N84 10057

HIGH-VOLTAGE (270 V) DC POWER-GENERATING SYSTEM FOR FIGHTER AIRCRAFT

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The Naval Air Development Center's high-voltage, direct-current advanced power-generating system will be used to retrofit current and future military aircraft.

Some of the reasons for choosing high-voltage direct current are the following:

(1) Reduced weight in power-generating systems. Weight is reduced mainly by eliminating the constant-speed drive through direct coupling. Also, the use of more-efficient direct-current generators allows the peripherals, especially coolers, to be smaller and therefore lighter. Also, use of a flat-cable conductor, rather than the conventional round conductor, increases current density by increasing the busing area, and therefore reduces the amount of copper, saving weight. The weight of avionic power supplies is reduced mainly by using high-frequency switching regulators.

(2) Increased efficiency. Efficiency has been increased to 85 to 90 percent by eliminating the constant-speed drive.

(3) Elimination of power interruptions with direct current. Load relays can make contact with a second bus before breaking connection with the first.

(4) No speed restrictions. The main power generators operate between 9000 and 18 000 rpm.

(5) No powerline constraints.

(6) Increased personnel safety by eliminating the hold-on frequency, present in ac systems, which causes muscle contractions.

By using 270 V dc most aircraft loads can be kept below 2 A. This reduces conductor size. The Naval Air Development Center (NADC) has 2-A power controllers, which can be used for almost all of the aircraft loads.

The NADC advanced aircraft electrical system (fig. 1) comprises three subsystems:

(1) Power-generating subsystem. A 270-V, 43-kVA generator will be used, either a solid-rotor generator (new technology) or a wound rotor. The choice will depend on the results of in-house testing. The generator control unit (GCU), which acts as a normal regulator for the generator, also supplies fault interruption signals to the bus contactor. This isolates the generator from any downstream faults. The bus contactor presently used has arc suppression by means of a semiconductor switch. The semiconductor switches on to suppress the initial arc and then an electromechanical relay takes over. Power-conditioning devices are used in retrofit aircraft to convert the 270 V to existing 400-Hz, 115-V power or to 28-V power.

(2) Solid-state electrical logic system (SOSTEL). This system is used for power management. It comprises the main and redundant processors (Navy AYK14 computer), solid-state switches or transducers, a multiplex system, power controllers (used instead of electromechanical devices and circuit breakers to save weight), and a demultiplex system. The system built-in test unit (BITE) monitors the condition of the power controllers and the solid-state switches, either the on-off condition or the fault condition. Under fault condition the processors provide either a redundant source of power or fault isolation.

(3) General-purpose multiplex system. The 1553B databus is used as a datalink between the aircraft avionic systems and the SOSTEL system.

Table I shows the status of hardware development. Most of the material is at NADC under advanced development or scheduled to be delivered. Some of these due dates, especially the August 1982 dates, have been delayed 6 to 8 months because of funding constraints.

The NADC will be testing the solid-rotor generator within the next month or so. The 500-W bidirectional power converter and the ground power monitor have been delivered. The flat power cable is under development. Again, 28-V power controllers have been delivered and tested. The alternating-current controllers have not been delivered. A 270-V, 1-hp brushless motor will be tested shortly.

Figure 2 shows the 270-V dc solid-rotor generator. The regulator is large because it was developed under funding that required few size constraints. The generator weighs about 65 lb.

Table II shows the power distribution. Under full-load conditions efficiency is 85 to 90 percent.

Figure 3 shows changes to be proposed in the power characteristic curves for military standard 704. The low limit will be raised from the standard 125 V to 175 V, and the high limit will be lowered from approximately 425 V to 350 V. Data for preliminary testing on a solid-rotor generator are well within those limits both under fulland low-load conditions. Further testing may indicate that those limits can be brought to an even closer tolerance.

Figure 4 shows the hybrid bus contactor. It uses an electromechanical relay, which is current technology, but includes the recent development of arc suppression with semiconductor switches. In the future, complete semiconductor circuit breakers may replace this contactor.

Figure 5 shows the dc-to-dc power converter. Full-load efficiency for a 3-kW unit is approximately 80 percent. The power converter can go either from 270 V dc to 28 V dc or the reverse. It supplies an emergency source of power by allowing the use of shipboard batteries. Its characteristics are given in table III.

Figure 6 shows a ground fault monitor. It integrates ground cart power to prevent getting transient power from the ground cart. When the ground cart power is within the range of military standard 704, the contact supplying ground power to the aircraft closes.

Figure 7 shows a bus fault sensor. It supplies fault signals to the SOSTEL system. It is not a switching unit but merely supplies the signals for switching redundant power sources and fault isolation.

Figure 8 shows the flat conductor cable that will be used. This cable is rated at 140 A. A round conductor containing a similar amount of copper would be rated at about 80 A. So again, both weight saving and increased current are achieved. NADC has found that because of insulation restraints the use of flat conductor cable is only feasible at 10 A and above. Average percent weight savings (table IV and fig. 9) are approximately 24 percent on a metal aircraft and 32 percent on a composite aircraft. The reason for the different values is that the composite aircraft uses the standard two-conductor system, whereas the metal aircraft uses aircraft shielding as the ground return. The weight of a typical military aircraft could probably be reduced by approximately 880 lb.

Figure 10 shows the 270-V dc controllers, which handle most of the aircraft loads that use the 270-V system. The controllers are approximately 2-1/2 in. long, 1-1/2 in. wide, and 3/4 in. thick. They weigh about 8 oz.

Something new NADC is doing with this system is using computer-aided stability analysis. The software (designated EASY) was developed by Boeing for the U.S. Air Force. Boeing has developed a high-voltage direct-current component library for NADC. This library mathematically models different system components. Therefore different parameters can be input to study the effect of transients on overall system stability.

Figure 11 shows the airframe/system simulator. The power controllers and some of the SOSTEL system are already installed on it. It will be operational, funding permitted, probably in late 1983.

The long-range goals of the NADC program are shown in table V.

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TABLE I. - AAES HARDWARE DEVELOPMENT STATUS

ITEM	STATUS & REMARKS
45 KW 270 VDC WOUND ROTOR GEN	ADM SCHEDULED DELIVERY AUG 1982
45 KW 270 VDC SOLID ROTOR GEN	6.2 MODEL UNDER TEST, TRANSITIONS FY-83
90 KW 270 VDC [TBD] GEN	ADM DEV FY-84, ROTOR TYPE TBD
500 W BI-DIRECTIONAL PWR CONV	28 VDC ←→ 270 VDC ADM UNDER TEST
3 KW PWR CONVERTER	ADM UNDER TEST
10 KVA PWR CONVERTER	6.2 MODEL UNDER TEST, TRANSITION TBD
GROUND PWR MONITOR	ADM UNDER TEST
GROUND PWR CONVERTER	ADM DEV COMPLETED TEST SCHEDULED FY-82
HYBRID BUS CONTACTER (400 A)	UNDER 6.2 DEV, TRANSITIONS FY-83
FLAT PWR CABLE	UNDER 6.2 DEV, TRANSITIONS FY-83
SOSTEL CONTROL GROUP	FTM SCHEDULED DELIVERY AUG 1982
28 VDC PWR CONTROLLERS	ADM INSTALLED IN SIMULATOR
115 VAC PWR CONTROLLERS	ADM SCHEDULED DELIVERY AUG 1982
270 VDC PWR CONTROLLERS	6.2 MODEL UNDER TEST, TRANSITIONS FY-82
TRANSDUCER SWITCHES	ADM TOGGLE, PROXIMITY, & PUSH BUTTON IN TEST
ROTARY TRANSDUCER SWITCHES	ADM UNDER TEST
MIL-STD-1553 DATA MUX	ADM UNDER TEST
SYSTEM LOAD CENTER	INITIATE ADM DEV FY-84
270 VDC EMERGENCY GEN	INITIATE ADM DEV FY-84
BUS FAULT SENSORS	INITIATE ADM DEV FY-85
270 VDC BRUSHLESS MOTORS	6.2 EFFORT TRANSITIONS FY-85

TABLE II. - 270-V dc SOLID-ROTOR GENERATOR (45 kW)

[Efficiency, ~90 percent; MIL-L-23699 oil; current, 166 A.]

Voltage, V	S	Front bearing	Rear bearing	Coolant inlet	Coolant outlet
		Temperature, °F			
270.05	9 076	110	110	68	78
270.03	9 190	150	140	71	81
270.03	9 245	166	156	76	88
270.00	14 300	200	190	75	90
270.00	14 008	220	210	81	97
270.00	17 997	258	242	89	107
270.00	18 100	270	248	87	92

dc voltage, V	dc current, A	Voltage, V			Current, A			Power, W			Efficiency
		A	B	C	A	B	C	A	B	C	
10-kVA inverter											
250	11.5	116	116	116	7.25	7.25	7.25	850	850	850	0.89
250	22	115	115	115	14.5	14.5	14.5	1650	1650	1650	.90
250	32.5	114.5	114.5	114.5	21.75	21.75	21.75	2500	2500	2500	.92
250	44	113.5	113.5	113.5	29	29	29	3300	3300	3300	.90
Test data											
270	10.5	116	116	116	7.25	7.25	7.25	850	850	850	0.90
270	20.5	115	115	115	14.5	14.5	14.5	1675	1675	1675	.91
270	30.5	114.5	114.5	114.5	21.75	21.75	21.75	2500	2500	2500	.91
270	40.5	114	114	114	29	29	29	3250	3250	3250	.89
Efficiency											
280	10.5	115.5	116	116	7.25	7.25	7.25	850	850	850	0.87
280	20	114.5	115	115	14.5	14.5	14.5	1700	1650	1700	.90
280	29.5	114	114.5	114.5	21.75	21.75	21.75	2500	2500	2500	.91
280	39	113.5	114	114	29	29	29	3300	3300	3300	.91

TABLE III. - CHARACTERISTICS OF BIDIRECTIONAL POWER CONVERTER

(a) General characteristics

Inlet voltage, V	Inlet current, A	Outlet voltage, V	Outlet current, A	Efficiency, percent
290	1.20	32.78	0	--
270	1.21	32.56	0	--
240	1.23	31.89	0	--
290	3.73	28.15	25	65
270	3.93	28.01	25	66
240	4.32	27.66	25	66
290	6.36	27.69	50	75
270	6.75	27.62	50	76
240	7.46	27.51	50	77
290	8.98	27.56	75	79
270	9.57	27.49	75	80
240	10.65	27.39	75	80
290	11.63	27.43	100	81
270	12.43	27.36	100	82
240	13.89	27.26	100	82

(b) Upmode characteristics

24 V dc			270 V dc			Efficiency, percent
Voltage, V	Current, A	Power, W	Voltage, V	Current, A	Power, W	
24.0	3.77	90.5	260.5	0.2	52.1	57.6
↓	4.85	116.4	260.8	.3	78.2	67.2
	7.25	174.0	261.0	.5	130.5	75.0
	9.75	234.0	261.5	.7	183.0	78.2
	12.4	297.6	261.8	.9	235.6	79.2
	13.7	329.8	261.9	1.0	261.9	79.4
	16.4	393.6	261.9	1.2	314.3	79.8
	17.8	427.2	261.9	1.3	340.5	79.7
	19.2	460.8	262.0	1.4	366.8	79.6
	20.0	480.0	262.0	1.45	379.9	79.2
	21.0	504.0	262.0	1.5	393.0	78.0

(c) Downmode characteristics

24 V dc			270 V dc			Efficiency, percent
Voltage, V	Current, A	Power, W	Voltage, V	Current, A	Power, W	
28.0	0.5	14.0	270.0	0.10	27.0	51.8
27.9	1.94	54.1	↓	.40	108.0	50.0
27.8	4.25	118.2		.60	162.0	80.0
27.6	7.30	201.5		.90	243.0	82.9
27.4	9.80	268.5		1.20	324.0	82.9
27.3	11.65	318.0		1.40	378.0	84.1
27.2	13.30	361.8		1.60	432.0	83.7
27.2	15.00	408.0		1.80	486.0	83.9
27.1	15.40	417.3		1.85	499.5	83.5

TABLE IV. - WEIGHT ANALYSIS SUMMARY[a]

	Metal aircraft	Composite aircraft
	Flat cable weight saving, percent	
High	+22.0	+33.6
Medium	+26.8	+31.2
Low -1	+ 4.5	-15.6
Low -2	-40.6	-69.0

[a]If all power runs above 10 A in a typical military aircraft were converted to flat cable, this would result in a weight saving of 880 lb.

TABLE V. - LONG-RANGE GOALS OF NADC PROGRAM

FUNCTION	CONVENTIONAL	ADVANCED
POWER GENERATION	115/208 VAC 400 HZ	270 VDC
• POWER CONVERSION	TRANSFORMER/RECTIFIER	DC-AC & DC-DC CONVERTERS
• BUS CONTACTORS	ELECTROMECHANICAL	SOLID STATE
• POWER BUS	STRANDED CABLE	FLAT
• FLEXIBILITY	NONE	PROGRAMMABLE
CONTROL & PROTECTION		
• CONTROL SWITCHES	ELECTROMECHANICAL	SOLID STATE-LOGIC LEVEL
• FEEDER PROTECTION	THERMAL/MAGNETIC CIR BRKR	SOLID STATE POWER CONTROLLER
• POWER TRANSFER	ELECTROMECHANICAL RELAY	
• LOAD MANAGEMENT	MANUAL & FIXED	AUTOMATIC & PROGRAMMABLE
• CONTROL WIRING	DEDICATED	TSP & FIBER OPTICS
• CONTROL DATA TRANS.	POINT-TO-POINT	DIGITAL MULTIPLEXED
BUILT-IN-TEST	NONE	100% TO WRA
REDUNDANCY	LIMITED	UNLIMITED
PACKAGING	BLACK BOX	MODULAR

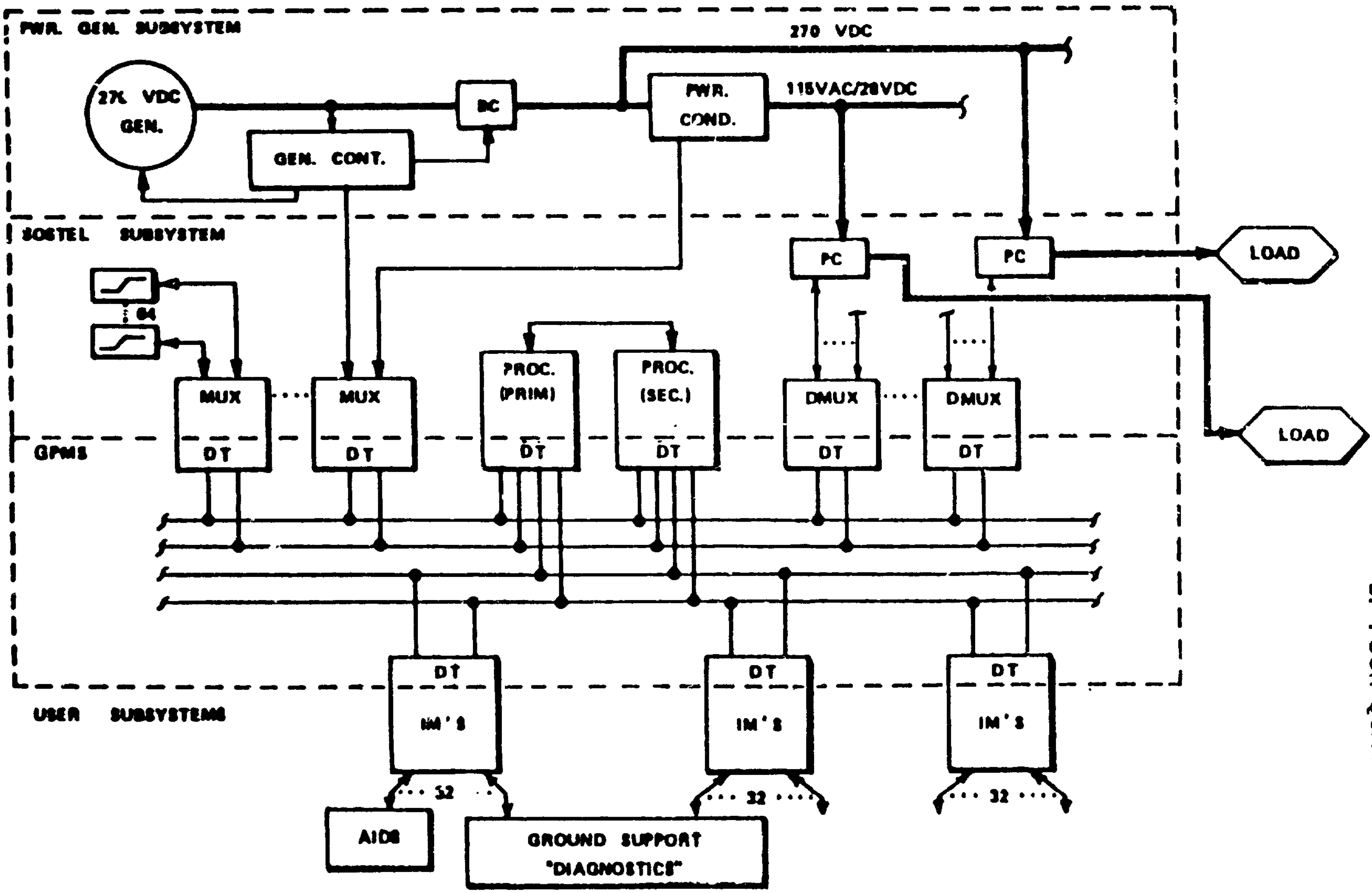

Figure 1. - Advanced aircraft electrical system (AAES).

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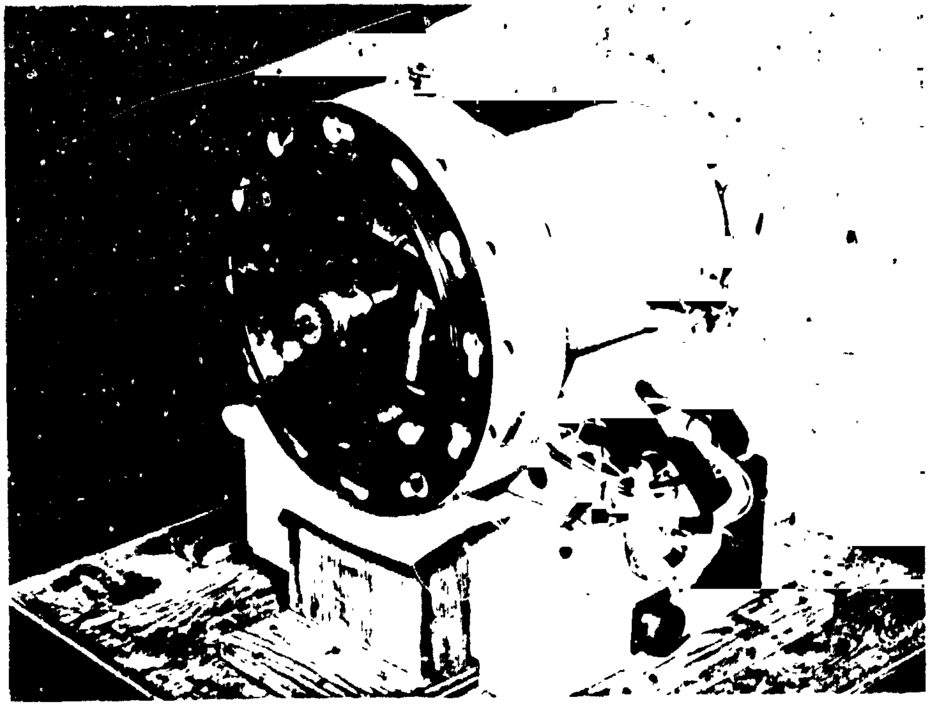

Figure 2. - 270-V dc solid-rotor generator.

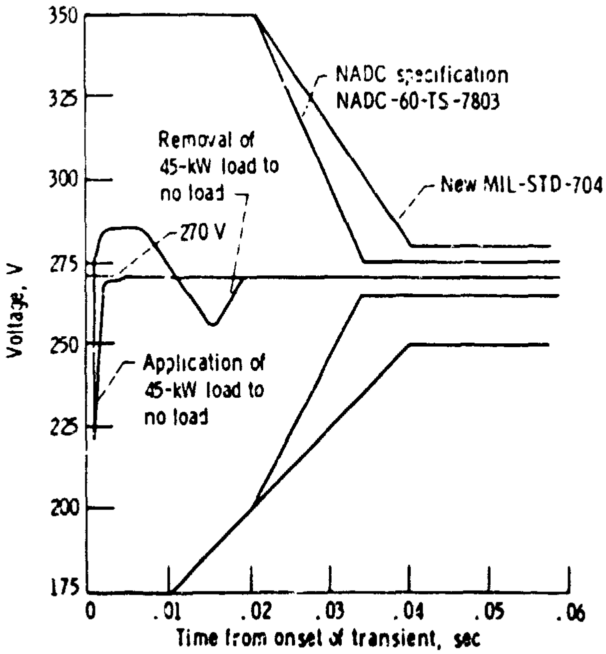

Figure 3. - Transient response of 270-V dc solid-rotor generator system.

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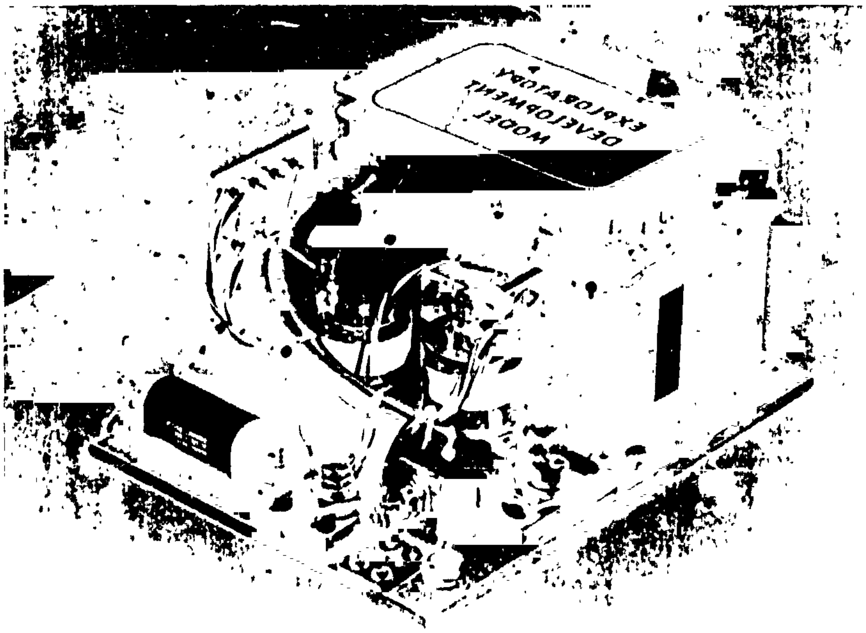

Figure 4. - 250-A, 270-V dc hybrid bus contactor.

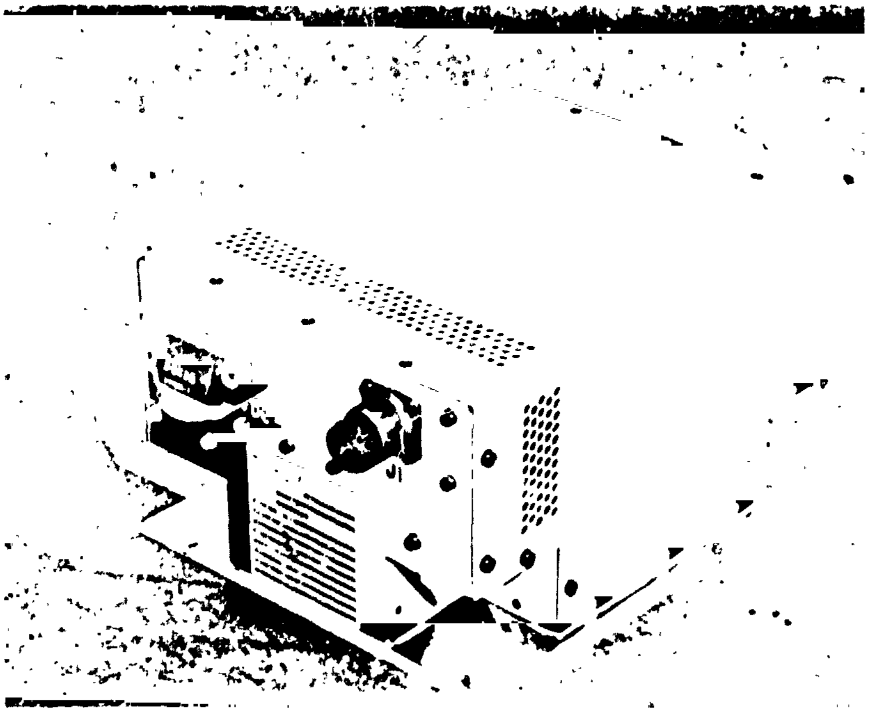

Figure 5. - 270-V-to-28-V, 3-kW power conditioner.

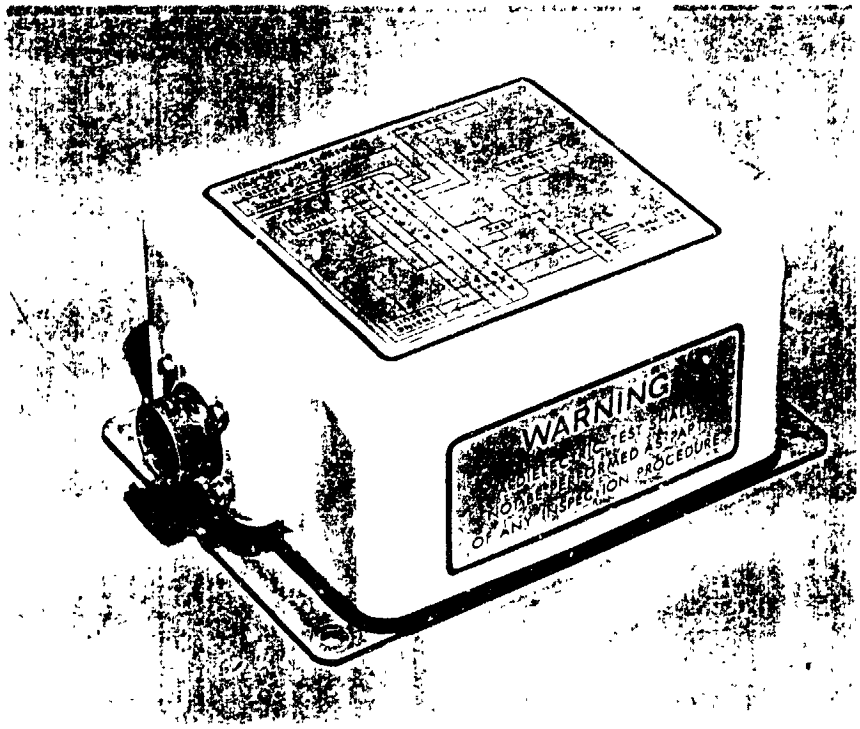

Figure 6. - 270-V dc power monitor.

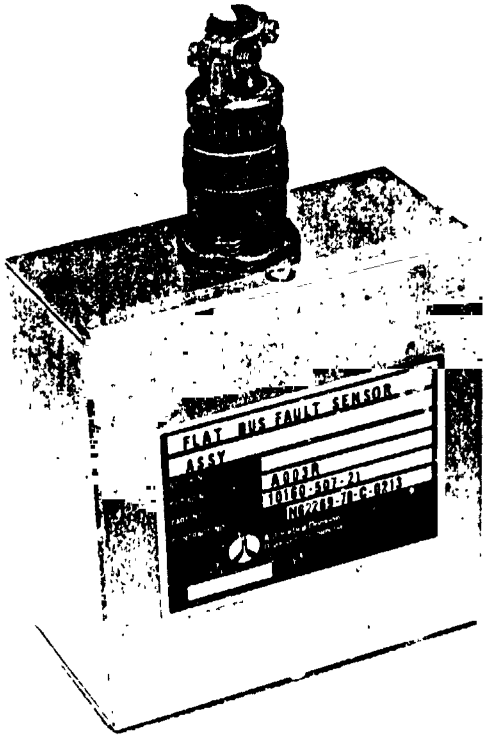

Figure 7. - Flat bus fault sensor assembly.

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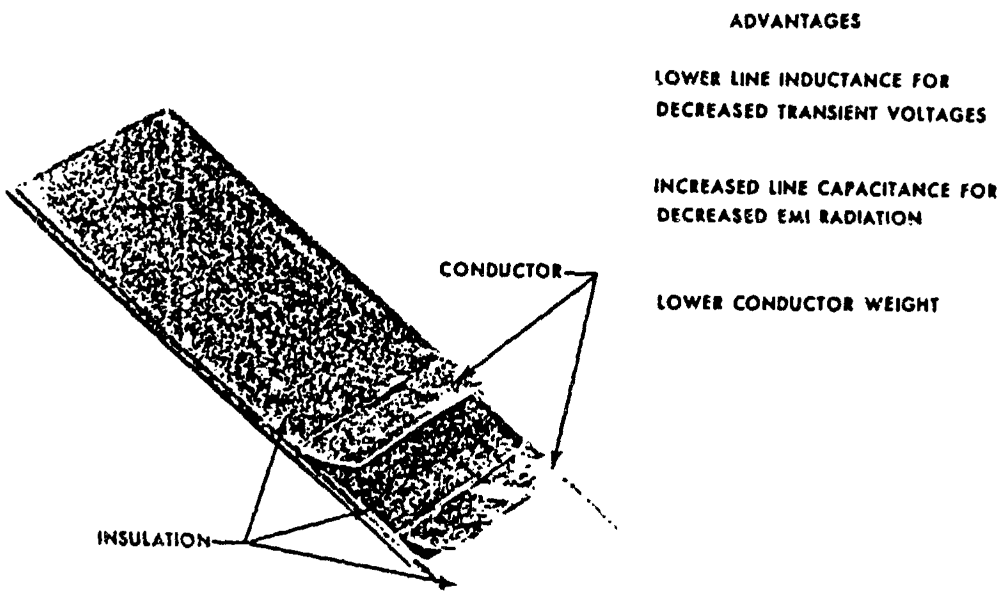

Figure 8. - Flat conductor cable.

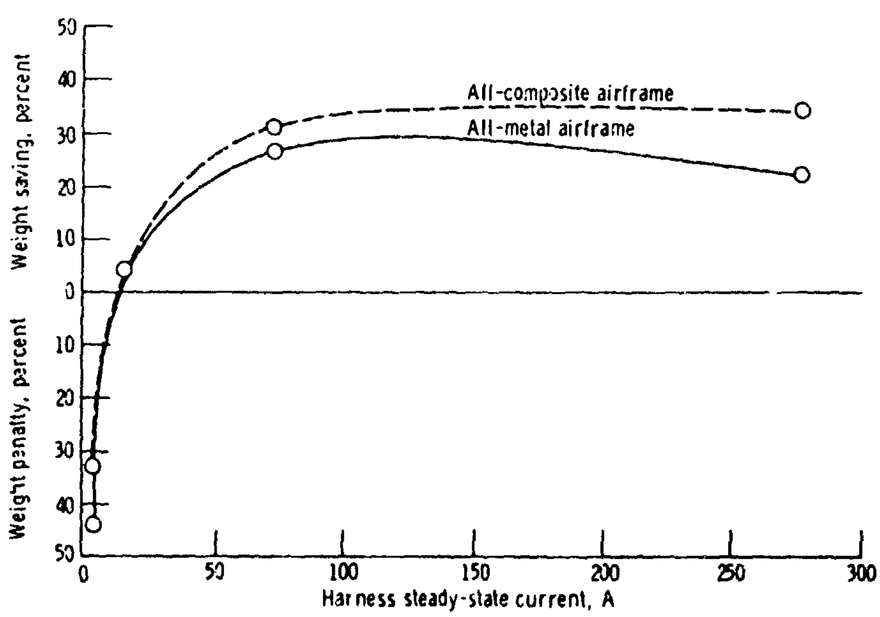

Figure 9. - Weight effects of flat cable versus round cable in 270-V dc power distribution system. (If all power runs above 10 A in the AWACS were converted to flat cable, a weight saving of 880 lb would result.)

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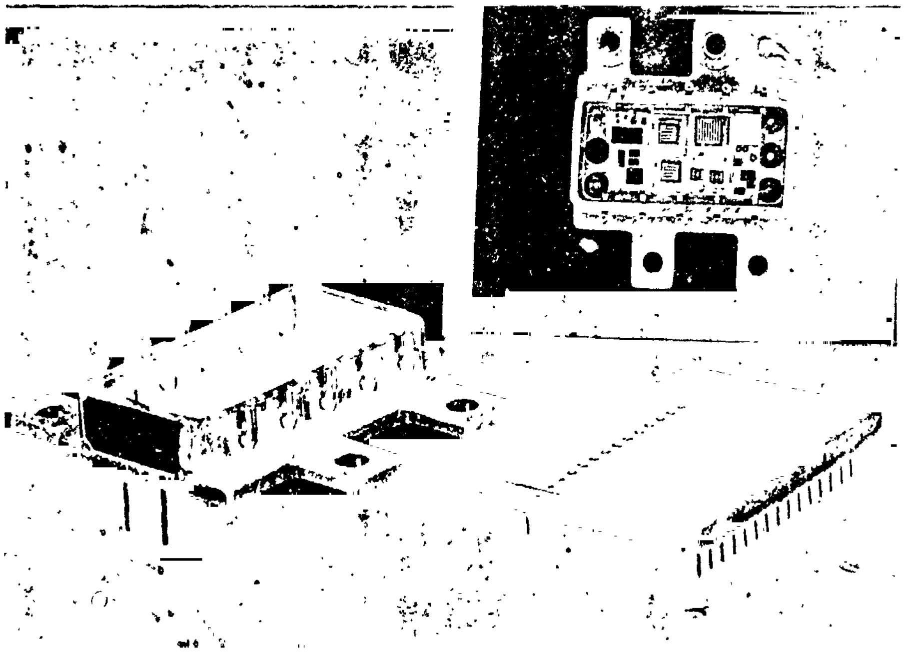

Figure 10. - 270-V dc power controllers.

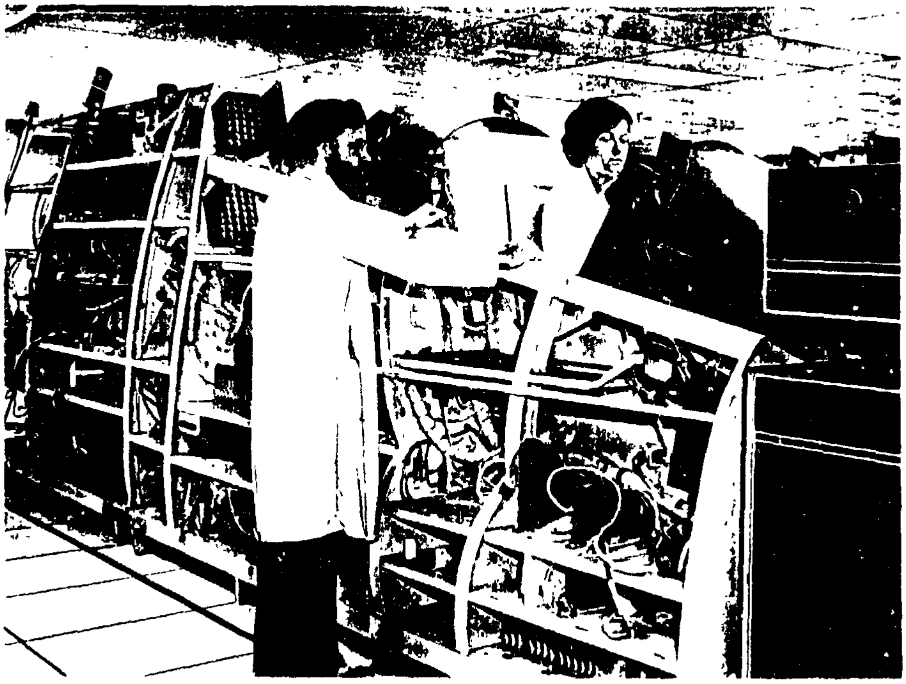

Figure 11. - AAES airframe/system simulator.