



SOLID STATE ELECTRIC POWER SUPPORT EQUIPMENT FOR B-1B HANGAR MAINTENANCE

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power. The off-the-shelf units will require	some modifications	to reduce the	e harmonic dis-
tortion and to improve the voltage regulation	in order to meet	current speci:	fications (MIL-M-
4803D, General Requirements for Motor-Generat	ors). Specification	ons for solid	state frequency
The frequency requalition of the solid state f	tem manager and	will be simila	ar to MIL-M-48031
addition, the wide power factor operating ran	requency converter	r maintenance	and anticinated
improvement in the mean time between failure	continue to make t	his technology	attractive as
an alternative for providing 400 Hertz facili	ty power for aircr	aft use.	
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SOLID STATE ELECTRIC POWER SUPPORT EQUIPMENT FOR B-1B HANGAR MAINTENANCE

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APPROVED: Specific action by organizations or units will not be taken as a result of this report unless requested by HQ SAC under separate cover.

FOR THE COMMANDER IN CHIEF

CHARLES C. CARPENTER, Colonel, USAF Director of Aircraft Maintenance DCS/Logistics Headquarters Strategic Air Command

#### SUMMARY

Two commercially available solid state frequency converters (90) KVA, 60 Hertz to 400 Hertz, 3 phase WYE systems) were evaluated in a field test to determine if their electrical power output quality was acceptable for U.S. Air Force systems. Load bank and aircraft testing determined that the solid state frequency convertors are capable of producing acceptable power. The offthe-shelf units will require some modifications to reduce the harmonic distortion and to improve the voltage regulation in order to meet current specifications (MIL-M-4803D, General Requirements for Motor-Generators). Specifications for solid state frequency conversion equipment are being drafted by the item manager and will be similar to MIL-M-4803D. The frequency regulation of the solid state frequency converters was exceptionally good. In addition, the wide power factor operating range, easy access for maintenance, and anticipated improvement in the mean time between failure continue to make this technology attractive as an alternative for providing 400 Hertz facility power for aircraft use.

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#### I. INTRODUCTION

1.1 PURPOSE: The purpose of this engineering project was to investigate and document the performance of 230 volt, 400 Hz solid state frequency converters for possible U.S. Air Force use.

1.2. BACKGROUND: HQ SAC/LGSE and SM-ALC/MMI were approached by two manufacturers of solid state frequency conversion equipment with offers to provide articles for test at no cost to the government. This technology has the promise of providing high quality power with reduced operating and maintenance cost. The initial cost of the solid state frequency converters also appears to be competitive with the motor-generator type equipment currently in the Air Force inventory. SM-ALC and both manufacturers wanted to test 230 volt, 400 hertz, three phase WYE systems since this voltage is used on the B-1B and is also expected to be used on future aircraft.

#### II. PROCEDURES

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The objective of the test was to investigate the performance, electrical properties and construction of two solid state frequency converters. An ECU-105 motor-generator was also tested to provide control data. The following three power conversion units were tested:

(a) Article 1 was a 90 KVA, 230 volt, three phase WYE, solid state frequency converter manufactured by Jetway Division of Abex Corporation. Jetway representatives were invited to monitor the test.

(b) Article 2 was a 90 KVA, 230 volt, three phase WYE, solid state frequency converter manufactured by Controlled Systems incorporated. Controlled Systems representatives were invited to monitor the test.

(c) Article 3 was a 75 KVA, 230 volt, three phase WYE, ECU-105 motor-generator currently in the Air Force inventory and available at Dyess AFB, Texas.

The test sequence is described below. Two series of tests were conducted. The first test sequence appraised each unit's performance on a load bank and the second applied power to an aircraft to ensure that anticipated aircraft hangar maintenance loads could be supplied by each unit.

2.1 LOAD BANK TEST -- This test sequence provided the data necessary to determine the output voltage adjustment range, voltage and frequency regulation, voltage modulation, phase voltage imbalance, total harmonic distortion, and transient voltage and frequency stability. Descriptions of these parameters are contained in appendix A. The test aquipment configuration is shown in appendix B, figure 1.

(a) Allow the unit to warm-up for 10 minutes at50 percent load.

(b) Determine the range of output voltage adjustments and the adjustment step size under no load conditions. Set the output voltage to 230 volts line to neutral.

(c) Under balanced conditions, with 1.0 power factor loads at 0, 25, 50, 75, and 100 percent of the rated load measure the:

-- Voltage (line to neutral) and current on each phase at the input panel (Fluke 8060, 801-600).

-- Voltage (line to neutral) and current on each phase at the output panel (Fluke 8060, 801-600).

-- Voltage, current, KVA, KW, KVAR, and power factor at the load end of the cutput cable (Dranetz 808).

-- Frequency on each phase of the output (Fluke 8060).

-- Maximum and minimum output voltage waveform peak heights on each phase in a two minute period (Sencore Oscilloscope).

--- Harmonic content of the output voltage waveform on each phase (HP-331A).

(d) Repeat step (c) with the power factor changed to Ø.8 lagging.

(e) Load one phase at a time to 50 and 100 percent of the rated per phase load (power factor=1.0) and at each step measure the:

-- Voltage, current, KVA, KW, KVAR, and power factor at the load end of the output cable (Dranetz 808).

-- Harmonic content of the output voltage waveform on each phase (HP-331A).

(f) Repeat step (e) with the power factor changed to Ø.8 lagging.

(g) Monitor the voltage and frequency transpent response to sudden load changes with a Dranetz 606-3 Line Disturbance Analyzer. The Dranetz 606 was configured to monitor three phase, 400 Hz WYE connected power systems. The following data are recorded.

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-- Slow average output voltage. This is the average output voltage over a 10 second period. Deviations greater than plus or minus 3 volts and the time the deviation occurred are printed.

-- Sag/Surge voltage. Any deviation of plus or minus three volts from the slow average output voltage was recorded. The voltage used for sag/surge measurements is the average voltage over 8 periods of a 400 Hz signal. The duration of the sag/surge is recorded as the number of cycles where the 8 period average voltage remained three volts or more away from the slow average output voltage. The time the deviation started is also printed.

-- Impulse voltage. Whenever a "spike" or impulse voltage (duration of Ø.5 to 800 microseconds) differed from the anticipated instantaneous voltage by plus or minus 50 volts, the time, phase and peak voltage deviation from the AC line voltage were printed.

-- Output frequency deviation. Whenever the one second average frequency deviated more than plus or minus 4 Hz from the last printed value (nominally 400 Hz), the frequency and time of occurrence were printed.

First, the generator was subjected to a step decrease in load from 50 percent load with a 1.0 power factor to no load. After the voltage and frequency stabilized, the 50 percent, 1.0 power factor load was reapplied as a step function.

Then, the load was increased to 100 percent of the rated output with a 1.0 power factor. The generator was then subjected to a step decrease from full to no load. After the voltage and frequency stabilized, the 100 percent, 1.0 power factor load was reapplied as a step function.

(h) Repeat step (g) with a Ø.8 power factor.

2.2 AIRCRAFT TEST -- This test examined the ability of each unit to supply power to an wircraft. The power units were instrumented with a Dranetz 808 Power Demand Analyzer and a Dranetz 606-3 Power Line Disturbance Analyzer connected to the end of the output cable through the remote sensing leads. The equipment configuration is shown in appendix B, figure 2. The test steps consisted of:

(a) Applying power to the aircraft in the basic power-on configuration, load management mode 4 (LM 4). All switches were in the post flight configuration.

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(b) Turn-on the fuel transfer pumps.

(c) Turn-on the fuel boost pumps by placing the engine start switches to the run position.

(d) Return all switches their original position and remove external power from the aircraft.

### III. RESULTS AND DISCUSSION

3.1 LOAD BANK TEST -- All of the data collected during this portion of the test are tabulated in appendix C and F. Several general comments about the test data and procedures are required before proceeding into a detailed discussion of the data.

The test was started in Dyess AFB Aerospace Ground Equipment (AGE) facility but had to be terminated and restarted in hangar 5020. The AGE facility power was rated as 480 V line to line; but when measured, the voltage was found to be 419 V line to line. Since the manufacturers had been informed that the input voltage would be 480 V, their equipments were not configured for 419 V input. Since Jetway had a variable tap input transformer on their unit they could, with minor rewiring, handle the lower voltage. However, since the CSI unit did not have variable input capability the testing was moved to another facility where the no load input voltage was 495 V line to line. At full load, the input voltage only dropped to 481 V line to line. All of the data obtained prior to moving to the new facility is not presented in the data tables. Thus, the test data was collected with virtually identical input voltages, loads and test equipment. A different ECU-105 was used for the test conducted in hangar 5020.

When a different ECU-105 was used for testing in hangar 5020; discrepancies in the data led to the discovery of a problem with the first ECU-105. The new ECU-105 used in the AGE shop test required maintenance since the input power required to operate at no load approached 30 KVA. This unit was later found to be "stuck in the start mode". The ECU-105 appeared to operate normally, and the problem would probably not have been discovered in normal use.

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The three units tested provided the opportunity to examine different mounting options. The ECU-105 was skid mounted while the Jetway unit was trailer mounted and the CSI unit was a floor/wall mountable unit. Both CSI and Jetway indicated that their companies had floor and trailer mountable versions of their equipment. SAC prefers that the mounting of the units be an option decided at the time of purchase. Some applications can use the floor/wall mounting system to get the equipment out of the way while trailer mounting provides the flexibility to reposition the units in hangars where they are most needed. Trailer mounted units also help to reduce the length of 400 Hz power output cables.

The output voltage adjustment on all test articles was continuous over at least a 40 volt range. The Jetway unit voltage adjustment was not easily accessible and required a circuit card to be removed. This needs to be changed and steps / were taken to modify this feature during the test. The CSI voltage adjustment consisted of an easily turned knob on the exterior control panel of the unit. This should be changed to require a screwdriver in order to prevent unintentional changes to the output voltage. ECU-105 voltage adjustment could be accomplished with a screwdriver and was accessible on the controlpanel.

The remote sensing cable, manufactured by Burton Electric worked well. Voltage measurements at the load bank and at the remote sensing lead terminations were within Ø.5 volts of each other. These leads were used to measure the voltage at the end of the output cable.

The results are presented in relation the the rated output of Both solid state converters were rated at 90 the test article. KVA while the ECU-105 is rated at 60 KW or 75 KVA at a 0.8 power factor. There were no power factor restrictions on the solid state frequency converters and the maximum KW rating was also 90 In order to keep any comparison of data as fair as possible, KW. the loads are expressed as a percentage of the rated load. The real power limit of the solid state converters was treated as if the rated output in KVA was at a Ø.8 power factor. Thus, the base for the solid state frequency converter real power load percentages is 72 KW (90KVA \* 0.8). The loads applied to each unit were matched as well as possible.

Balanced three phase loads -- Each load was balanced as 3.1.1 well as possible given the capabilities of the load bank. In the discussion that follows, references to 1.0 and 0.8 power factors should be understood to be the nominal values that were attempted to be matched. The same situation applies to the term balanced . three phase loads. No effort was spared to obtain equal currents in each phase; however, some imbalance existed in all loads. Failure to obtain well balanced loads will most seriously affect the phase voltage imbalance. If the currents in the output cable are unequal, the voltage drops in each phase will be unequal causing the measured phase voltage imbalance to be higher than if the load was perfectly balanced. The potential problem of unbalanced loads did not seriously affect the phase voltage imbalance as discussed further in section 3.1.1.2. The other calculated parameters, voltage regulation, frequency regulation and voltage modulation, are less sensitive to slightly unbalanced conditions since these parameters are based on either averages or single phase data. The results obtained from balanced three phase loads are summarized in table 1 for all three test articles. The following discussion will be based on the data summarized in table 1 and found in appendix C.

	6.6 6.8 7.8 5.5 56 56 56 57 59 59 50 50 50 50 50 50 50 50 50 50 50 50 50		NOMINAL	1.0 pf		:: ::		NOMINAL Ø	.8 pf	
	LI LOAD X II	1.05	24.08 ;	47.41 (	70.41	98.68	24.17	49.79	76.52	99.5
	PF	0.90	Ø.99 i	0.99	Ø.99 ;	Ø.99 !!	0.83	0.80	Ø.83	0.8
STATE	EFFICIENCYX !!	0.89	27.87	32.38	35.57	39.10	33.51	42.14	46.Ø1	48.0
	II PVIX II	Ø.16	0.22	0.24	Ø.26	0.25	0.22	Ø.81	Ø.42	Ø.5
SUMMARY	li Vreg X ii	0.00	0.42	9.48	0.21	1.61 !!	1.57	1.01	1.10	1.8
	li Freg X II	0.00	9.09	9.00	0.00	9.99 ::	9.09	0.00	0.00	0.0
	Avg Vmod X 11	Ø.12	Ø.10	0.15	0.15	0.12	Ø.19	Ø.17 ;	Ø.12	0.1
	II Avg THD II	1.32		1.74	1.88	1.74	i   	1.92 ;	i	1.9
	LOAD X II	1.06 ;	24.63	47.93	71.71	97.20 ::	25.10	48.31	72.45	103.0
	:: PF ::	Ø.89	9.99	Ø.99	Ø.99 ¦	0.99	Ø.83 (	0.81	Ø.83	Ø.8
CSI SOLID	EFFICIENCYX II	12.59	25.64	32.38	32.64	35.92	33.94	38.24	43.18	44.4
STATE	II PVI X II	0.12	0.07	0.07	0.09	0.09	0.43	Ø.81	Ø.16	Ø.4
CONVERTER	li Vreg X II	Ø. <b>Ø</b> 9	Ø.29	Ø.96	Ø.28	Ø.49	0.86	1.66	2.40	4.3
SUNMARY	Il Freg X II	Ø.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Avg Vmod X 1	1.16	1.57	Ø.65	1.13	0.79	1.10	Ø.87	Ø.61	Ø.7
	II Avg THD II	3.45		2.32		4.60		2.33	i	2.Ø
	ILOAD X II	1.25	29.37	49.01 1	80.73	101.66 ;;	26.99	60.17	72.67	104,4
	PF	Ø.89	0.99	Ø.99	Ø.99	Ø.99	Ø.82	Ø.85	Ø.84	0.8
ECU-105 MOTOR-	EFFICIENCYX ::	5.88	24.95	38.02	48.98	54.42	33.37	53.95	57.99	64.1
GENERATOR	PVIX	0.07	Ø.Ø6	Ø. 19	Ø.43	0.22	0.17	0.57	Ø.15	0.3
SUMMARY	Vreg ¥	0.00	0.03	Ø.18 !	Ø.29	0.19	Ø.47	Ø.16	Ø.26	Ø.2
	} Freg X	Ø.ØØ :	Ø.Ø1	0.03	0.03	Ø.00	0.02	Ø.Ø2	Ø.Ø3	0.0
	Avg Vmod X 11	0.07	Ø.Ø5	0.02	0.07	0.05 11	Ø.15	Ø.Ø5	0.05	0.0
	I Avg THD	Ø.44		0.42		0.40		Ø.39		0.3

TABLE 1: Data Summary for Balanced Three Phase Loads at 1.0 and 0.8 Power Factors (pf)

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3.1.1.1 Efficiency -- The efficiency data obtained during the test was not usable. In using the Fluke 8060 multimeter with the matching inductive AC current pick-up 801-600, significant errors were introduced into the data. The equipment was bench checked with short duration current pulses in an attempt to simulate the solid state frequency converter input waveform and the multimeter/probe values were found to be in error by as much as 15 percent relative to measurements made with the meter alone. The error is believed to be the result of the inductive probe acting as a highpass filter. This problem only affects the input of the solid state frequency converters since they draw current only when required to form the output sinusoidal. Retrospectively, the input and output power flow should have been measured with watt meters and power factor meters of a type similar to that used by utility companies. in any case, the efficiency data must be neglected.

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3.1.1.2 Phase voltage imbalance -- The phase voltage imbalance remained less than one percent for all balanced three phase loads at 1.0 and 0.8 power factors. The solid state frequency converters had very flat response curves for 1.0 power factor loads while the motor-generator exhibited greater data spread (See Appendix D, Figure 1). The 0.8 power factor data for all test articles showed a response curve similar to the shape of the 1.0 power factor ECU-105 response curve. Since all three test articles displayed similar curves for 0.8 power factor loads, this shape is not thought to be caused by normal data distribution. However, at this point, the shape of the curve cannot be explained.

3.1.1.3 Voltage regulation -- With 1.0 power factor loads only one data point (100% load for the Jetway test article) fell outside the desired voltage regulation limit of 1.0 percent. See Appendix D. Figure 3 for the plotted data. The data obtained for Ø.8 power factor loads (See Appendix D, Figure 4) was not as favorable. Both solid state frequency converters failed to maintain the voltage regulation below 1.0 percent. The lack of adequate regulation could have been caused by readjusting the voltage regulators when the test location was changed to avoid the hangar low voltage problem previously discussed. Both output voltage and line drop compensation were adjusted by the solid state converter manufacturer's representatives when the test location changed. The adjustments were quickly made without technical data and more meticulous adjustment procedures may be all that is required to improve the regulation. After the test started, no further adjustments were allowed. If better adjustment procedures do not correct the problem, another possibility is changing the regulator design. In any case, the output voltage regulation of the colid state frequency converters will require improvement to meet the anticipated voltage regulation specification of one percent. This should not be a serious problem since numerous pleces of electrical generating equipment are capable of meeting this requirement.

3.1.1.4 Frequency regulation -- The frequency regulation of all three test articles at both 1.0 and 0.8 power factors (See Appendix D, Figures 5 and 6) was well within acceptable operating limits for aircraft power. The frequency regulation of the crystal controlled solid state frequency converters was perfect at all load and power factor settings.

3.1.1.5 Voltage modulation -- The maximum voltage regulation allowed under MIL-M-4803D(USAF) is 1.0 percent. The percent voltage modulation for two of the test articles (the ECU-105 and Jetway) remained under 0.2 percent for all loads and power factors (See Appendix D, Figures 7 and 8). Voltage modulation greater than 1.0 percent was recorded for the CSI test article under some of the load conditions. These high voltage modulation values were observed for both 1.0 and 0.8 power factor loads.

3.1.1.6 Totai harmonic distortion -- The total harmonic distortion was unacceptable on the CSI test article and marginal on the Jetway test article in relation to the maximum of 2.0 percent referenced in MIL-M-4803D (See Appendix D, Figures 9 and 10). The same limit is expected to apply to solid state frequency converters when their general requirement specification is completed. CSI literature indicates that they have a harmonic filter available as a option that will reduce the harmonic content of their output to less than 2.0 percent.

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3.1.2 Single phase loads -- The single phase loads tested are worst case conditions where only one phase is loaded to a percentage of the single phase'rated power (1/3 of the total rated output power) at both 1.0 and 0.8 power factors. This load is not expected to be encountered in normal operations, however there may be occasions when single phase motors would be operated from the three phase sources. Fault conditions could also result in somewhat similar conditions where one phase is drawing significantly higher current than the other two phases. The data obtained can be found in appendix C and is summarized in table 2. The no load data points used in the appendix D figures are obtained from the no load balanced three phase data presented previously in table 1. The following discussion is based on the data in table 2.

TABLE 2: Data Summary for Single Phase, 1.0 and 0.8 Power Factor Loads.

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			11	NOMINAL	1.Ø PF ;	NOMINAL	Ø.8 PF ::
JETWAY		LOAD %	11	49.91	96.61 ;	46.Ø5	87.11 ::
STATE		PF		Ø.99	Ø.99	Ø.78	Ø.89 ::
CONVERTER		PVI %		1.51	4.13	5.16	8.61
SUMMARY		Vreg %		1.9Ø	3.68	Ø.73	1.70
	;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;	Avg THD		2.29	2.97 (	3.27	5.02
CSI SOLID		LOAD %		45.91	83.74 ;	43.09 ;	84.35
STATE		PF	· · ·	Ø.99	Ø.99	Ø.79	Ø.87
CONVERTER		PVI %		4.63	8.32	9.Ø2	14.13
SUMMARY		Vreg %	 	Ø.23	Ø.26	Ø,41	Ø.62
	• •     •	Avg THD		3.68	5.03 ;	4.33	? FQ FLUX !!
ECU-105		LOAD %		51.63	92.02 :	55.31	89.87
GENERATOR		PF		Ø.99	Ø.99	Ø.88	Ø.87
SUMMARY		PVI %		1.65	3.18	2.57	4.69
		Vreg %		1.55	2.88	2.Ø1	3.94
	;; ;;	Avg THD	· · ·	Ø.49	Ø.67	Ø.51	Ø.67

3.1.2.1 Phase voltage imbalance -- All three test articles failed to remain within the 3.0 percent phase imbalance upper limit as specified in MIL-M-4803D, paragraph 3.7.9, when the maximum single phase load was applied. The data for 1.0 and 0.8 power factor loads are plotted in appendix D, figures 11 and 12. With this severe single phase load, maintaining the phase voltage imbalance would probably require circuitry that could independently sense and control each phase voltage. This requirement, due to the extreme nature of the load, warrants reconsideration when the specifications for solid state frequency conversion equipment are finalized.

3.1.2.2 Voltage Regulation -- Voltage regulation requirements for single phase loads are not specifically stated in MIL-M-4803D, but the specification does call for the output voltage to be controlled to within 1.0 percent "throughout the power factor and load range" in paragraph 3.7.4. Appendix D, figures 13 and 14, show that the only the CSI test article achieved this level

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of performance. This was not expected since the CSI test article did not perform this well for the balanced three phase loads. This performance is also attributed to adjustment of the voltage regulator as was the poor performance described in paragraph 3.3.3.2. These findings support the opinion that the observed voltage regulation is not a serious problem for any of the test articles.

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3.1.1.3 Total harmonic distortion -- The total harmonic distortion for single phase loads is presented in appendix D, figures 15 and 16. The total harmonic distortion limit of 2.0 percent as contained in MIL-M-4803D, paragraph 3.7.7, does not clearly apply to single phase loads. Only the ECU-105 test article maintained the harmonic content within 1.0 percent for all single phase loads. The CSI test article had a frequency flux at the nominal 100 percent load, 0.8 power factor data point, that prevented obtaining harmonic content data.

3.1.3 Load bank shock loads -- All three test articles were shock loaded and unloaded at nominal loads of 50 percent and 100 percent of the rated output at both 1.0 and 0.8 power factors. The actual shock loads are documented in appendix E and the results are shown in table 3.

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	<b>P</b> 223
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	<b>د</b> ۲۹۴
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TABLE 3. Shock Load Transient Voltag	ge and Duration Summary
--------------------------------------	-------------------------

	11	11	11		JETWAY	<u>а</u> П		CSI	11		ECU-105	::
		11	11			!!		***	!!			!!
	11	11	11	MAXIMUM 11	::	11	MAXIMUM II	::	::	MAX HUM 11	11	11
	11	11	11	SAG/SURGE! :	TOTAL !!	11	SAG/SURGE!!	TOTAL !!		SAG/SURGE!!	TOTAL !!	11
	11	11	11	VOLTAGE !!	RECOVERY !!	11	VOLTAGE ::	RECOVERY !!	11	VOLTAGE !!	RECOVERY ::	11
LOAD	11	PF 11	SHOCK	DEVIATION::	TIME (SEC) ::	TYPE II	DEVIATION	TIME (SEC) ::	TYPE 11	DEVIATION	TIME (SEC) ::	TYPE II
2222225	a=	=====;;	=====;;	=======;;	**********	*****			=====;;	=======;;	=======;;	=====;;
	11	1.8 ::	ON	-16 ;;	6.64 ::	UD !!	-8 ::	Ø.Ø2	0D ::	NR II	!!	11
	- 11		!!	!!		!!	!!	!!	!!	********	!!	!!
	11	1.0 ::	OFF II	32 ::	Ø.18 👯	0D !!	8	Ø.Ø6	OD ::	NR 11	!!	11
50 X	11	!!			!!						!!	
•• •	H	Ø.8 !!	ON 11	-12 !!	6.64 1	UD 11	-12 11	6.20 1	00 11	-12 11	Ø.11 11	00 11
	11	!!	!!	!!		!!	!!		!!			!!
		a.a.!!	OFF !!	34 !!	6.26	00 ::	12 11	0.94 11	00 ::	16 !!	6.12	00 !!
2222222	as!!	22322!!		========!!	123212X25!!	======!!	==========!!	==============	=====!!	========!!		=====!!
	11	1 6 !!	ON !!	-30 !!	A 1A !!	10 !!	-18 !!	G GA !!	00 !!	-A !!	6 12 !!	00 !!
		!!		!!	!!	!!	!!		!!	!!	!!	!!
		1 41 1	055 11	54 11	a 24 !!	00 11	19 11	a ag !!	00 !!	101 11	G 24 !!	00 11
188 V		1.0 11		11 90			11 21				U.24 11	
100 4		a o + i			a 1a 11		-14 !!	1 10 11	00 11	_ 20 + 1	A 25 11	00 11
		19.0 ii	- UNI ii	-30 11	1 <b>0.110</b> ii	00 11	-14 ii	1.13	00 11	-20 11	10.25	00 11
	11	;;		;;	ii		ii	ii	;;	ii	ii	;;
	;; ;;	<b>U.</b> 8 ii	UPF ii	08 ;;	<b>U.30</b> ii		20 ;;	Z.14 ii		28 ;;	10.42 ii	

NR = no recorded transients

00 = overdamped

UD = underdamped

The data in table 3 is derived from Dranetz 606-3 Line Disturbance Analyzer recorded deviations. Presently, no equivalent to MIL-STD-704D, Aircraft Electric Power Characteristics, exists for 230 volt systems. However, if the same time and voltage deviation limits as shown in MIL-STD-704D, figure 5, are transposed to a 230 volt steady state limit, a possible reference is obtained. This 230 volt based, AC voltage transient response envelope is shown in appendix F, figure 1. An oscillograph is required to precisely determine if the transient response remains within the appendix F, figure 1 envelope and the Dranetz 606-3 simply cannot provide the data required for an exact determination of the transient response. Since the rise time to the peak voltage is not known, it is not possible to develop a second order mathematical model of the response. In order to make a reasonable determination as to whether the envelope is broached, some rather broad assumptions must be made. Assuming that the highest voltage deviation occurs at the onset of the transient and that the voltage decays exponentially, returning to the original steady state value at the recovery time shown in table 2, a first order model can be derived.

First, define tau as :

Total Recovery Time au = -----4

and the equation:

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 $V = 230 + Ae^{(-t/teu)}$ 

where V is the instantaneous voltage at time t and A is the signed magnitude of the maximum voltage deviation. This equation was utilized to develop the possible response curves for the test articles contained in appendix F, figures 2 through 7. The limits displayed in appendix F, figure 1, are also displayed on the other figures.

The calculated response curves for the Jetway test articles are shown in appendix F, figures 2 and 3. The unit failed to respond fast enough to prevent the voltage from exceeding the limits for the 100 percent sudden load removal. The voltage response to the other shock loads essentially (a few data points did not) remained within the voltage limits of appendix F, figure 1.

The calculated response curve for the CSI test article are shown in appendix F, figures 4 and 5. None of the calculated response curves exceeded the limits when 1.0 power factor loads were applied and removed. The response seen with 0.8 power factor loads had small magnitude deviations, but the long response time caused the calculated response curves to exceed the desired limits.

The calculated response curve for the ECU-105 test article are shown in appendix F, figures 6 and 7. None of the calculated response curves exceeded the limits when 1.0 power factor loads were applied and removed. With 0.8 power factor loads, only the 100 percent shock load calculated response curves went out of the limits.

The mathematically generated data basically confirm that the voltage response needs to be improved for the voltage to remain in the desired limits when a 100 percent shock load is applied or removed. The calculated data also show that, for the normally encountered case where the shock load represents less than 50 percent of the units rated output, the voltage limits are essentially maintained except for some 0.8 power factor loads.

## 3.2 AIRCRAFT POWER-ON TEST RESULTS

The aircraft test was significantly less demanding than the load bank test. The shocks were not as great and the overall loads did not push the operating limits of the test articles. Only the Jetway and ECU-105 test articles were applied to the aircraft, B-18 #050. The CSI test article was not included in this portion of the test due to the high harmonic content and voltage modulation on their standard unit. Also, in keeping with the purpose of the test to document the feasibility of solid state frequency conversion technology for Air Force aircraft power generation, one solid state frequency converter could provide the required data.

When power was applied to the aircraft in the basic LM-4 configuration, the power consumption was 7.9 KVA at a Ø.99 power factor. No transients were observed with either test article when this load was applied. Next, the fuel transfer pumps were turned on increasing the load to 27.5 KVA at a Ø.88 lagging power The Jetway voltage deviated slightly from the steady factor. state value of 228 volts on each phase. Both the A and C phase voltage climbed to 236 volt and damped out in Ø.Ø6 seconds while the B phase voltage climbed to 234 volts for 0.04 seconds. The Jetway voltage control appeared overdamped in this situation since no oscillations were recorded. The ECU-105 steady state voltages on A, B and C phase were 232, 232 and 230 volts respectively. The ECU-105 voltage transients oscillated between the values of 222 volts and 236 volts for Ø.4 seconds before damping out to the steady state conditions. The time required for each half cycle (time between consecutive steady state crossings) was approximately 0.08 seconds. The main fuel boost pumps were then energized by placing the engine start switches in the run position thus increasing the electrical load to 42.1 KVA No transients were recorded for at a Ø.84 lagging power factor. the Jetway test article. The ECU-105 B phase voltage sagged to 224 volts for 0.04 seconds. When the loads were removed by first turning off the fuel transfer pumps followed by the fuel boost pumps, no additional voltage transients were recorded. The aircraft accepted the electrical power from both the Jetway and ECU-105 test articles and the routine maintenance task of pressurizing the fuel manifolds was completed without any problems.

## IV. CONCLUSIONS

The solid state frequency converters were found to provide acceptable power. The frequency regulation was excellent, but the voltage regulation and total harmonic distortion will need improvement before solid state frequency converters can replace motor-generators. Procurement specifications being prepared by SM-ALC/MMIEC address the problems observed during this engineering project. Power generating equipment built to meet the SM-ALC specification will have power quality equivalent to motor-generators. The two off-the-shelf converters tested should be able to meet the final procupement specification with. relatively minor modifications. The anticipated improvement in mean-time-between failures, reduced time to repair, and unlimited. power factor range make solid state frequency converters a viable, option for replacing motor-generators. As the aircraft load power factors become more reactive, the unlimited power factor range will become more important.

#### IV. RECOMMENDATION

HQ SAC/LGME recommends that:

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a. AFLC SM-ALC/MMI release procurement specifications and stock list solid state frequency converters.

b. HQ SAC/LGSE arrange to purchase five stock listed solid state frequency converters as replacements for condemned motorgenerators, providing the projected life cycle cost is favorable.

c. HQ SAC/LGSE, with LGME assistance as required, inspect the initial solid state frequency converters and monitor their performance during the first year of operation. This would ensure documentation and resolution should unforeseen problems develop.

d. Contracts include warranty provisions that specify 20,000 hours before failure.

# V. DISTRIBUTION

- 11 HQ SAC/LGME(5)/LGMS/LGSE(2)/LGXB/LGMA/DEEQ, Offutt AFB, NE 68113-5001
- 5 SM-ALC/MMI/MMIK/MMIE/MMIEC(2), McClelian AFB, CA 95652-5000
- 1 96 BMW/MA, Dyess AFB, TX 79607-5000
- 1 28 BMW/MA, Elisworth AFB, SD 57706-5000
  - 6 Appendices
  - A. Electric Power Support Equipment
  - Test Descriptions B. Test
  - Instrumentation
  - C. Load Bank Test Data
  - D. Figures
  - E. Shock Loads
  - F. Transient Response Figures

Appendix A

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## APPENDIX A

## ELECTRIC POWER SUPPORT EQUIPMENT TEST DESCRIPTIONS

# I. INTRODUCTION

This appendix describes the procedures and data that will be collected for tests of electrical generating equipment for aircraft use. The tests come from numerous sources and have been modified to suit the needs of HQ SAC. These tests do not constitute a initial article inspection as required by AFLC. The tests provide SAC with an abbreviated inspection/evaluation of electrical generating equipment before SAC has to operate the equipment under field conditions.

### II. GENERAL SYSTEM CHECKS

2.1 VOLTAGE ADJUSTMENT -- The range of output voltage adjustment and the adjustment step size. if applicable, will be determined by adjusting the voltage regulator under no load conditions. Voltage measurements can be made at either the load or the unit end of the output cable for this test. The desired range is plus or minus ten percent of the rated output voltage.

2.2 WORKMANSHIP -- Any deficiencies in the construction or design of the unit will be noted. Examples are sharp edges, poorly fitting joints, dissimilar metal contact, metal shavings, cold or sloppy electrical connections and unreadable/unclear operating and maintenance instructions.

2.3 MAINTAINABILITY -- Although this test cannot accurately predict the mean time between failure for the test article some qualitative assessments can be made concerning the unit's maintainability. This qualitative assessment will include:

- Periodic maintenance requirements.

- Ease of access for periodic maintenance.

- Ease of access to electronic components.

- Maintenance personnel and equipment requirements.

### III. TEST DESCRIPTIONS

3.1 EFFICIENCY -- The efficiency (Ef) in percent is defined as:

where Sin is the total input power in thousand volt amperes (KVA) and Sout is the output power in KVA. A Fluke 8060 true RMS

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multimeter with an 801-600 inductive current probe will be used to measure each phase current. The voltage of each phase (line to neutral) will also be measured with the Fluke 8060 multimeter. The value for the total power (S) for both input and output is found with the equation:

#### S=(Van\*la)+(Vbn\*lb)+(Vcn\*lc)

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Measurements of the efficiency shall be made at three phase balanced loads. Data points will be obtained with loads close to the Ø, 25, 5Ø, 75, and 1ØØ percent of the rated load at a power factor of Ø.8Ø lagging. Another set of data points will be obtained with a 1.Ø power factor. Voltage measurements will be made at the input and output terminals of the unit to prevent the power cables from altering the basic unit parameters.

3.2 REGULATION -- The ability of the unit to maintain a set voltage and frequency for loads varying from Ø to the full rated output will be examined. In this test, the unit will be operated at Ø, 25, 50, 75, and 100 percent of the rated output for power factors of Ø.80 lagging and 1.0. The line to neutral voltage of each phase will be measured at the load end of the output cable. A Dranetz 808 power Demand Analyzer will provide the voltage, current, load and power factor data. The frequency will be measured at any convenient point on the output cable. Either an oscilloscope with digital frequency readout or a Fluke 8060 multimeter will be used to measure the output frequency.

3.2.1 <u>Voltage regulation calculation</u> -- The voltage regulation (VRx) in percent as a function of the load is calculated with the equation:

where Vo is the no load average line to neutral voltage and VI is the average line to neutral voltage when loaded at x percent of the rated output. MIL-M-4803 requires the VR to be less than or equal to one percent at all loads.

3.2.2 <u>Frequency regulation calculation</u> --The frequency regulation (FRx) in percent as a function of the load is calculated with the equation:

where Fo is the no load average frequency and FI is the average frequency when loaded at x percent of the rated output.

3.3 VOLTAGE MODULATION -- The ability of the unit under test to maintain a voltage without fluctuation at a given load is

represented by the percent voltage modulation. The peak line to neutral voltage waveform value is observed for two minutes and the highest peak voltage (Vpm) and the lowest peak voltage (Vpl) are recorded. The RMS values are calculated by assuming a true sinusoidal waveform, thus:

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 $Vmax = (Vpm)/(2^{.5})$  $Vmin = (Vp!)/(2^{.5})$ 

where Vmax is the maximum RMS voltage and Vmin is the mimimum RMS voltage observed during the two minute period. The percent voltage modulation (VM) is defined as:

.Vmax-Vmin
VM = ----- x (100)
Vmax+Vmin

The voltage measurements will be made with balanced three phase loads and with 0.80 lagging and 1.0 power factors at each load. Test loads will include 0, 25, 50, 75, and 100 percent of the rated unit output. The percent voltage modulation should be less than one percent for all load and power factor combinations.

3.4 TRANSIENT STABLLITY -- The ability of a power generating unit to respond to sudden changes in load is examined by recording the parameter of interest as a function of time. The worst case situation is to apply a full load step function to the output and to monitor the response followed by a sudden removal of the load after the unit stabilizes. This should be done for both 0.8 lagging and 1.0 power factors.

A Dranetz 606-3 Line Disturbance Analyzer was used to monitor the voltage and frequency transient response to sudden load changes. The Dranetz 606 was configured to monitor three phase, 400 Hz WYE connected power systems. The following data was recorded.

> -- Slow average output voltage. This is the average output voltage over a 10 second period. Deviations greater than plus or minus 3 volts and the time the deviation occoured are printed.

-- Sag/Surge voltage. Any deviation of plus or minus three volts from the slow average output voltage was recorded. The voltage used for sag/surge measurements is the average voltage over 8 periods of a 400 Hz signal. The duration of the sag/surge is recorded as the number of cycles where the 8 period average voltage remained three volts or more away from the slow average output voltage. The time the deviation started is also printed.

-- Impulse voltage. Whenever a "spike" or impulse voltage (duration of 0.5 to 900 microseconds) differed

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from the anticipated instantious voltage by plus or minus 50 volts the time, phase and peak voltage excluding the AC line voltage was printed.

-- Output frequency deviation. Whenever the one second average frequency deviated more than pfus or minus 4 Hz from the last printed value (nominally 400 Hz), the frequency and time of occurrence were printed.

First, the generator was subjected to a step decrease in load from 50 percent load with a 1.0 power factor to no load. After the voltage and frequency stabilized, the 50 percent, 1.0 power factor load was reappled as a step function. Then, the load was increased to 100% of the rated load with a 1.0 power factor. The generator was then subjected to a step decrease from full to no load. After the voltage and frequency stabilized, the 100 percent, 1.0 power factor load was reappled as a step function. These steps were repeated with a 0.8 power factor

The output voltage should not deviate more than plus or minus 10.0 percent from the voltage prior to the transient. Within 0.2 seconds from the onset of the transient, the voltage should return to within 2.0 percent of the initial voltage. MIL-SPEC-704D, figure 5 contains additional guidance for 115 volt aircraft systems.

The transient frequency response is the frequency of the output signal on the desired phase measured as a function of time from the start of the step change in the load. The frequency should remain in the range 393.0 hertz to 407.0 hertz. Within 3.0 seconds the frequency should recover to 400.0 hertz plus or minus 0.5 hertz.

3.5 PHASE VOLTAGE IMBALANCE -- The phase voltage imbalance (PVI) in percent is defined as:

$$ABS(Vmax-Vavg)$$

$$PVI = ---- x (100)$$

$$Vavg$$

where,

Van+Vbn+Vcn Vavg = -----Ś

and Vmax is the line to neutral voltage of the phase with the largest deviation (positive or negative) from Vavg. Van, etc. represent the voltage measured from the designated phase line to the neutral line.

The PVI will be measured for a balanced three phase 0.8 lagging power factor load at 100 percent of the rated output. For these conditions, the PVI should be less than 1.0 percent. With two

phases at no load and one phase operating at 100 percent load (1/3 rated output)with a 0.8 power factor the PVI should be less than 3.0 percent.

3.6 TOTAL HARMONIC DISTORTION -- The total harmonic distortion (THD) in percent was measured directly with a HP 331A Distortion Analyzer.

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Appendix B

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AIRCRAFT TEST INSTRUMENTATION FIGURE 2:

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Appendix C

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Jethan Solid Statië Frequency Convertor Tidee Physe

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		11 227.2	226.2	226.1	226.6	230.8	8.625	228.0 11	229.1	230.6 11	228.4	226.2	217.4 11	211.5 111
	11 Wen	111 227.8	227.1	227.0	227.7	231.6	224.5	231.2	230.6	232.8 11	234.4	242.9	238.9 11	247.1 111
	c[1]	111 0.4326	24.96	50.26	24.22	102.70	31.63	(3.25	86.28	114.30 11	0.4368	0.4762	0.449 11	0.4647 111
	4111	111-1.646	26.07	50.72	24.98	103.10	30.03	66.14	8.8	1102-811	50.02	100.0	62.84 11	108.3 111
	111c	11 1.612	25.98	50.63 1	75.25	103.00	31.77	65.64	8.25	116.10 11	1.681	1.825	11.751 11	111 658.1
	LIND (KVK)	111 0.09605	5.68	11.43	16.%	23.65	7.12	14.57 11	22.17	26.55 11	0.1017	0.1136	11 6501.0	0.1095 111
	11150 (KWI)	111 0.3741	5.90	11.47	17.01	23.81	6.72	15.08	21.96	27.38 11	11.65	22.92	13.66	22.92
	11110 (KW)	E296.0 111	5.4	11.59	17.25	24.11	7.13	15.18	22.22	27.51 11	0.394	0.4435	0.4185 11	0.4596 111
	111	111 U. 8359	12.51	1 8 <b>1</b> .1-5	51.21	71.77	20.97	<b>14.</b> 01	(c6.38	<b>B1.44</b>	12.1	23.42	14.12	23.49 111
	111ffus (KH)	111 0.09083	5.67	11.43	16.44	23.85	5.82	88	18.28	23.14 11	0.03244	0.09905	0.09652 11	111 66960.0
	(H4) 09111	H0(0.3304	5.63	11.46	16.38	23.00 []	5.74	11.68 11	1 06.81	24.43 11	11.65	22.92	1 10.63 11	20.46 111
-	111CO (KH)	1626.0 111	5.94	11.58	£.7	24.11	5.81	12.44	18.39	24.42	0.3565	11 2668.0	0.3751 11	0.41 111
	111	111 0. 7584	12.50	34° 40	51.18	71.11	17.37	<b>8</b> 8	54.92	72.00 11	12.1	23.42		20.97 111
	111FIG (KVHR)	111 0.03823	0.00	0.00	62.0	0.0	4.11	8.47	12.55	13.01 11	0.04253	0.05577	0.03852 11	0.64691 111
	111BA1 (KWRP)	111 0.1594	96.0	0.50	95.0	4.0	3.50	9.54	12.18	12.37 11	0	0	8.581 1	111 66.01
	111-0 (KVAR)	111 0.1632	0.00	0.00	0.00	0.00	4.14	8.70	12.47	12.66	0.1678	0.1921	0.1805 11	0.2076 111
	IIITUTEL (KVER)	111 U. 3609	0.36	G. 50	1.77	0.46	11.74	26.71	37.21	36.05	0.2103	0.2479	8.805 11	10.59 111
		111111	1 6.0 1	0.99	1 66.0	66.0	0.62	0.61	0.821	0.67 11	0.91	0.87	E5.0	0.90
	1118U (PF)	06.0 111	96.0	6.0	1 66 .0	0.59	0.65	0.77	0.63	0.63	1 66.0	66.0	11 82 0	0.89
	111C0 (PF)	06.0 111	1 66.0	1.66 n	1 66 0	0.99	10.01	0.02 11	0.63	0.63	0.90	0.90	106.0	69.0
	111TOTHL (PF)	111 0.90	1 66 0 1	0.99 1	0.95	11 65 0	0.63 1	08.0	0.83	0.68	66.0	0.99	1 92.0	0.69 111
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	10 ST	BH			   	  - 	   	!   		   			   						! ! 	  - 	 					
	TWAY SOL			22	280.0	280.0	280.0	130.1	115.1	121.5	229.0	228.1	229.0	7.97	6.08	79.8	400.1	400.1	400.1	689	682	682	682	629	681	
	ц		1.0	20	282.0	282.0	282.0	94.8	86.2	86.0	228.1	227.6	228.4	53.2	53.7	53.6	400.1	400.1	400.1	683	681	680	680	679	623	
2				: :														   					   			
222				25	284.0	284.0	284.0	54.5	51.7	51.1	228.6	228.2	229.1	26.6	27.9	27.8	400.1	400.1	400.1	686	683	683	685	682		
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29.6	228.8	227.3 11	228.8	228.0 1	227.7	226.4	223.9	215.5	231.0	222.2	11 231.9	236.5
8.8	228.5	227.0 11	220.5	220.3	228.0	223.7	223.5	218.4	11 218.2	208,7	307.6	136.7
229.2	228.7	227.1	226.0	228.4	226.4	226.5	224.2	220.1	237.2	244.8	11 26.5	225.5
6611-	25.21	8.6	1 61 °C	102.20	8	62.68	2.2	129.00	11 0.4727	0.5299	0.408	0.4982
1.69	26.33	20.90	ŦŔ	102.20	3.08	65.14	93.67	125.80	92. <b>\$</b>	*	10°56	116.10
1.633	36.23	50.05	3.5	102.40	89.58	63.27	88.17	128.80	ě.	1.705	222.1	1.772
14960	1 2.819 1	11.36 11	17.34	29.59	7.419	14.8	20.97	29.53	10.1091	0.123	1 0.1022	0.1173
3676	• 001	11.65 11	12.51	8.8	6.979	14.57	8.8	8.8	11 10.67	19.61	11 12.58	22.73
8744	6.95	11.64	12.43	23.60	¢.5	14.33	20.03	29.30	0.4043	0.4156	0.4328	0.4472
0.0577	16.71	3.8	52.15	20.69	21.77	2.2	62.05	66.27	11 11.13	20.30	13.09	23.27
08062	5.82	11.56 11	17.34	8.8	6.038	11.53	17.94	24. BC	0.08005	0.07793	0.07046	0.06390
0.3505		11.65.11	17.37	3.8	6.021	11.48	17.67	24.79	11 10.68	19.64	9.826	2.41
0. 3336	6.05		12.43	23.60	5.922	11.89	17.32	24.7	11 0.3717	0.3694	1 0.40%	0.4226
0.7648	17.92	8.8	52.15	20.69	8.2	¥.8	8	74.3	11.13	20.90	11 10.30	20.24
05292	0.00	8.0	8	8	118.4	9:036	11.6	14.08	0.0742	1 0.09534	11 0.07408	1 0.09706
. 1653	0.00	8.0	8.0	8.0	3.529 I	6:036	11.31	13.78	0.00	8.0	1 7.963	11.25
. 1699	8.0	8.0	8.0	8	4.430	9.003 I	11.68	56 . 61	11 0.159	0.151	11 0.1399	0.1478
1 1886.0	0.0	8.0	8	8.0	12.28	25.08	2	41.65	0.2332	0.2464	.077	11.49
0.94	66.0	0.99	0.99	0.95	0.61	0.62	0.63	0.87	11 0.73	0.63	0.69	0.56
0.90	0.99	0.99	6.0	6.0	0.6	0.76	2	0.87	66.0	0.99	e2.0	0.97
0.69	0.9	0.9	0.99	0.8	0.0	0.83	0.83	0.87	0.92	0.93	0.9	0
0.89	6.0	8.0	6.0	0.9	0.63	0.01	0.63	0.67	0.99	ē.99	8	0.67
9.60		2.30 11		1.69		2.30		1.96	3.60	5.30	8	5.60
÷.		2.39		1.60		2.30		1.96	3.50	4.6	<b>B</b> n	9.30
3.30		2.26		4.50 11		2.40		2.04	R.6	1 08.80	×. %	13 FLUK

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5W		8	278	378	278	173.1	168.8	146	221.4	220.4	221.9	136.8	137	135.4	<b>6</b>	<b>6</b> 00	<b>8</b>	668	624	671	662	656	664	
	-																							
		ĸ	280	2P.J	280	132.2	112.4	121.9	225.8	225.5	226.4	98.1	69.3	97.9	<b>4</b> 00	400	400	685	683	686	676	675	678	
i S		20	282	282	282	102.7	84.4	98.9	228.4 11	225.7	228.5 11	66.6	70.2 11	68.4	400	00 00	6 0 0	690	696	11 102	684	676 11	691 11	
	0																							
Ka RXG COLENCY CO REE PHASE		25	284	284	284	63.8	54.9	49.2	229.9	230.3	228.5	35.5	33.4	35.1	400	00 <del>1</del>	400	704	707	695	685	683	686	
	=							==:																
I STRTE		100	276	278	276	170.7	167.6	154.6	230.	230.	230.6	106.6	107.2	106.6	400	400	4 00	202	102 102	10 <u>7</u>	983 9	589 9	69	
Soc			==:    o																				: :	
SYSTEMS		R	10 10 10 10 10 10 10 10 10 10 10 10 10 1	8	0 N	138.	137.	131.1	230.	230.	231.	80.	<b>81.</b>	80.	4	4	Ą	Ŕ	02	69	9	69	68	
CONTROLLED	1.0	20	282	282	282	90.4	. <b>.</b>	87.8	229.5	229.4	530	54.1	55.3	54.2	400	9 <del>0</del>	400	669	203	702	688	689	695	
KC						   10	0							2		g	0	0	0	2		Y		-
ŝ		<u>5</u> 2	30	8	26		61.	58.	3	230.	230.	27.	29.	28.	4	4	4	21	N.	2	59	99	63	
8			98		98	2	œ	m	~	4	m		~	~	8	8	g	- Se		50	8	12	60	
8		0			N	1		•	231	162	231	0			4	4	4		~			ſ~	~	
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ראנ דעו		REME	NANI			PUT			UTPU			TPUT			EO C	EQ C	EQ (	ē	80	8	BO	88	8	
		IMEASU		c S	c C C	41 41	qI	o I I	C usy	uq A	Co L		91 	IC	I RO FE	I BO FR		× • • •			Vmin			
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ECU-105 NOTOR-GENERATOR

	, <b>.</b>					BRLANCED 7	REE PHRSE			111	 		KD CREY		E
	-			1.0	•			0.00	-		0.1				
TRUMENT	I I MERSUREMENT	0	8	8	R	100	8	8	R	8	8	ğ	8	8	=
Drametic 808		11 227.7	227.6	227.5	227.1	226.9	226.5	227.6	227.4	226.4	227.9	228.2	228.9	228.0	===
at the Load	4	227.9	227.0	227.6	228.0	227.8	220.7	229.4	226.0	227.4	222.3	217.4	217.7	208.5	
	Li Non	227.6	227.6	226.9	228.1	227.2	23.2	227.9	227.2	227.7	222.4	217.9 11	222.9	219.0	
	•[1]	0.424	23.16	39,70	54.45	69.12	8	61.71	3.12	108.60	0. Å	<b>0</b> , <b>#</b>	0.49	0.40	
-	4111	11 1.685	8.8	8	74.49	80.03	27.64	8.83	76.14	106.10	4.8	63.47	28.67	96.97	
	1110	1.580	\$8.82	3.73	74.82	69.17	\$.3	65.92	27.29	106.10	8	8.1	8.1	1.53	
	I I RO (KVR)	260.0	2.2	6.08	14.2	8	2.08	4.9	12.08	24.60	0.10	0.11	0.11	0.11	===
	I I BO (KVA)	1.98	8	10.61	12.10	20.71	6.32	13.50	12.26	24.13	10.03	18.19	12.12	20.22	==;
	IIICO (KVA)	0.360	5.97	10.01	17.05	<b>3</b> 0. <b>#</b>	6.87	8.1	17.06	24.17	1.0	0.32	0	0.33	==
	I I TOTAL CKVA)	0.640	12.80	8.8	48.93	61.61	SZ .61	4.4	16.15	72.66	10.43	18.59	12.57	20.66	
		190.001	8.3	8.6	14.77	8	2.2	11.71	14.56	20.68	0.09	0.69	0.10	<b>6</b> 0'd	==
	(11100 (101)	0.947	6.8	10.61	12.10	12.02	6.17	11.39	1.8	21.09	10.03	18.19	10.70	17.50	==
		0.323	8.0	10.01	17.05	8	2.20	12.40	14.74	20.73	0.51	0.31	0.91	0.31	==;
•	I I TOTAL (KU)	0.752	17.80	8.8	2	61.61	16.15	36.10 11	43.65	62.56 11	10.43	18.59 11	31.11	17.98	
	I I I I I I I I I I I I I I I I I I I	0.052	0.00	8	8	0,00	8	r.	<b>.</b> .	13.32	8.0	50.0	0.0	0.06	
	I I BO CKURR	0.164	8	0.0	0.00	0.00		6.21	9. <del>3</del>	11.73	0.0	8.0 0	5.69	9.30	
	LICO (KVAR)	11 0.159	8	8	0.0	8.0	3.69	9.41	9.35	12.33 111	0.14	0.12	0.14	0.14	
•	I TOTAL (KURR)	11 0.375	0.0	8	8	8	11.36	22.37	27.78	82.39	0.19	0.17	5.00	10.17	
	LIRO (PF)	9	0.99	0.99	0.99	0.99	0.62	0.63	0.85	0.64	0.96	0.87	0.69	<b>8</b> .0	
	LI FBO (PF)	0.90	0.99	0.99	6.0	0.99	0.82	0.69	<b>9</b> .0	0.67 111	0.99	0.99 11	0.08	0.87	
	LICO CPF5	0.90	0.99	0.99	66.0	0.99	0.62	0.69	0.04	0.66	0.91	11 66'0	16.0	0.91	
	ITOTAL CPF)	0.89	0.99	0.99	0.99	0.%	0.82	0.65	0.94	8	0.99	0.99	8	29.0	
TOTAL	11THD A0	•		0.43		0.42		0.36		0.33 11	0.51	0.64	1 0.51	0.66	
DISTORTION	IITHC BO	11 0.425		0.42		0.36		14.0		0.37	0.47	0.69	0.47	0.61	=
	11H0 CB	11 0.425		G		0.41		<b>q</b> 0		0.36	0.50	0.67	0.56	0.7 <b>3</b>	
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				1.0				0.60			= :
INSTRUMENT	I I MERSUREMENT	0	55	20	52	100	55	20	ĸ	100	
FLUKE 8060	I Ven INPUT	111 286.0	284.0	282.0	280.0	279.0 1	1 284.0	282.0	280.0	278.0	
	hen Labr	11 286.0	284.0	282.0	280.0	278.0	284.0	282.0	280.0	278.0 [	
	Vcn	111 286.0	284.0	282.0	280.01	278.0	284.0	282.0	280.0	278.0	
	IIIA INPUT	5	1 56.9	4.63	80.1	91.9	48.4	66.1	74.5	94, 4	
	dI I	00	59.2	66.2	64.3	96.1	51.9	70.2	7.87	98.6	==:
	IC	8 0	61.0	67.3	82.9	94.5	52.3	69.0	77.4	<b>28.5</b>	= = :
	I Van OUTPUT	229.4	229.5	229.4	229.1	228.9	230.3	229.5	229.2	228.2	
	l Vbn	229.5	229.7	229.5	229.9	229.8	230.7	1 6.162 1	228.6	229.3	==:
		229.4	229.3	228.7	228.1	229.2	231.1	229.2	229.1	229.6	
	IIIa OUTPUT	0.1	26.9	42.8	6.8.9	63.4	33.1	65.8	80.6	114.2	
	4I   1	1.00	28.2	49.0	79.2	94.1	29.5	62.8	81.6	111.2	
	IC	1.00	27.8	49.6	2.9.5	93.2	29.6	20.4	82.8	111.2	
	I RO FREG CHZ)	400.0	400.0	400.0	1 6 66E	400.0	400.0	400.0	399.9	399.91	
	IIBO FREG (Hz)	400.0	400.0	399.6	3668	400.0	400.1	399.9	399.9	399.9	
	IICO FREQ (HZ)	400.0	400.1	1 8 668	359.8	400.0	406.1	399.9 1	399.9	399.9	
0-SCOPE	Vmax RO	668	669	693	669	669	672	669	699	667	
	80	111 667	670	670	673	672	673	676 1	568 I	670	
* *** *	0	111 668	668	667	667	670	675	669	669	671	
	llVmin AO	111 667	668	668	668	668	670	669	669	665	
	08	111-567	699	670	672	671	671	675	667	699	= = :
••••••••••••••••••••••••••••••••••••••	C	111 666	668	667	666	670	673	6689	668	670	

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Appendix E

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## JETHAY SOLID STATE FREQUENCY CONVERTER

			SHOCK LORD	CONFIGURATI	ONS ::
		1.0			
INSTRUMENT	HEASUREHENT	50	100	50	100
Dranetz 808	:Van ::	226.3	231.6	231.7	232.2
at the Load,	Von	226.1	231.4	230.2	230.6
	Ven	227.0	232.7	229.4	232.8
	:Ia ::	50.26	103.30	62_81	114-30
	ііь	50.72	103.90	59_10	118.70
	Ic	50.63	103.10	64.57	118.10
	RO CKURS	11.43	24.05	14_55	26.55
	BO (KVA)	11.47	24.05	13_61	27.38
	CO (KVR)	11.58	24.22	14_81	27.51
• •	TOTAL (KVR)	34.48	72.33	42,92	81.44
::	RO (KH)	11.43	24.05	11,98	23.14
· · · · · · · · · · · · · · · · · · ·	180 (KH)	11.46	24.05	11_98	24-42
	C0 (KH)	11.58	24.22	12.14	24.42
• • • • • •	TOTAL (KH)	31.48	72.33	36.11	72.00
* *	RO (KVAR)	0.00	0.00	8_26	13.01
• •	BO (KVAR)	0.50	0.06	6.16	12.37
	CO (KVAR)	0.00 !	0.00	8,48	12.66
5 8 6 9 6 9	TOTAL (KVAR)	0.50	0.06	23.20	38.05
· · · · · · · · · · · · · · · · · · ·	RO (PF)	0.99	0.99	0_82	0.87
	BO (PF)	0.99	0.99	0,88	0.89
	C0 (PF)	0.99	0.99	0_82	0.89
• • • • • •	TOTRL (PF)	0.99	0.99	0,84	0.88 :::

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		CSI	SHOCK LOAD	CONFIGURATI	ONS
:::::::::::::::::::::::::::::::::::::::		1.0			
INSTRUMENT	HEASUREMENT	50	100	50	100
Dranetz 808::	Van	229.0	228.3	227.1	223.6
at the Load	Vbn	228.4	228.2	224.1	220.8
6 1 6 6 7 6	Vcn	229.1	228.9	226.1	221.9
1 ) 1   1   1   1   1   1	Ia	50.45	101.80	61.89	129.40
1 1 1 1 1 1 1 1	іь	51.16	102.00	65.28	131.20
4 4 4 4 4 4	Ic	50.37	101.10	64.05	130.20
	RO (KVR)	11.65	23.45	14.05	29.94
	BO (KVA)	11.78	23.49	14.63	20.99
	CO (KVA)	11.64	23.35	14.48	28.91
	TOTAL (KVA)	35.07	70.30	43.15	86.94
	R0 (KH)	11.65	23.45	11.67	25.26
· · · · · · · · · · · · · · · · · · ·	во (кн)	11.78	23.49	11.43	25.36
	CO (KH)	11.64	23.35	11.31	21.93
	TOTAL (KH)	35.08	70.30	34.97	75.97
::	AO (KVAR)	0.00	0.00	7.84 ::	13.35
1 1 1 1 1 1 1 1	BO (KVAR)	0.00	0.00	9.05	14.05
4 8 1 1 4 8 8 8	CO (KVAR)	0.00	0.00	8.38	14.64
	TOTAL (KVAR)	0.00	0.00	25.27	42.06
	AO (PF)	0.99	0.99	0.83 ::	0.89
	BO (PF)	0.99	0.99	0.79	0.87
4 4 4 4 4 4 4 4	CO (PF)	0.99	0.99	0.82	0.86
• • • • • • • • •	TOTAL (PF)	0.99	0.99 ::	0.81	0.87

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## ECU-105 HOTOR-GENERATOR

			SHOCK LOAD	CONFIGURATI	ONS ;
		1.0		0.8	
INSTRUMENT	MERSUREHENT	50	100	50	100
Dranetz 808:	Van >	228.3	227.5	227.7	226.9
	Vbn	228.9	227.4	229.6	223.6
	: Ven	229.8	227.9	230.2	227.6
	Ia	50.15	101.70	61.27	116.30
	Ib	40.06	102.30	49.58	122.40
	Ic	41.42	92.35	54.06	108.00
	RO (KVR)	11.58	23.36	13.95	26.39
	BO (KVA)	9.22	23.49	11.38	27.37
	CO (KVA)	9.57	21.26	12.44	24.60
	TOTAL (KVA)	30.37	58.11	37.79	78.33 ::
	RO (KH)	11.58	23.36	11.63	23.46
::	BO (KH)	9.22	23.49	9.54	23.24 ::
	СО (КН)	9.57	21.26	10.32	21.38
· · ·	TOTAL (KH)	30.38	68.11	31.50	68.09
	AO (KVAR)	0.00	0.00	7.70	12.09
	BO (KVAR)	0.00	0.00	6.22	14.46
	CO (KVAR)	0.00	0.00	6.94	12.16
	TOTAL (KVAR)	0.00	0.00 :::	20.87	38.71
	RO (PF)	0.99	0.99 :::	0.83	0.89
	BO (PF)	0.99	0.99	0.84	0.85
	CO (PF)	0.99	0.99	0.83	0.87
	TOTAL (PF)	0.99	0.99	0.83 !!	0.87

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Appendix E

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FIGURE 1. AC VOLTAGE TRANSIENT LIMITS.



\* Derived from MIL-STD-704D, Figure 5.

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