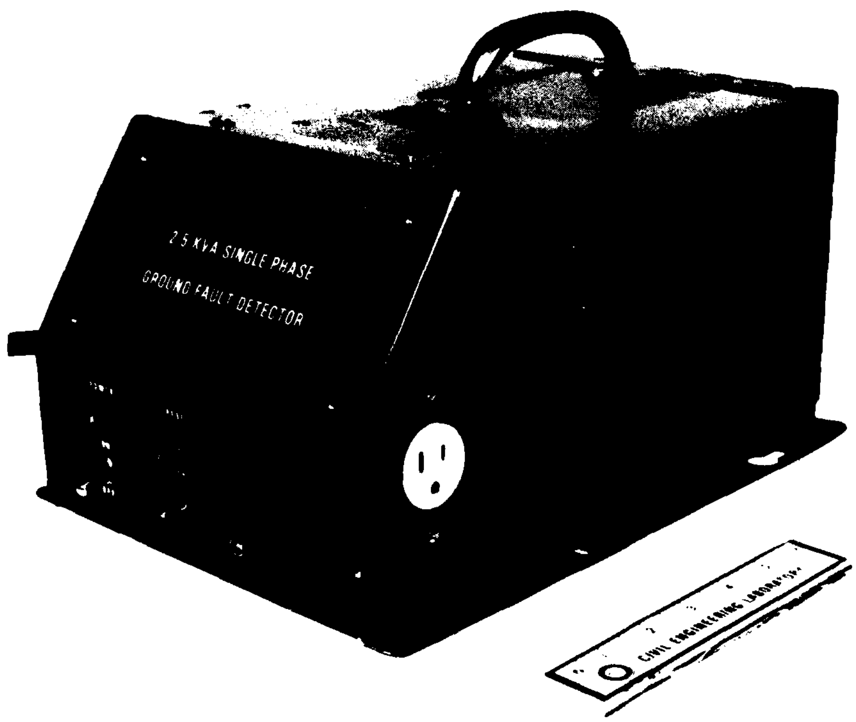

Figure 3. View of 2.5-kVA ground fault detector from right front.

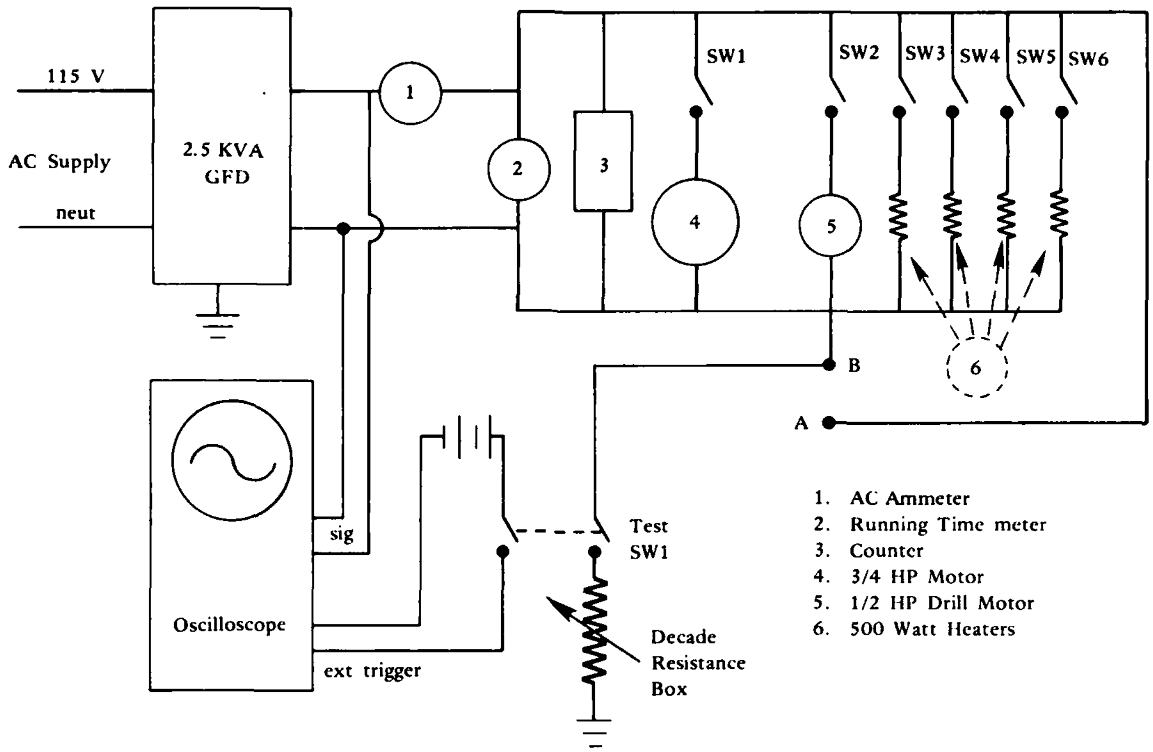

Figure 4. Test circuit for shutdown test.

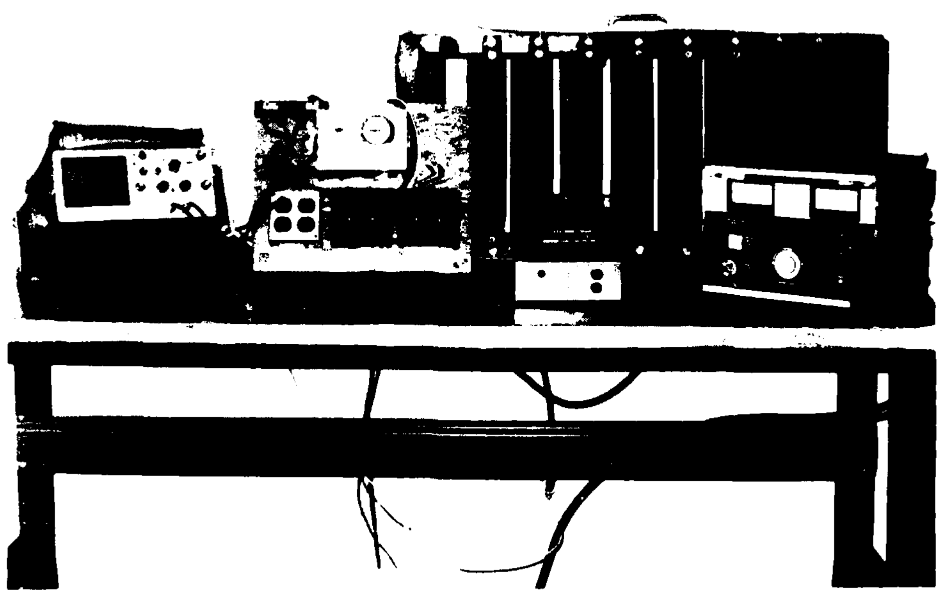

Figure 5. Test setup for the shutdown time tests.

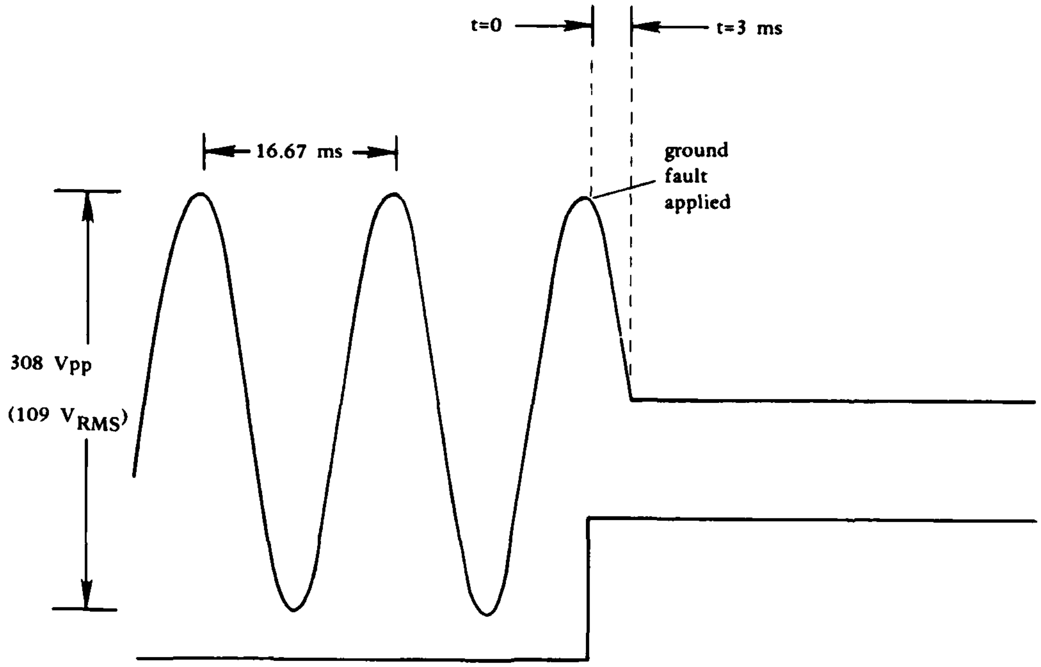

Figure 6. Sample of scope signal at shutdown.

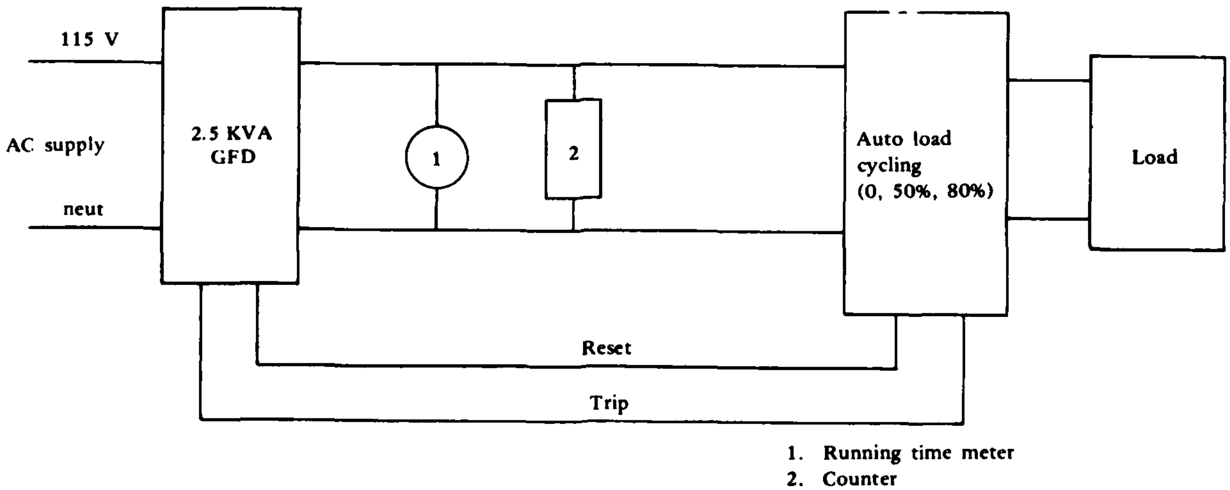

Figure 7. Test circuit for life cycle test.

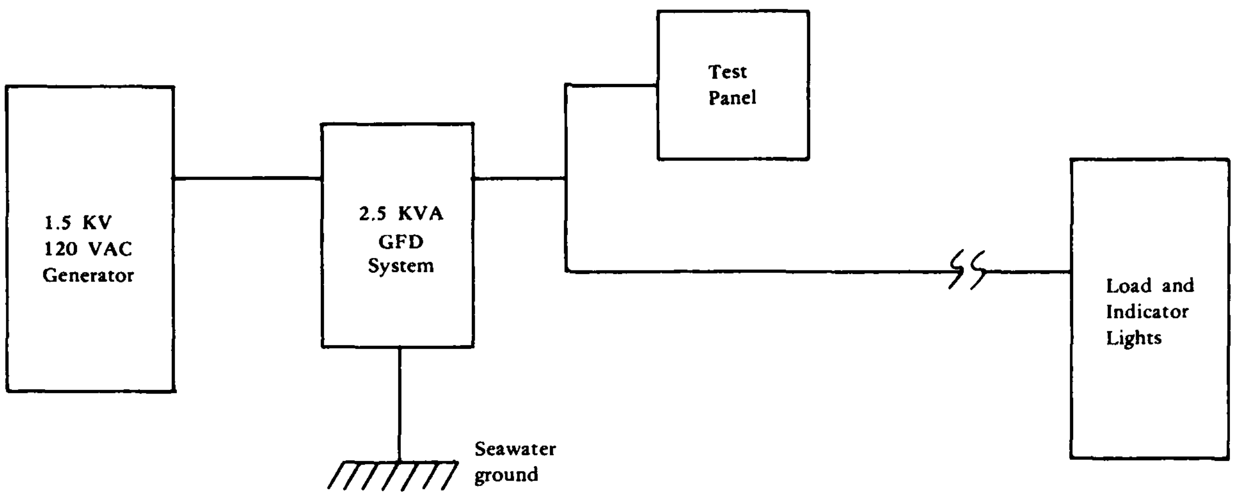

Figure 8. Block diagram of test circuit for ocean test.

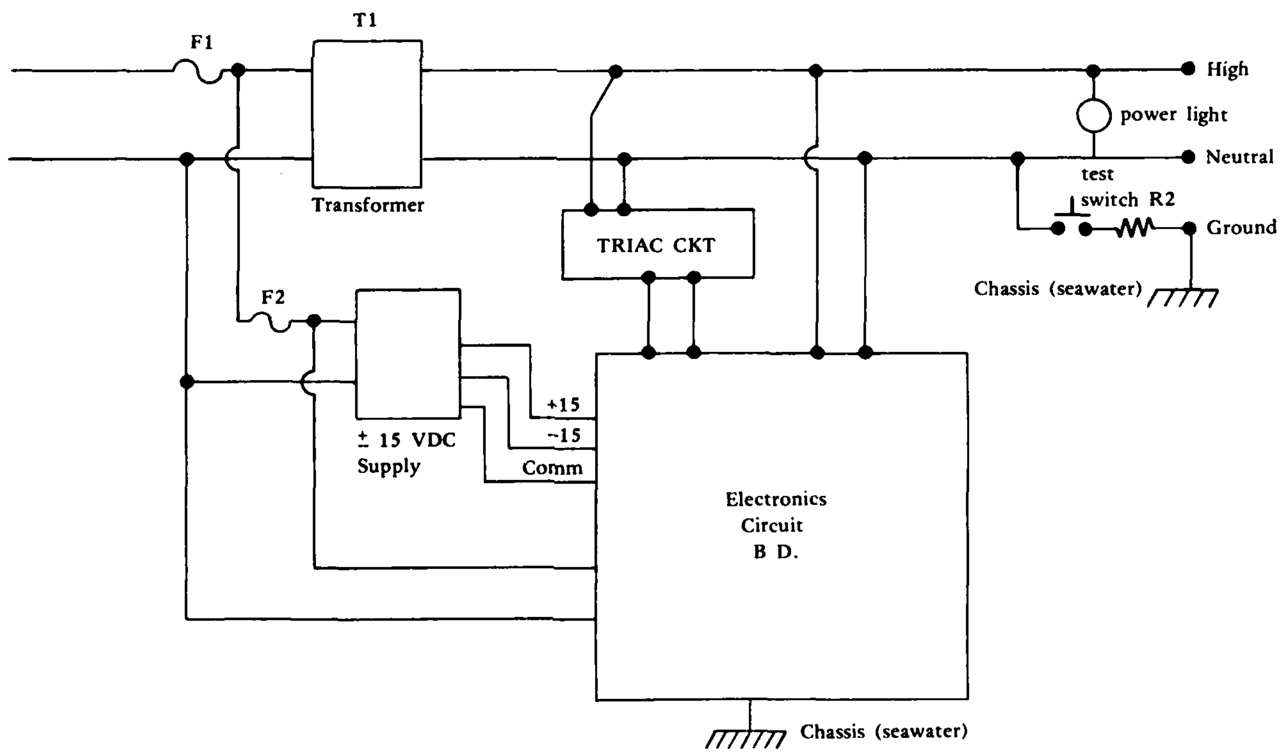

Figure 9. System block diagram of ground fault detector for repairs.

Appendix A

2.5-kVA GROUND FAULT DETECTOR TEST PLAN

1.0 PURPOSE

To gather the data required to secure Approval for Full Production for the 2.5-kVA Ground Fault Detection (GFD) system.

1.1 References

(a) Integrated Test and Evaluation Plan Underwater Safety Devices, Nov 1983.

(b) 2.5-kVA GFD Systems Operating and Service Manual

2.0 TEST OBJECTIVES

2.1 Operational

2.1.1 Measure times for shutdown of power when test circuit simulates reduction in resistance associated with ground faults.

2.1.2 Estimate frequency of occurrence and conditions under which undesired, nuisance power shutdowns may occur.

2.1.3 Test power shutdown performance while loads operate at ends of cable as long as 1,000 feet.

2.1.4 Provide validation of successful operational performance with ocean systems.

2.2 Safety and Suitability

2.2.1 Identify any hazards that may be associated with a diver's use of the devices.

2.2.2 Estimate reliability, maintainability, and availability.

2.2.3 Identify requirements for calibration, special tools, and test equipment that are necessary for operational employment of the devices by Underwater Construction Teams (UCTs).

2.2.4 Provide tentative concepts for field and depot maintenance procedures.

2.2.5 Estimate spare and replacement parts required for employment of the devices in the field by UCTs.

2.2.6 Evaluate requirements for packaging, handling, storage, and transportation.

2.2.7 Evaluate adequacy of the Operations and Maintenance Manuals that are anticipated to accompany the engineering models.

2.2.8 Estimate the skill levels and training required of Naval Construction Force personnel who may be operating and maintaining the devices.

3.0 PERSONNEL AND EQUIPMENT

3.1 <u>Personnel</u>

3.1.1
- (a) Project Engineer
- (b) Electronics Technician
- (c) NCEL Divers
- (d) UCT Divers

3.1.2 All personnel shall complete test data form J.

3.2 <u>Equipment</u>

3.2.1
- (a) Oscillograph recorder
- (b) AC voltmeter
- (c) AC ampmeter
- (d) Decade resistance box
- (e) Storage oscilloscope
- (f) Underwater control canister
- (g) Auto load cycling box
- (h) Resistive
- (i) 1/2-hp drill motor
- (j) 3/4-hp electric motor

4.0 OPERABILITY TEST PROCEDURES

NOTE! REVIEW ALL TEST DATA FORMS BEFORE STARTING TESTS TO BE SURE ALL NECESSARY DATA ARE LOGGED.

4.1 Shutdown Time Test

4.1.1 Connect the 2.5-kVA GFD system into test circuit as shown in Figure A-1.

4.1.2 Plug in the GFD system, close SW3, and turn on power to the load.

4.1.3 Set the decade resistance box for 60 kΩ and close test switch 1. Slowly reduce the decade box resistance (Rg) in 1-kΩ steps until the GFD system trips. Log the decade box resistance on test data form B. Open SW1. Repeat this test three times and log all data. Turn off SW3 and test SW1.

4.1.4 Set up oscilloscope to measure GFD system trip time. Set decade resistance box to 15 kΩ. Close SW1, SW3, and SW3. Monitor the AC ampmeter and set the load current to 15 ±3 amps using the remaining load switches. Close test SW1 and log all data on test data form B. Repeat this test 40 times. Turn off all load switches and test SW1.

4.1.5 Connect test SW1 to point B (Figure A-1) and repeat paragraphs 4.1.2, 4.1.3, and 4.1.4; log all data on a new form B.

4.1.6 Replace the oscilloscope with the oscillograph recorder in the test circuit and repeat paragraph 4.1.4 (delete the test requirement of repeating 40 times). Perform the test as many times as necessary to obtain a permanent record of the system shutdown time.

4.1.7 If at any time during the operability test a power shutdown occurs for any reason other than a planned trip, testing shall be terminated and a test data form C shall be completed.

4.2 Nuisance Trip Test

4.2.1 If no nuisance trips have been recorded or if the reason for a trip has not been determined, conduct the following test to try to induce a false trip. Record all data on form C.

4.2.2 Using Figure A-1, connect the decade resistance box to point A. Turn on the GFD system and random load switches until the AC ampmeter reads approximately 10 amps. Do not turn on the drill motor as part of the load at this time. Set the decade resistance box at 5 kΩ above the highest value obtained in paragraph 4.1.3. Turn on test SW1. Start and stop the drill motor (five times) while observing for nuisance trips. Monitor the load voltage wave shape for noise spikes created by the fluctuating load. Record all observations.

4.2.3 If no trip occurs, lower the decade box resistance 500 ohms and repeat paragraph 4.2.2.

4.2.4 Continue dropping the resistance in 500-ohm steps until nuisance tripping occurs or until the normal trip resistance is reached. If no nuisance trips occur, log this observation.

4.3 Life Cycle Tests

4.3.1 Connect the auto load cycling box to the GFD system as shown in Figure A-2. Record reading of the counter.

4.3.2 Turn power on to the GFD and auto load cycling box. Allow system to run until 3,000 cycles have been counted or the system malfunctions. If a system malfunction occurs, fill out test data forms F, G, and H. If no malfunctions occur, fill out only forms F and H at the end of the test.

4.4 Ocean Systems Test

4.4.1 Locate the 2.5-kVA system on Pier 5. Connect the underwater control canister to the GFD system. Ground the case of the canister to the case of the GFD system. Turn on the GFD system and press the test switch on the canister control panel. When the test switch is pressed, the GFD system should trip and remove AC power from the control canister. Record all test data on form D for this test sequence.

4.4.2 Using a small boat, deploy the control canister and the 1,000 feet of control cable in a straight run out from the pier. Using the canister tag line, lower the canister approximately 1 foot below the surface. Turn on the GFD system and visually check the canister and GFD for proper operation (canister light on, GFD did not trip). Lower the canister to the bottom and secure the tag line to the pier for use during recovery.

4.4.3 Press the test switch and check the GFD for shutdown. Log required information on test data form D. Repeat this test 40 times or until a failure is recorded. If a system failure occurs, log all data on the pertinent forms (F, G, and H). If repairs cannot be made quickly, recover the underwater control canister and cable. After repairs have been completed, start test again at paragraph 4.4. Should a trip occur at any time other than a planned shutdown, fill out form C immediately.

4.4.4 Upon completion of the 40 cycles, recover the underwater control canister and cable. Return all the equipment to Building 570.

5.0 LOGISTIC SUPPORTABILITY

5.1 All personnel participating in the 2.5-kVA GFD system testing shall fill out test data form I.

6.0 SAFETY TESTS

6.1 During the test program all participants shall be alert to any safety hazard that may develop in association with the 2.5-kVA system. All observations shall be recorded on test data form E at the time the hazard develops.

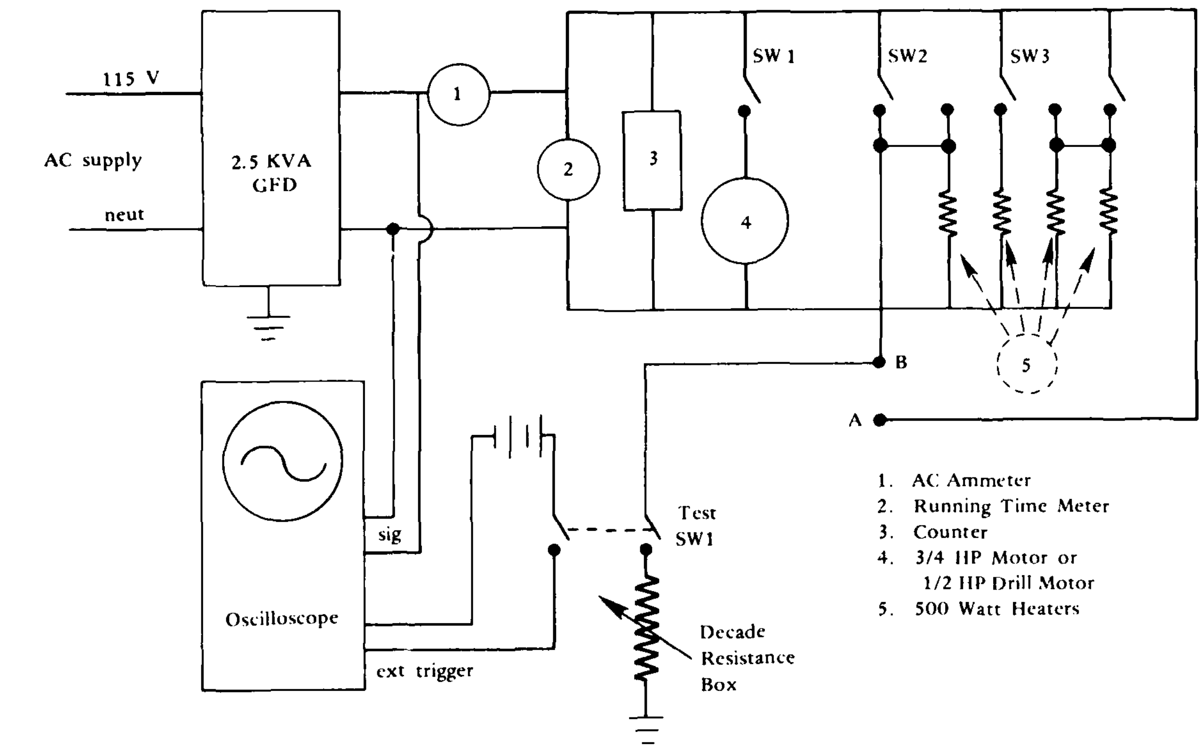

Figure A-1. Test circuit for shutdown test.

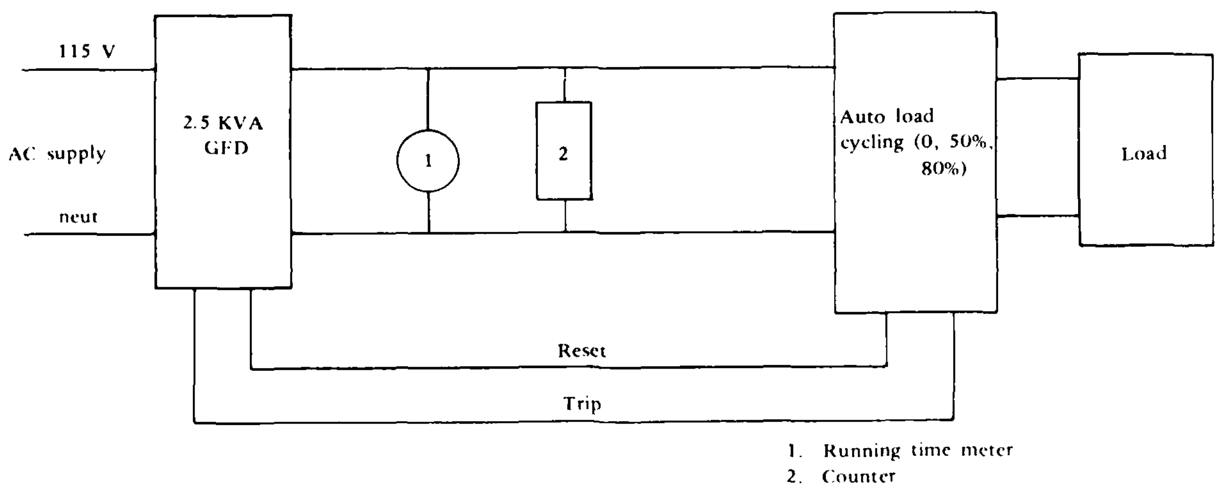

Figure A-2. Life cycle test setup.

Appendix B

TEST DATA FORMS

TEST DATA FORM B

LABORATORY TESTS
FOR
POWER SHUT-DOWN BY GROUND FAULT DETECTORS

This data form is to be filled in during operability tests of the Ground Fault Detectors.

GROUND FAULT DETECTOR CAPACITY: 2 KW; PHASE CHARACTER: 1φ
NAME OF TEST ENGINEER: LEE TUCKER
DATE OF TESTING: 8 MARCH 1984

TIME GROUND FAULT DETECTOR OPERATING	
TIME ON	TIME OFF
1300	ON/OFF MANY TIMES DURING THE TEST *
Running Time Readings	
6.1	9.6
Total on time = 3.5 HR	

TIME TESTS BEGIN: 1250
TIME TESTS END: 1700

CABLE LENGTH: 10 FT.
DESCRIPTION OF APPLIED LOAD: RESISTIVE + 3/4 HP MOTOR

GROUND RESISTANCE POWER SHUT-DOWN TRIP SETTING: Results of Para 4.1.3

Trip #1
52 K → 51 K

Trip #2
52K → 51K

Trip #3
52K → 51K

* Running time meter used to register system on time.

TEST DATA FORM Bc (CONTINUATION SHEET)

GROUND FAULT DETECTOR CAPACITY: 2 KW; PHASE CHARACTER: 1 Φ
NAME OF TEST ENGINEER: LEE TUCKER
DATE OF TESTING: 8 MARCH 1984

RECORD OF POWER SHUT-DOWN TIMES (Para 4.1.4)

TEST NUMBER (SEQUENTIAL)	GROUND RESISTANCE R_g (KILO-OHMS)	POWER SHUT-DOWN TIME (MILLI-SECONDS)	ANOMALOUS OBSERVATIONS (e.g. - FAILURES, CALBIRATIONS, ETC.)
1	15 KΩ	4	Load current = 14.9 a.
2		8	Voltage = 106.9 Vac
3		9	Load = 3 - 500 W
4		1	resistors +
5		4	3/4 HP Motor
6		4	
7		3	Ground fault resistance
8		9	hooked to point A
9		2	
10		4	
11		7	
12		9	
13		4	
14		2	
15		8	
16		4	
17		9	
18		6	
Note time of completion of test series.			
19		3	
20	15 KΩ	2	

TEST DATA FORM 8c (CONTINUATION SHEET)

GROUND FAULT DETECTOR CAPACITY: 2 KW; PHASE CHARACTER: 1φ
NAME OF TEST ENGINEER: LEE TUCKER
DATE OF TESTING: 8 MARCH 1984

RECORD OF POWER SHUT-DOWN TIMES

TEST NUMBER (SEQUENTIAL)	GROUND RESISTANCE R_g (KILO-OHMS)	POWER SHUT-DOWN TIME (MILLI-SECONDS)	ANOMALOUS OBSERVATIONS (e.g. - FAILURES, CALIBRATIONS, ETC.)
21	15 KΩ	8	
22	↑	7	
23		2	
24		8	
25		4	
26		—	→ Scope did not trigger
27		2	
28		9	
29		4	
30		8	
31		3	
32		2	
33		2	
34		2	
35		8	
36		7	
37		9	
38		5	
39		2	
Note time of completion of test series.			
40		6	
41	↓	7	
42	15 KΩ	8	

Para 4.1.5

TEST DATA FORM Bc (CONTINUATION SHEET)

GROUND FAULT DETECTOR CAPACITY: 2.5 KW; PHASE CHARACTER: 1φ
NAME OF TEST ENGINEER: LEE TUCKER
FLOYD NELSON
DATE OF TESTING: 3-8-84

Time ON – 9.6
Time OFF – 11.8

RECORD OF POWER SHUT-DOWN TIMES

TEST NUMBER (SEQUENTIAL)	GROUND RESISTANCE R_g (KILO-OHMS)	POWER SHUT-DOWN TIME (MILLI-SECONDS)	ANOMALOUS OBSERVATIONS (e.g. - FAILURES, CALBIRATIONS, ETC.)
1	15 K	6	15.0 Amps
2		8	
3	↓	8	Rg hooked to point B of Figure 1
4		7	
5		1	
6		4	
7		2	
8		2	
9		3	
10		→	Sope [sic] did not trigger
11		3	
12		4	
13		6	Total on time = 2.2 HR
14		2	
15		4	
16		5	
17		9	
18		5	
19		6	
20	15K	7	

TEST DATA FORM 8c (CONTINUATION SHEET)

GROUND FAULT DETECTOR CAPACITY: 2.5 KW; PHASE CHARACTER: 1φ

NAME OF TEST ENGINEER: LEE TUCKER

FLOYD NELSON

DATE OF TESTING: 3-8-84

RECORD OF POWER SHUT-DOWN TIMES

TEST NUMBER (SEQUENTIAL)	GROUND RESISTANCE R_g (KILO-OHMS)	POWER SHUT-DOWN TIME (MILLI-SECONDS)	ANOMALOUS OBSERVATIONS (e.g. - FAILURES, CALBIRATIONS, ETC.)
21	15K	2	Para
22		5	
23		4	4.1.5
24		6	con't.
25		2	
26		6	
27		9	
28		6	
29		0.5	
30		2	
31		6	
32		4	
33		3	
34		2	
35		5	
36		5	
37		6	
38		5	
39		2	
40		6	
41		5	
42	15K	2	

TEST DATA FORM C

LABORATORY TESTS
FOR
NUISANCE SHUT-DOWNS CAUSED BY GROUND FAULT DETECTORS

This data form is to be filled out during operability tests of the Ground Fault Detectors.

GROUND FAULT DETECTOR CAPACITY: 2 KW; PHASE CHARACTER: 1ϕ
NAME OF TEST ENGINEER: LEE TUCKER + FLOYD NELSON
DATE OF TESTING: 12 MARCH 1984

TIME GROUND FAULT DETECTOR OPERATING	
TIME ON	TIME OFF
12.1	13.6

TIME TESTS BEGIN: 0930
TIME TESTS END: 1145

GROUND RESISTANCE POWER SHUT-DOWN
TRIP SETTING: 52K → 51K

Test per Para 4.2

TEST DATA FORM Cc (CONTINUATION SHEET)

GROUND FAULT DETECTOR CAPACITY: 2 KW; PHASE CHARACTER: 1φ
NAME OF TEST ENGINEER: LEE TUCKER & FLOYD NELSON
DATE OF TESTING: 12 MARCH 1984

RECORD OF NUISANCE SHUT-DOWN TESTS

TEST NUMBER (SEQUENTIAL)	CABLE LENGTH (FEET)	LOAD DESCRIPTION	POWER SHUT-DOWN (YES OR NO)	ANOMALOUS OBSERVATIONS (e.g. - FAILURES, CALIBRATIONS, ETC.)
1	10 FT	10 amps Resistive	NO	R_g = 57 KΩ Drill motor on/off 5 times
2	↓	↓	No	R_g = 56 KΩ
3	↓	↓	No	R_g = 55 KΩ
4	↓	↓	No	R_g = 54 KΩ
5	↓	↓	No	R_g = 53.5 KΩ
6	↓	↓	No	R_g = 53 KΩ
7	↓	↓	No	R_g = 52.5 KΩ
8	↓	↓	YES	R_g = 52 KΩ

Note time of completion of test series.

52 KΩ is within the tolerance of the system calibration (±5%) or 52.5 to 47.5 KΩ

TEST DATA FORM D

OCEAN OPERABILITY TESTS
FOR
ELECTRIC FIELD DETECTOR AND GROUND FAULT DETECTORS

This data form is to be filled in during operability tests of all safety devices in the ocean.

NAME OF TEST ENGINEER: LEE TUCKER
LOCATION OF TESTS: PIER 5
DATE OF TESTING: 3/19/84
TIME TESTS BEGIN: 0930
TIME TESTS END: 1200

MARINE CABLE LENGTH USED: 1000 ft
SEA TEMPERATURE: 60°F
AIR TEMPERATURE: 75°F
WEATHER CONDITIONS: WINDY

2.5 KW GFP

Para: 4.4
Ocean Tests

EQUIPMENT OPERATING TIME

ELECTRIC FIELD DETECTOR		2.5 KW GROUND FAULT DETECTOR		10 KW GROUND FAULT DETECTOR		25 KW GROUND FAULT DETECTOR	
TIME ON	TIME OFF	TIME ON	TIME OFF	TIME ON	TIME OFF	TIME ON	TIME OFF
		0955	1130				

System ground faulted 40 times during the 1 hr. 35 min test period - No false trips recorded. With out 1000 feet cable trip resistance to ground was 51-52K Ω - With cable trip resistance increased to 59K Ω

Appendix C

OPERATING AND SERVICE MANUAL FOR 2.5-kVA GROUND FAULT DETECTOR MODEL GFD 2.5-1P

by

MODUMEND, Inc.
30961 West Agoura Road
Suite 311
Westlake Village, CA 91361
(213) 889-5550

1.0 INTRODUCTION

The 2.5-kVA Ground Fault Detector (GFD) is designed to provide 115-VAC, 20-ampere, 60-Hertz single phase power that is electrically isolated from the AC source and to shut down for any of the following:

- The line-to-ground or line-to-shield resistance drops below 50 kΩ.
- The load current exceeds 100% of rated current (20 amperes).
- A component failure occurs in the electronic circuits monitoring the ground fault resistance.

2.0 OPERATING INSTRUCTIONS

2.1 Prior to using the GFD, verify basic operation by checking it with the TEST SWITCH as follows:

- Turn on the power.
- Depress the RESET SWITCH.
- Depress the TEST SWITCH and verify that the indicator light goes off (simulates a 20K insulation resistance).

2.2 When using the GFD under normal operating conditions and the system shuts down, one of the following conditions may exist:

- The load may exhibit an insulation resistance less than 50K.
- The load may be drawing more than 20 amperes of current.
- The GFD unit is not operating properly.

Refer to the troubleshooting section of this manual for procedure to identify problem.

3.0 THEORY OF OPERATION

3.1 <u>General Description</u>

3.1.1 The ground fault detection circuit monitors the AC power in the load for an insulation resistance below 50 kΩ. If the resistance should drop, causing a leakage current of about 4 mA to flow in the ground circuit, the main solid state relays will open. The system is also designed to monitor the AC current supplied from the source to the load and open the main solid state relays if the current exceeds 20 amperes.

A third mode of operation may also shut the system off. The overall circuit design is such that a component failure in any of the monitoring circuits will shut the system down.

During normal operation, the load is supplied with 115 VAC via the secondary of the isolation transformer. The positive side of a DC voltage supply is connected to both AC lines on the load side of the transformer. This connection is made though a pair of matched resistors. The negative side of the DC voltage supply is connected to chassis ground. The negative side of the DC voltage supply is also connected to the ground wire in the load circuit and the cable shield, if it is used. As long as the insulation resistance in the load cable does not fail, DC current will not flow. If the insulation resistance drops either from deterioration due to age, abrasion, or from damage during handling, a small DC current will flow in the monitor circuit. Should the resistance drop below the predetermined value, a trip signal is initiated and sent to the solid state relays. The trip signal is also delayed for approximately 12 msec and then used to turn on the gate signal to a triac that is connected across the secondary of the isolation transformer. This delay allows time for the solid state relays to open before the load lines are short circuited. Thus, the solid state relays are not subjected to the short circuit currents, and transients are not induced back into the supply system. If for some reason the solid state relays do not open, the short circuit currents cause the line fuse to open. During normal operation, the triac also functions as a low resistance path for discharging any stored energy in the load circuit.

3.2 Circuit Description

3.2.1 The circuit description can be seen best by observing both the block diagram and schematic of the GFD system.

Transformer T1 and relays K3 and K4 provide system isolation and circuit breaker functions, respectively. The solid state relays are ideal because of their fast turn on/off times compared to electromechanical devices. Relays K3 and K4 are Mil-Spec packaged in sealed aluminum cases. The relays provide reliable operation over a line frequency range of 45 to 440 Hertz. Input control is from 4 to 32 VDC and synchronous zero voltage turn on and zero current turn off results in lower EMI levels than with mechanical devices.

Triac Q7 is used as the secondary shutdown device. The triac turns on 12 msec after the control signal is provided to the solid state relays.

Under normal operation, CR15, CR16, R14, R15, and R16 provide half-wave rectification and attenuation. This signal is referenced to a negative voltage that is adjustable by potentiometer R29. This voltage becomes the reference for comparator U1. The (-) input of U1 has a similar circuit and when no leakage exists U1-1 is biased to a +15 VDC. Relays K1 and K2 are energized, which provides an on condition to relays K3 and K4. With K1 energized the gate to Q7 is open.

If the insulation resistance between ground (GRN) and ACC (WHT) or AC (BLK) should drop below 50 kΩ, the -145-VDC power supply will establish a current path through diodes CR13 or CR14. The voltage developed by this leakage current will cause U1-8 (-) to become more negative than

U1-9 voltage; therefore, U1-1 will switch to a -15 VDC. CR18 becomes back biased so that no base voltage is provided to Q1, Q4, and Q5. This condition immediately removes the control voltage to K3 and K4. Within one half cycle (8.33 msec) the contacts will open, removing the AC voltage from the load. The secondary system has not actuated because capacitor C4 prevents the coil voltage of K1 from dropping instantaneously. The time constant is set for the contact of K1 to close in approximately 12 msec, which activates triac Q7. This shorts the AC line, discharging any energy stored in the cable or load. If K3 or K4 should not open when Q7 turns on, the short will cause fuse F1 to open. Relay K2 will open in about 35 msec, which is long after system shutdown. The main purpose of K2 is for system turn on. The time constant is set such that the K1 contact opens before the K2 contact closes. This condition prevents the triac from shorting the AC lines during turn on.

A third monitor to cause system shutdown is the line current monitor. Current transformer T2 along with the associated circuit will trip U1 when 20 amperes of input current are demanded by the load. Transformer T2 with the full wave bridge and R3 produce a DC voltage proportional to current. Resistors R4, R5, and R6 provide attenuation and calibration adjustment for the circuit. Capacitor C2 provides filtering and also damping for instantaneous current surges. Zener CR9 keeps the voltage at the base of Q6 below the turn on point until 20 amperes of current are flowing. When Q6 turns on, the system is shut down.

Several other built-in features may also shut down the system. Transistor Q4 is the primary control device for the solid state relays K3 and K4. If the control line to them should draw more than normal current, then Q2 will turn on and trip U1 to shut down power. This trip current is set for about 50 mA. Also, if Q4 should short from collector to emitter attempting to cause K3 and K4 to be stuck on, then Q3 turns on which, in turn, causes more than 50 mA of current activating Q2, resulting in system shutdown.

4.0 SERVICING INFORMATION

4.1 U1 Reference Adjustment

4.1.1 Disconnect all loads from the GFD and turn on power.

4.1.2 Connect a multimeter to U1-9. Set the meter for DC voltage measurement (0-2 VDC range).

4.1.3 Adjust potentiometer R29 for -1.35 VDC ±0.02 VDC.

4.1.4 With R29 adjusted as specified, measure the DC voltages shown on the schematic. NOTE: Depress the RESET SWITCH if the cathode of CR18 is not at about +10 VDC.

4.2 Current Limit Adjustment

4.2.1 Turn potentiometer R5 completely clockwise.

4.2.2 Connect a variable load to the GFD.

4.2.3 Turn on power to the GFD and set load to draw 15 amperes of current.

4.2.4 Slowly increase load current to 20 amperes.

4.2.5 Adjust R5 counterclockwise until the GFD trips.

4.2.6 Reduce the load and depress the RESET SWITCH and the GFD should come back on.

4.2.7 Recheck setting by increasing the load current slowly and recording the current at which the unit trips.

4.2.7 Repeat steps 4.2.3 through 4.2.7 as necessary to obtain the correct trip point.

4.3 Circuit Timing

NOTE: No adjustments are provided for changing the timing of the control functions. The operational times are given to aid in performing major repairs.

4.3.1 The turn off time for K3 and K4 is 8.33 msec or less measured from the time a ground fault is applied to the GFD.

4.3.2 The turn off time of K1 is 12 msec and is set by the RC circuit of R10 and C4.

4.3.3 The turn on time of K2 is 5 msec after K1 turns on.

5.0 RECOMMENDED SPARE PARTS LIST

5.1 Power Supply (PS1) Item 16, 1 each.

5.2 Relay, Solid State (K3, K4) Item 15, 1 each.

5.3 One complete circuit board (Figure 3).

5.4 Receptacle, AC Item 53, 1 each.

LIST OF MATERIAL

Item	Required	Part No.	Manufacturer	Description
1	1	TVA-1526	Sprauge	Capacitor, 250 μf, 250 V (C1)
2	1	30D	Sprauge	Capacitor, 100 μf, 50 V (C2)
3	1	30D	Sprauge	Capacitor, 10 μf, 50 V (C3)
4	1	30D	Sprauge	Capacitor, 33 μf, 35 V (C4)
5	1	39D	Sprauge	Capacitor, 500 μf, 40 V (C5)
6	1			Capacitor, 360 pf (C6)
7	4	1N4007		Diode, power (CR1-CR4)
8	4	1N4003		Diode, power (CR5-CR8)
9	1	1N4742		Diode, zener
10	2	1N4004		Diode, power
11	1	1N758A		Diode, zener
12	4	A114M	GE	Diode, F.R. (CR13-CR17)
13	1	1N5382		Diode, zener
14	3	J411-6WP	Teledyne	Relay (K1,K2,K5)
15	2	652-1	Teledyne	Relay (K3,K4)
16	1	LZD-22	Lambda	Power supply, ±15 VDC (PS1)
17	5	JAN 2N2219		Transistor (Q1,Q3,Q4,Q5,Q8)
18	2	JAN 2N2905		Transistor (Q2,Q6)
19	1	JAN 2N5807	RCA	Triac (Q7)
20	1	15K,1W		Resistor, carbon (R1)
21	1	20K		Resistor, carbon (R2)
22	1	1K		Resistor, carbon (R3)
23	1	200		Resistor, carbon (R4)
24	1	100289-501	IRC	Potentiometer, 500 ohm (R5)
25	1	1.2K		Resistor, carbon (R6)
26	2	2K		Resistor, carbon (R7,R25)
27	1	24K		Resistor, carbon (R8)
28	1	51		Resistor, carbon (R9)
29	2	150		Resistor, carbon (R10,R23)
30	4	58K		Resistor, carbon (R11,13,14,16)

continued

Item	Required	Part No.	Manufacturer	Description
31	1	820		Resistor, carbon (R12)
32	2	560		Resistor, carbon (R15,R19)
33	1	10K,2W		Resistor, carbon (R17)
34	1	200		Resistor, carbon (R18,R34)
35	1	510		Resistor, carbon (R20)
36	1	6.8K		Resistor, carbon (R21)
37	1	15		Resistor, carbon (R22)
38	1	27K		Resistor, carbon (R24)
39	1	390K		Resistor, carbon (R26)
40	1	1K		Resistor, carbon (R27)
41	1	3.9K		Resistor, carbon (R28)
42	1	100289-102	IRC	Potentiometer, 10K (R29)
43	1	8370K8	Cutler Hammer	Switch, toggle (S1)
44	2	J-0262	JBT	Switch, momentary (S2,S3)
45	1	9T51B0033	GE	Isolation transformer (T1)
46	1	CC2714	Western Elect.	Current transformer (T2)
47	1	N48X	Triad	Transformer (T3)
48	1	6185-100-1/4	Drake	Neon indicator (XD1)
49	1	HKP-HH	Bussmann	Fuse holder (XF1)
40	1	HKP	Bussmann	Fuse holder (XF2)
51	1	20 AMP		Fuse AGC
52	1	0.5 AMP		Fuse AGC
53	1	125V-20A	Leviton	AC receptacle
54	1	540	Calex	Voltage comparator (U1)
55	1	A734		Operational amplifier (U2)
56	1		Sprauge	Capacitor, 8 MFD, 50 V (C7)
57	1	12K		Resistor, carbon (R35)
58	1	5.1K		Resistor, carbon (R36)

NOTE: All resistors 1/2 W and 5% unless noted.

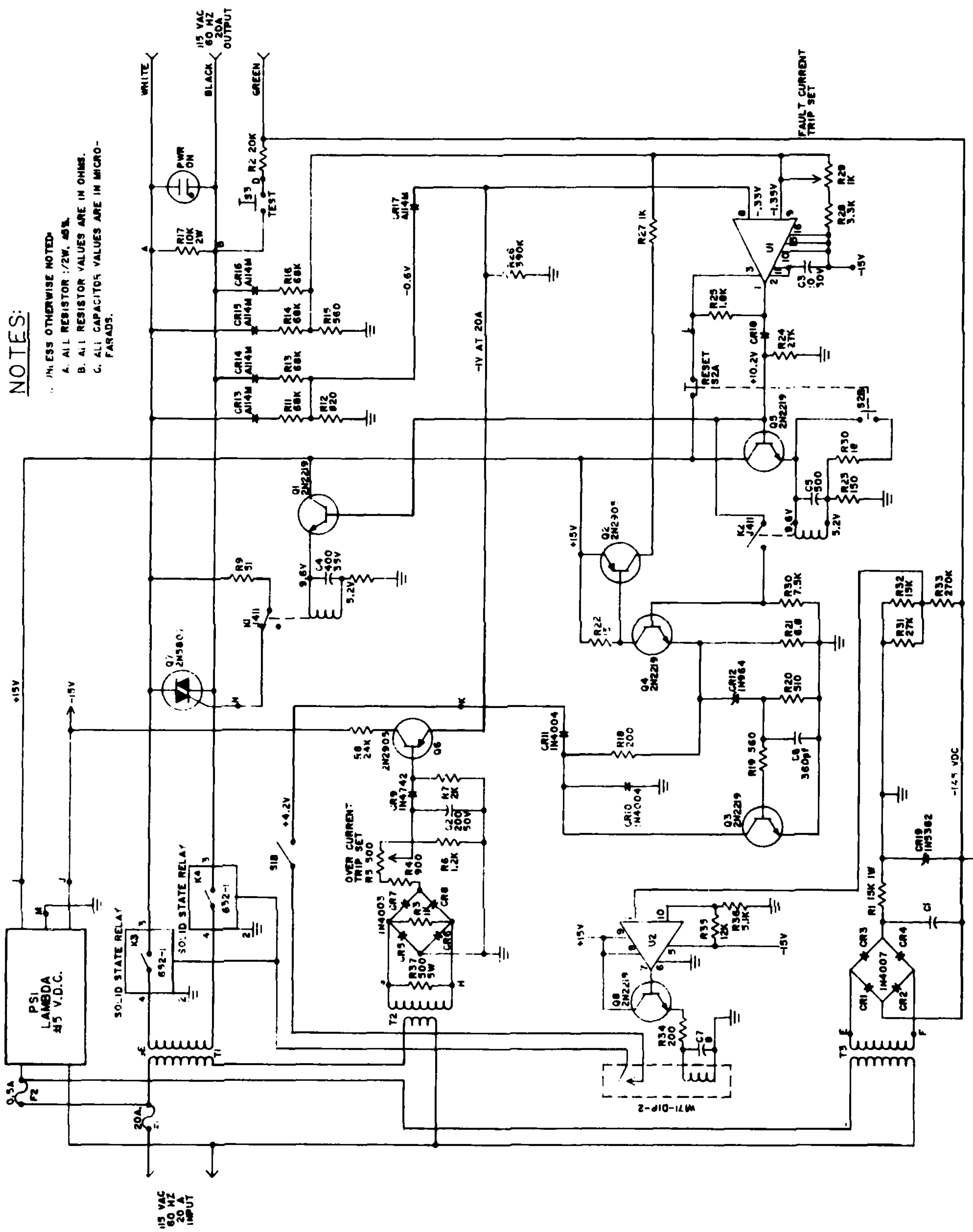

Figure C-1. Schematic of 2.5-kVA ground fault detector.

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SUBJECT CATEGORIES

1 **SHORE FACILITIES**
2 Construction methods and materials (including corrosion control, coatings)
3 Waterfront structures (maintenance/deterioration control)
4 Utilities (including power conditioning)
5 Explosives safety
6 Construction equipment and machinery
7 Fire prevention and control
8 Antenna technology
9 Structural analysis and design (including numerical and computer techniques)
10 Protective construction (including hardened shelters, shock and vibration studies)
11 Soil/rock mechanics
13 BEQ
14 Airfields and pavements
15 **ADVANCED BASE AND AMPHIBIOUS FACILITIES**
16 Base facilities (including shelters, power generation, water supplies)
17 Expedient roads/airfields/bridges
18 Amphibious operations (including breakwaters, wave forces)
19 Over-the-Beach operations (including containerization, materiel transfer, lighterage and cranes)
20 POL storage, transfer and distribution
24 **POLAR ENGINEERING**
24 Same as Advanced Base and Amphibious Facilities, except limited to cold-region environments
28 **ENERGY/POWER GENERATION**
29 Thermal conservation (thermal engineering of buildings, HVAC systems, energy loss measurement, power generation)
30 Controls and electrical conservation (electrical systems, energy monitoring and control systems)
31 Fuel flexibility (liquid fuels, coal utilization, energy from solid waste)
32 Alternate energy source (geothermal power, photovoltaic power systems, solar systems, wind systems, energy storage systems)
33 Site data and systems integration (energy resource data, energy consumption data, integrating energy systems)
34 **ENVIRONMENTAL PROTECTION**
35 Solid waste management
36 Hazardous/toxic materials management
37 Wastewater management and sanitary engineering
38 Oil pollution removal and recovery
39 Air pollution
40 Noise abatement
44 **OCEAN ENGINEERING**
45 Seafloor soils and foundations
46 Seafloor construction systems and operations (including diver and manipulator tools)
47 Undersea structures and materials
48 Anchors and moorings
49 Undersea power systems, electromechanical cables, and connectors
50 Pressure vessel facilities
51 Physical environment (including site surveying)
52 Ocean-based concrete structures
53 Hyperbaric chambers
54 Undersea cable dynamics

TYPES OF DOCUMENTS

85 Techdata Sheets
86 Technical Reports and Technical Notes
82 NCEL Guide & Updates
83 Table of Contents & Index to TDS
91 Physical Security
☐ None— remove my name

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