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POWER PROCESSING SUBSYSTEMS FOR THE 100-kWp SOLAR PHOTOVOLTAIC POWER SYSTEM AT THE NATURAL BRIDGES NATIONAL MONUMENT IN UTAH

30 June 1982

F.J. Solman
S.D. Coleman, Editor

Volume 5

Massachusetts Institute of Technology
Lincoln Laboratory
Lexington, Massachusetts 02173-0073

Prepared for
THE U.S. DEPARTMENT OF ENERGY
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ABSTRACT

The power processing subsystem for the Natural Bridges National Monument photovoltaic power system including inverters, battery chargers, battery, diesel generator, site transfer switch, transformer in-rush controller, furnace loads, and load control equipment are described. Components and subsystem testing are also discussed. The report, completed about two years after the system was installed, also includes the solution to operational problems. (A complete bibliography of reports and papers on the NBNM installation is contained in the Operations Manual, DOE/ET/20279-142.)

FOREWORD

Power Processing Subsystems for the 100-kWp Photovoltaic Power System at the Natural Bridges National Monument contains detailed information on the performance, test, and practical problems associated with the design, construction, test and evaluation of the working system.

Problems encountered and the analysis conducted leading to their solution is included here for historical accuracy and as a guide to engineers in the design and development of future systems. Some items, such as original drawings, have been omitted in general distribution copies.

Readers might remember, "Those who cannot remember the past are condemned to repeat it."

F. John Solman
15 May 1982

NBNM 100-kWp PHOTOVOLTAIC POWER SYSTEM

Overview of Manuals

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ACKNOWLEDGMENT

The following MIT Lincoln Laboratory personnel contributed jointly to this document:

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D. N. Klein

E. E. Landsman

1.0 CYBEREX 50-KVA INVERTER

1.1 General

This inverter is to be used to supply up to 50 KVA of electric power to general-purpose loads at Natural Bridges National Monument.

1.2 System Description

The inverter is comprised of a power inverter silicon controlled rectifier bridge assembly, low level waveform generation and control circuitry, under and overvoltage trip circuits, and alarm circuits. The inverter provides regulated 240/120 VAC 60-Hz single-phase output from a variable DC input voltage of 210 to 280 volts. Efficiency is over 80% at output power levels above 15 KW with total harmonic distortion less than 5%.

The waveform generation scheme is generally classed as pulse-width modulation. Two switching waveforms are generated with identical 60-Hz modulation and 600-Hz carriers displaced one-half period from each other. These are applied to the two sides of the power bridge. Carrier cancellation occurs at the output,and after filtering, the first distortion components appear around 1200 Hz.

1.3 Control and Monitor

1.3.1 The inverter must be supplied with an enable input of 24 VDC to enable the inverter turn-on procedure. Connections are on the relay socket mounted at the upper left rear panel. If at any time this input is removed, the DC circuit breaker will turn off. If the DC input voltage is less than 207 V or exceeds 285 V, the circuit breaker will also be tripped. Circuit breaker reset must be accomplished locally at the unit.

1.3.2 There is only one common monitor output which transfers if any failure alarm is activated. Front panel lights must then be observed to determine which alarm was activated. The common alarm connections are located on TB10 on the upper left side of the cabinet. See sections 1.6.7 and 1.6.8.

1.4 Cyberex Acceptance Tests

1.4.1 Introduction

On 26 and 27 April 1979 three representatives from MIT/LL visited Cyberex Inc. in Mentor, Ohio, for the purpose of acceptance testing and motor start testing. The acceptance test was a repeat of Cyberex's standard tests done to assure operation to specifications. The motor start testing was done to observe the inverter operation while starting motors similar to those at NBNM while maintaining fixed base loads.

1.4.2 Acceptance Testing

The inverter was resistive loaded only, since Cyberex did not have the convenient capability to provide a .8 P.F. load. The inverter was only rated 40 KW resistive but Cyberex personnel loaded it to 50-KW resistive to produce the same output current as a 50-KVA 0.8 P.F. load. Output voltage was measured by a Cyberex-supplied 300-volt Weston-type 904-AC voltmeter calibrated 15 September 1978 and output current was measured through a LL-supplied Abacus current transformer connected 200/5 amps and 5A current shunt read with a Cyberex-supplied digital AC voltmeter. This was checked against a Cyberex AC ammeter Weston-type 435 calibrated 15 September 1978 and Weston current transformer type 605. The inverter was supplied DC power from a Cyberex-built power supply. DC input current was read with a digital voltmeter across Cyberex 250A/50MV shunt #18. DC input voltage was measured with a 300-volt Weston-type 904-DC voltmeter. Table 1-1 summarizes the measurement results which met the Cyberex specifications.

Under and overvoltage breaker trip was verified. One panel-mounted output ammeter was found to be out of tolerance and it was to be replaced. An indicator light that was to indicate that the circuit breaker was enabled was found to be wired incorrectly. The inverter was then accepted contingent on minor work being completed.

1.4.3 Motor Start Testing

There are at present three induction motors which the site inverter must be capable of starting. The motors are used on equipment that

TABLE 1-1 CYBEREX 50-KVA INVERTER MODEL 240/50IFB1 S/N9794 26 April 1979
AT FACTORY

V(in) VDC	I(in) ADC	P(in) KWDC	V(out) VAC	I(out) AAC	P(out) KWAC	EFF	DISS KW	THD %
210	12.25	2.57	244	0			2.57	4.4
230	11.80	2.71	245	0			2.71	4.4
260	11.50	2.99	246	0			2.99	4.6
280	11.50	3.22	246	0			3.22	4.8
210	77.50	16.28	244	53.2	13.0	.798	3.30	3.8
230	71.50	16.45	245	53.2	13.0	.793	3.50	4.0
260	65.30	16.98	246	53.6	13.2	.777	3.80	4.2
280			246	54.0	13.3			
210	135.2	28.40	244	97.6	23.8	.838	4.20	3.7
231	123.5	28.50	245	97.6	23.9	.838	4.20	3.9
260	112.3	29.20	246	98.0	24.1	.826	4.80	4.2
280	105.9	29.60	247	98.0	24.2	.815	5.20	4.4
210	222.4	46.70	243	162.4	39.5	.845	7.20	3.5
230	204.8	47.10	244	162.4	39.6	.841	7.50	3.8
260	184.8	48.00	244	163.6	39.9	.831	8.10	4.3
280	174.0	48.70	246	163.6	40.2	.826	8.50	4.4
210	272.0	57.10	242	199.0	48.2	.843	9.90	3.5
230	250.0	57.50	244	199.0	48.6	.844	8.90	3.8
260	226.0	58.80	244	199.0	48.6	.826	10.20	4.2
280	211.4	59.20	245	200.0	49.0	.828	10.20	4.5

serves various utility functions and are summarized below:

1. The domestic water supply pump is used to transfer water from the main water storage facility (50,000-gallon capacity) to an intermediate tank (150 to 200 gallons) whence it is distributed to site users. The unit is a 3-hp Franklin electric pump, model #110-3062-403. During starting it drew 83 amps at 226 volts for approximately .25 seconds. Running current was 14 amps at 241 volts with a 0.84 power factor.

2. The air compressor system provides the maintenance area garage with compressed air and pressurizes the domestic water supply. The motor is a 3-hp G.E. triclad model #5K184AL202A. The motor draws 92 amps at 227 volts for a starting duration of about 1 second. Running current is 18 amps at 241 volts with a 0.73 power factor.

3. The artesian well pump supplies the site with a source of fresh water. It runs for a period of 12 hours nightly for 3 nights, pumping 15 to 20 thousand gallons of water into the main storage facility. At present it is a 2-hp Reda Pump Company model #46200K but a 5-hp 30-gallon-per-minute system is being considered. The starting current is 58 amps at 213 volts for less than 0.2 seconds. Running current is 14 amps at 234 volts with a 0.99 power factor.

It is possible that two motors could be turned on simultaneously, while the inverter is supplying the other system loads. It was necessary to find out as early as possible what might happen.

Besides being too complicated to set up a three motor test, the artesian well pump is only 2 hp and is on a time clock and runs only at night so a three motor start is extremely unlikely. Equipment was procured to simulate the actual equipment at the NBNM site. For the air compressor a system was assembled consisting of a Quincy compressor model #310-25 driven by an Ajax motor model #XTG-3-184T2. Figures 1-1 and 1-2 show the starting current and transient duration. It draws 92 amps at 212 volts with a 0.85 power factor for about 0.5 seconds. To simulate the domestic water supply pump an unloaded Leland-Faraday 3-hp

Fig. 1-1 Compressor Starting Current
80 A/DIV, 100 V/DIV, 5 ms/DIV

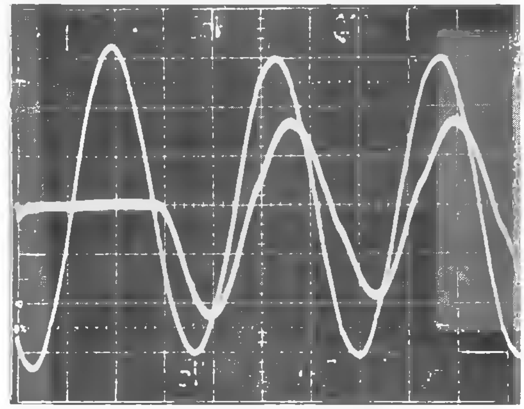


Fig. 1-2 Compressor Starting Transient
80 A/DIV, 100 V/Div, 100 ms/DIV

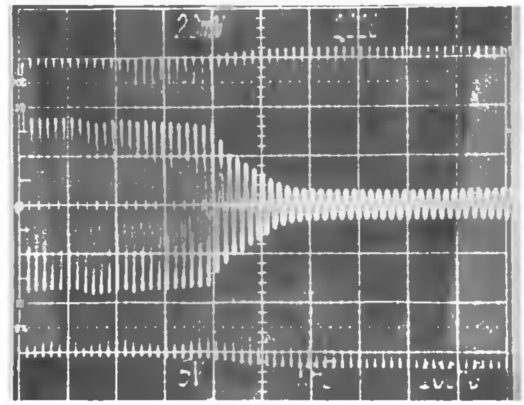


Fig. 1-3 Water Pump Starting Current
80 A/DIV, 100 V/DIV, 5 ms/DIV

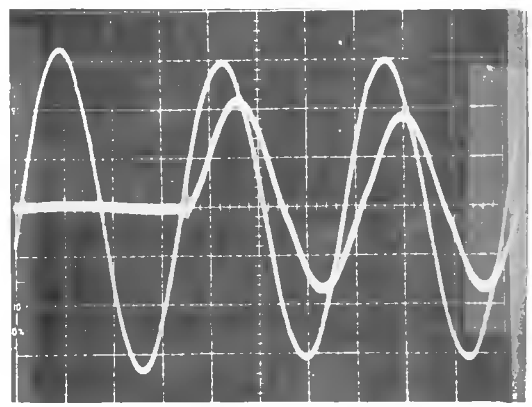
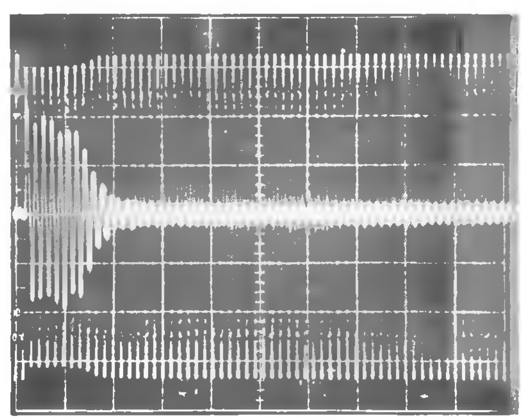


Fig. 1-4 Water Pump Starting Transient
80 A/DIV, 100 V/DIV, 100 ms/DIV
V = 212 V, I = 106 A



jet pump motor model #M-508 was used. The pump is centrifugal and thus presents little load to the motor during starting. Figures 1-3 and 1-4 show the starting current and transient duration. It draws 106 amps at 212 volts at a power factor of 0.73 for about .15 seconds.

A scheme was devised whereby each motor would have an undervoltage relay and time delay relay so that if the inverter voltage were to decrease due to overload, all motors would be turned off. Each motor would restart after different time delays. These devices were fitted to the motors and they were shipped to Ohio for the tests.

The inverter easily started both motors simultaneously as expected. More and more preload was added in anticipation of some sort of limitation being reached. The tests were stopped at 40-KW resistive preload (165A). Current limit for this inverter is set slightly above the current which represents 50-KVA output at 240V, or 208 amps, and is a peak responding circuit. The inverter went smoothly into current limit, the voltage dropped sufficiently to free up enough current to start the motors and the transient lasted less than 1 second. Figure 1-5 shows the inverter output voltage response following application of both motors while supplying a 40-KW load. Inverter voltage drops to 160V while both motors are stalled. After 0.3 seconds the pump motor has achieved speed and the voltage rises to 195 volts. The compressor motor is up to speed 0.4 seconds later. Since this transient was less than 1 second in duration, the undervoltage relays were never activated. As a check, the total locked rotor impedance load on the inverter can be calculated and then multiplied by the 208-amp current limit. The compressor locked rotor impedance is 1.95 + j1.22 ohms. The pump locked rotor impedance is 1.46 + j1.36 ohms and the 40-KW preload is 1.42 ohms. Combined impedance is 0.65 ohms which produces a 136-volt result. This compares favorably with the measured 160 volts because current limit is slightly higher and there is wiring resistance.

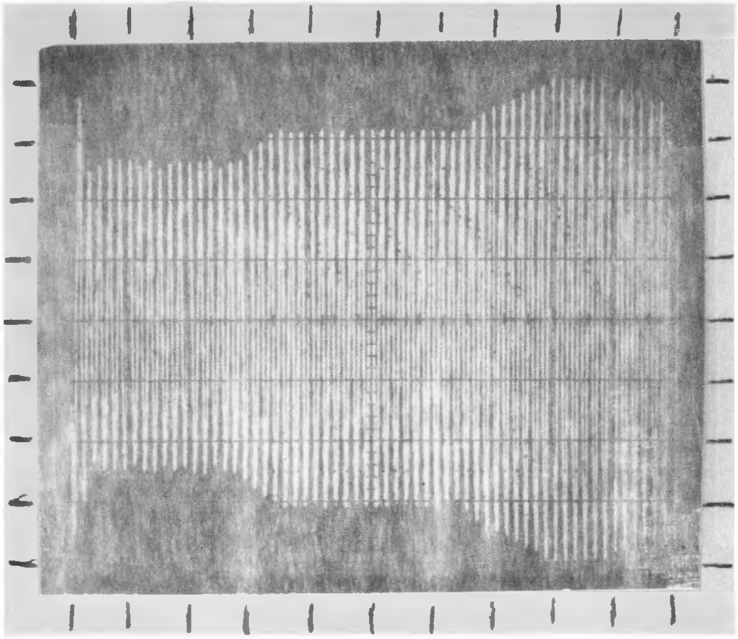


Fig. 1-5 Cyberex Inverter Worstcase Motor Starting

88 V/DIV, 100 ms/DIV, V_{in} = 235 VDC, I_{out} = 165A BASE

1.5 Cyberex In-House Testing

1.5.1 Introduction

After being uncrated, the inverter was inspected for physical damage and loose hardware. The AC and DC alarm boards had broken loose during shipment and resistors were damaged on the DC alarm board. These were replaced with locally available parts.

A set of internal photographs were taken. These are to be used as a record and to facilitate future repair.

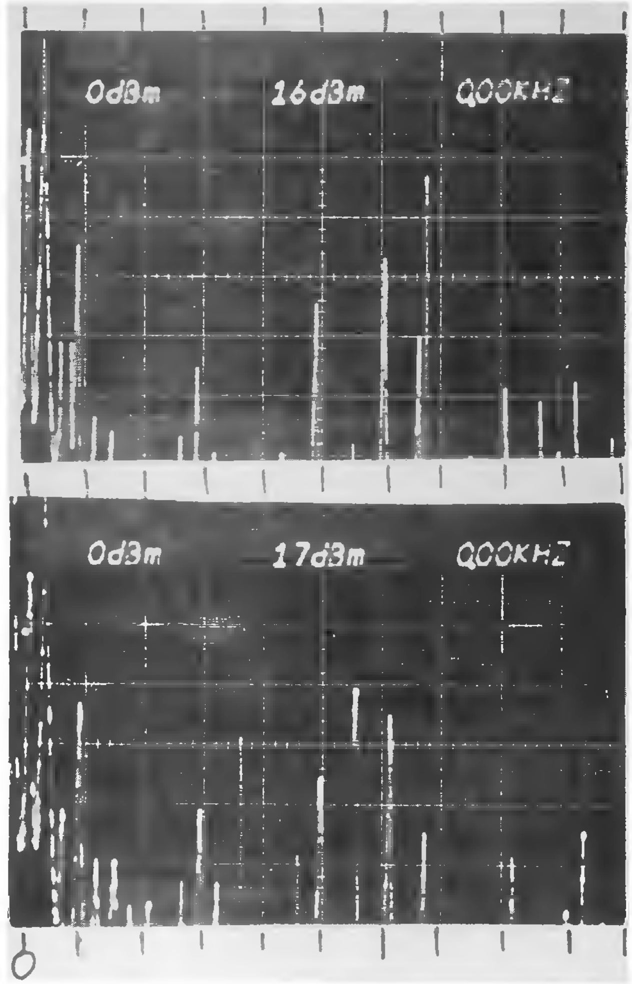
All factory adjustments were checked per the manual supplied by Cyberex. Schematics were studied and all pertinent waveforms were observed and photographed.

The inverter was operated at various power levels (resistive load) at various input voltages supplied by the Ratelco battery chargers. All data was recorded and spectrum pictures taken.

1.5.2 Data

Figure 1-6 is the output spectrum of the inverter when run at high and low input voltage at 30-KW resistive load. The third harmonic is 34-db down from the fundamental 60Hz (2%). The next significant components are at harmonic numbers 10, 17, 19 and 21, the largest of which is more than 30 db below the fundamental (3.2%). Calculation of total harmonic distortion as the root of the sum of the squares gives approximately 3.8% distortion. The components near the 20th harmonic are due to the manner in which the output waveform is synthesized. Figure 1-7 shows a typical output waveform in which the 20th harmonic is noticeable. It can be removed if it proves troublesome. Figures 1-6 and 1-8 through 1-12 show the output spectrum at various input and output conditions. The distortion does not significantly change. Some artifacts of the analyzer are present.

Table 1-2 presents the results of in-house measurements which are plotted in Figures 1-13, 1-14, and 1-15. Figure 1-13 also includes data from Table 1-1. LL data is 1 to 2 percent higher.



210 VDC

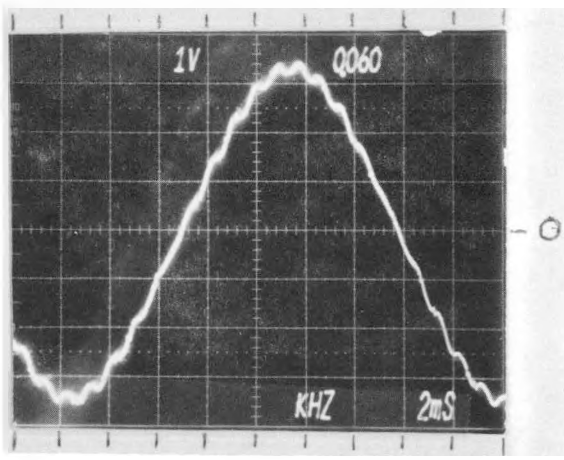
275 VDC

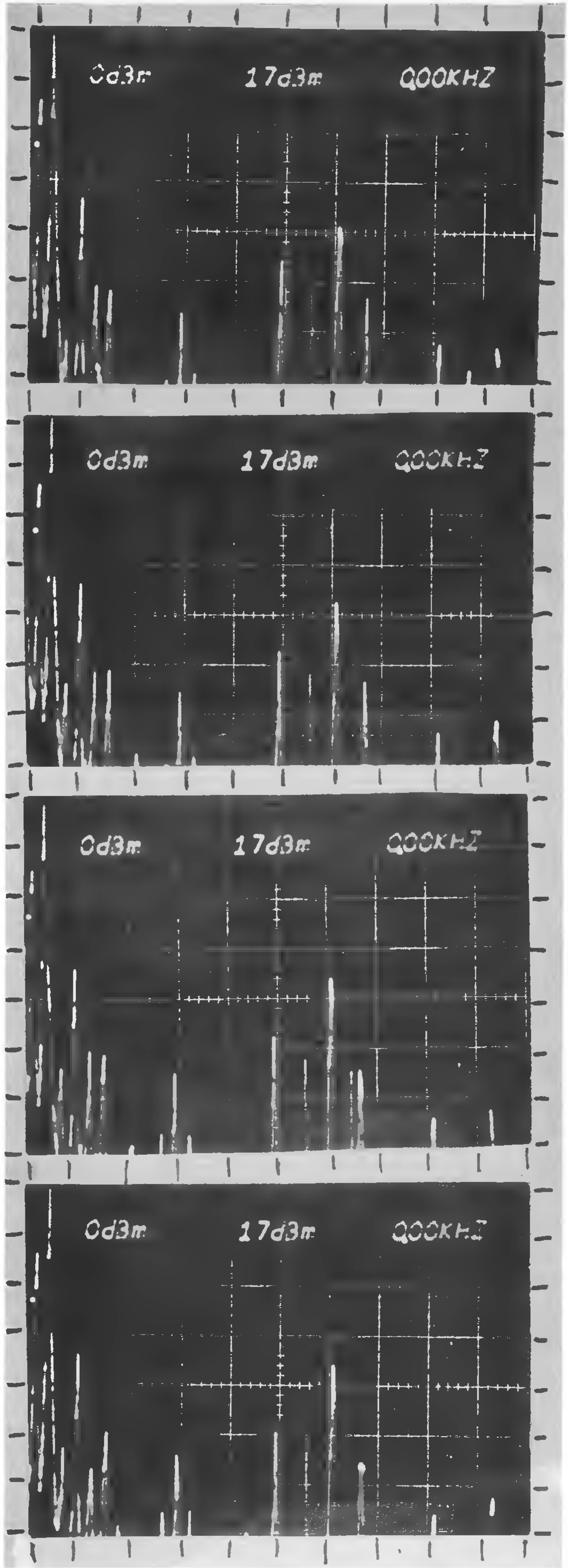
Fig. 1-6 Inverter Output Spectrum
30 Kw Load

10 db/Div, 200 Hz/Div

MIT/LL 10-18-79

Fig. 1-7 Inverter Output Waveform
210 V DC 30 Kw Load
100V/Div, 2 Ms/Div
MIT/LL 10-18-79





210 VDC

230 VDC

250 VDC

275 VDC

Fig. 1-8 Inverter Output Spectrum
No Load

10 db/Div, 200 Hz/Div

MIT/LL 10-18-79

210 VDC

230 VDC

250 VDC

275 VDC

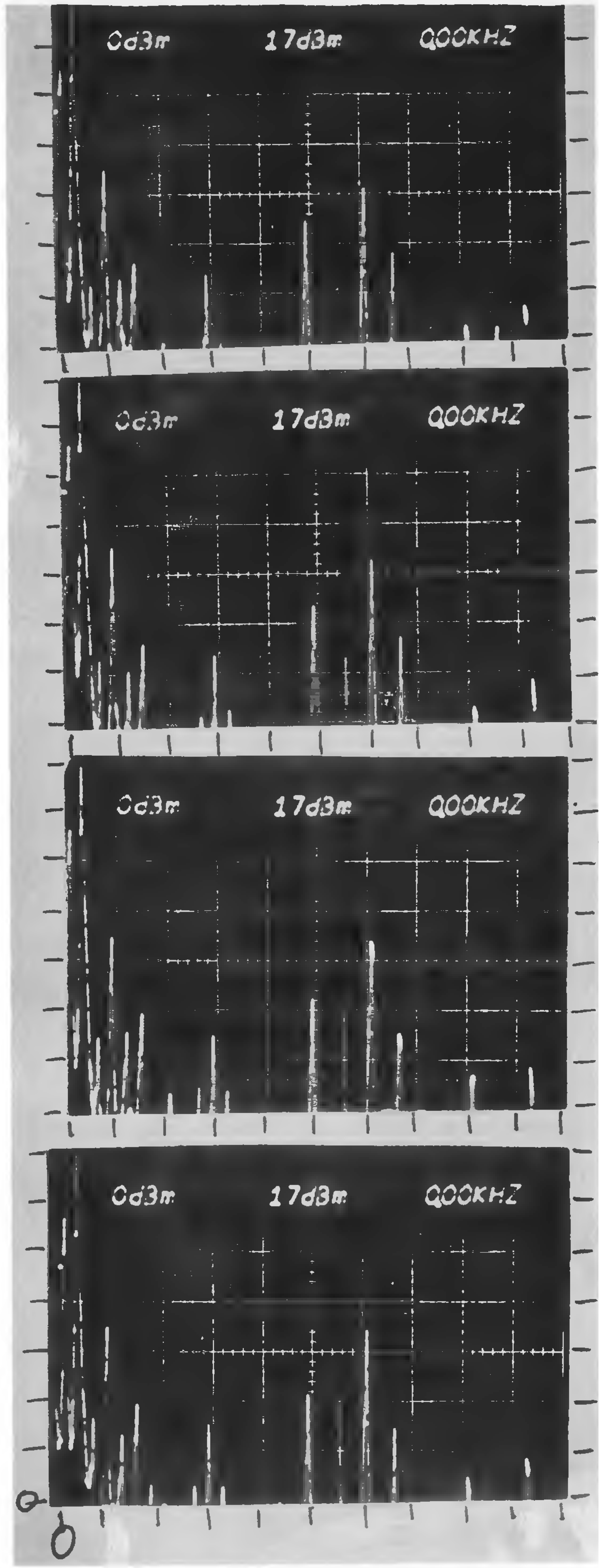
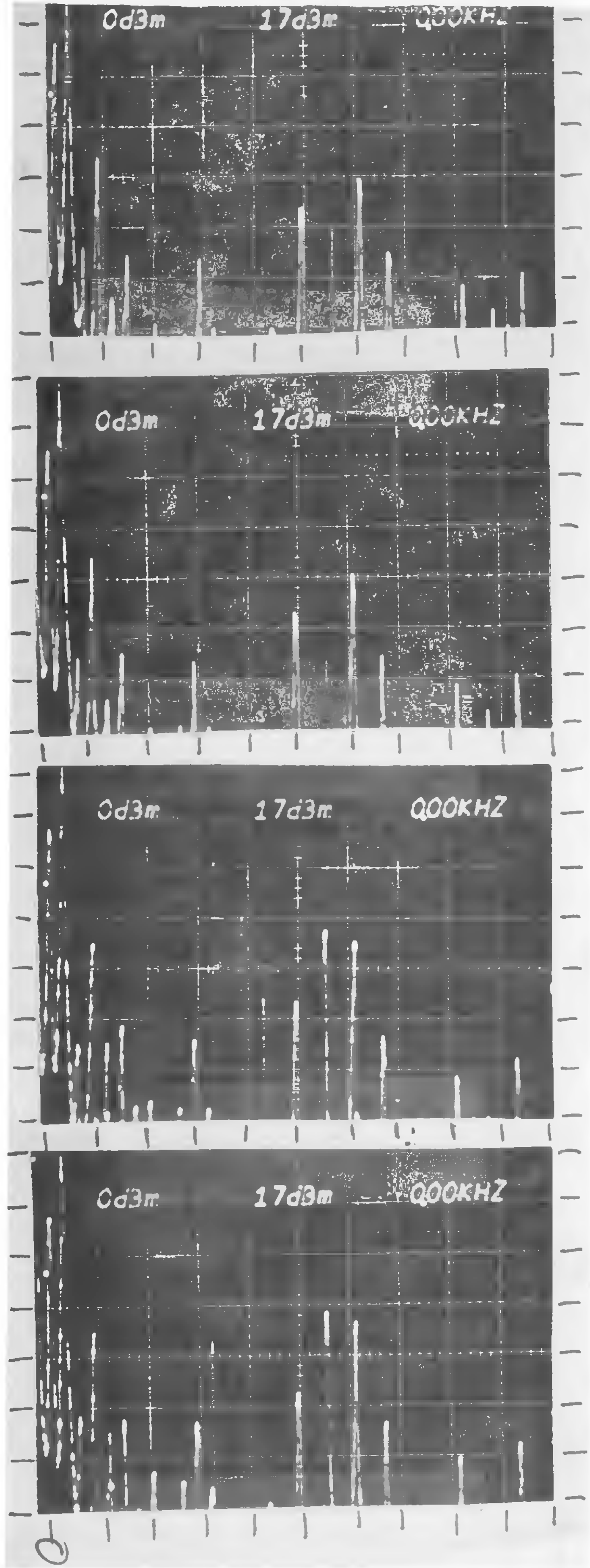


Fig. 1—9 Inverter Output Spectrum
5 Kw Load

10 db/Div, 200 Hz/Div

MIT/LL 10-18-79



210 VDC

230 VDC

250 VDC

275 VDC

Fig. 1-10 Inverter Output Spectrum
10 Kw Load

10 db/Div, 200 Hz/Div

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230 VDC

250 VDC

275 VDC

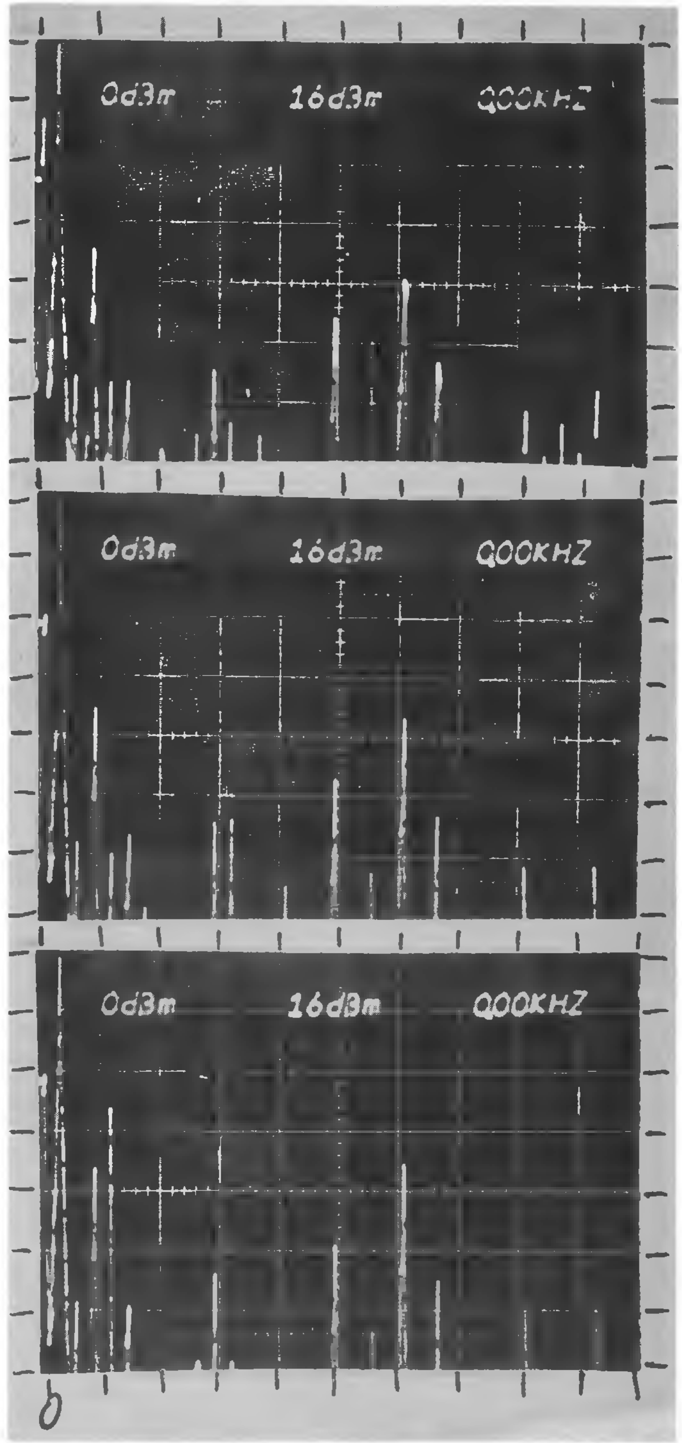

Fig. 1-11 Inverter Output Spectrum
20 Kw Load

10 db/Div, 200 Hz/Div

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Fig. 1-12 Inverter Spectrum
220V DC 36 Kw Load
10 db/Div, 200 Hz/Div

MIT/LL 10-18-79

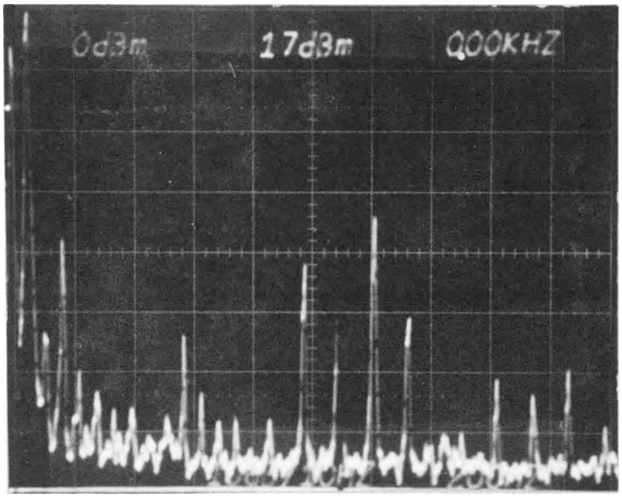


TABLE 1-2

CYBEREX INVERTER 50-KVA MODEL 240/50IFB1 S/N9794 IN-HOUSE MEASUREMENTS

V_{in} VOLTS	I_{in} AMPS	V_{out} VOLTS	I_{out} AMPS	P_{out} KW	P_{in} KW	EFF
210	12.0	238.2	0	0	2.5	-
230	11.8	239.2	0	0	2.7	-
250	11.6	240.0	0	0	2.9	-
275	11.5	240.6	0	0	3.2	-
210	36.0	238.2	20.3	4.8	7.6	.64
230	33.6	239.3	20.4	4.9	7.7	.63
250	32.0	240.3	20.7	4.9	8.0	.62
275	30.3	240.5	20.6	4.9	8.3	.594
210	60.3	238.2	40.9	9.7	12.7	.769
230	56.3	239.2	40.4	9.7	12.9	.747
250	53.0	240.0	41.0	9.8	13.3	.743
275	49.5	241.0	41.6	10.0	13.6	.737
210.5	110.0	239.9	82.0	19.7	23.2	.850
230	102.5	241.0	83.0	20.0	23.6	.849
250	95.5	237.6	81.5	19.5	23.9	.818
275	88.5	240.6	83.5	20.1	24.3	.826
210	161.5	237.5	122.5	29.1	33.9	.858
230	149.5	238.5	123.0	29.3	34.4	.853
250	139.0	239.0	122.7	29.3	34.8	.844
275	128.5	239.5	123.0	29.5	35.3	.834
227.8	191.5	238.2	156.0	37.2	43.6	.852

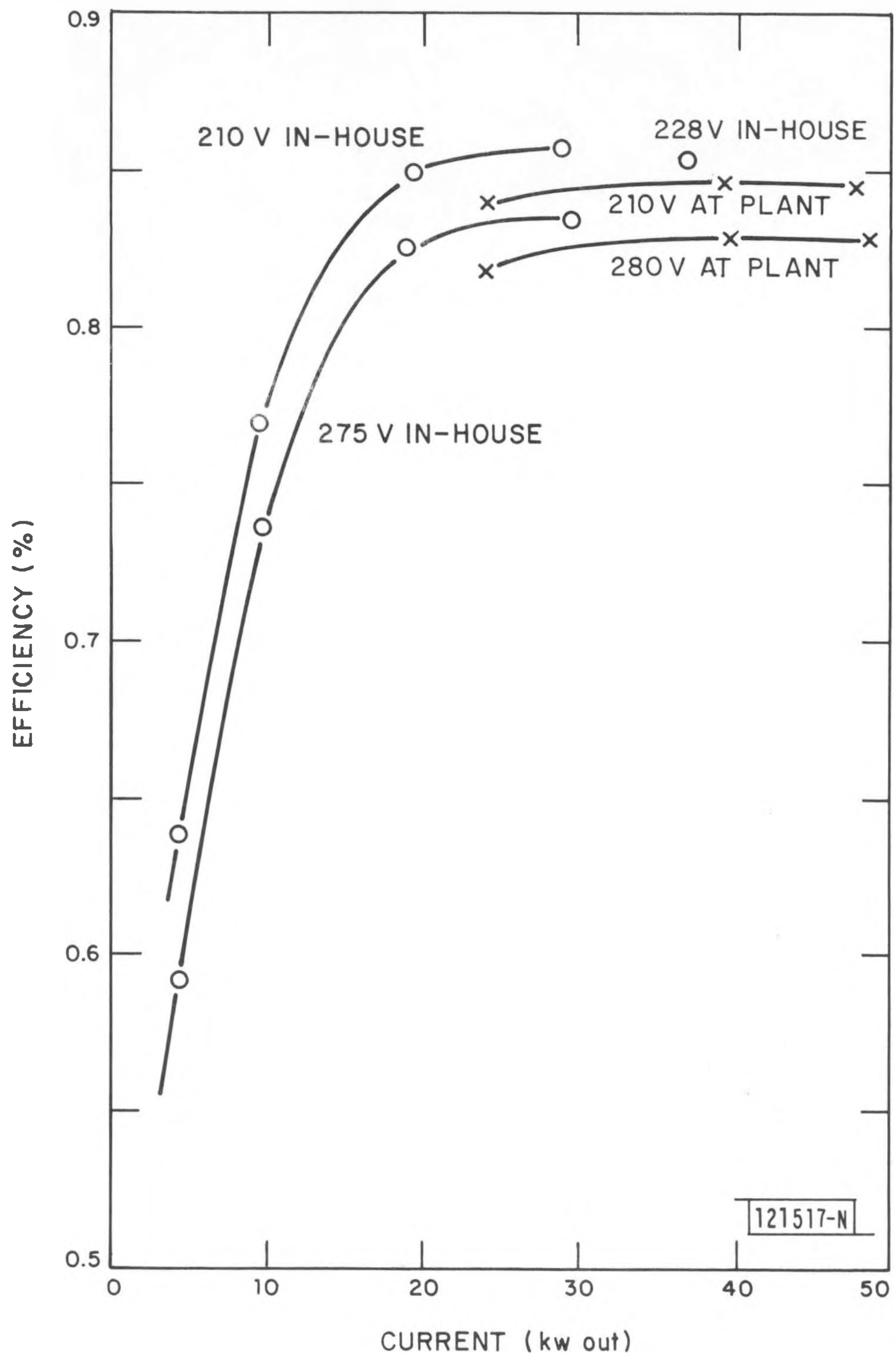


Fig. 1-13. Cyberex inverter MIT/LL 19 Oct. 1979 EEL model 240/50 IFB1, serial number 9794.

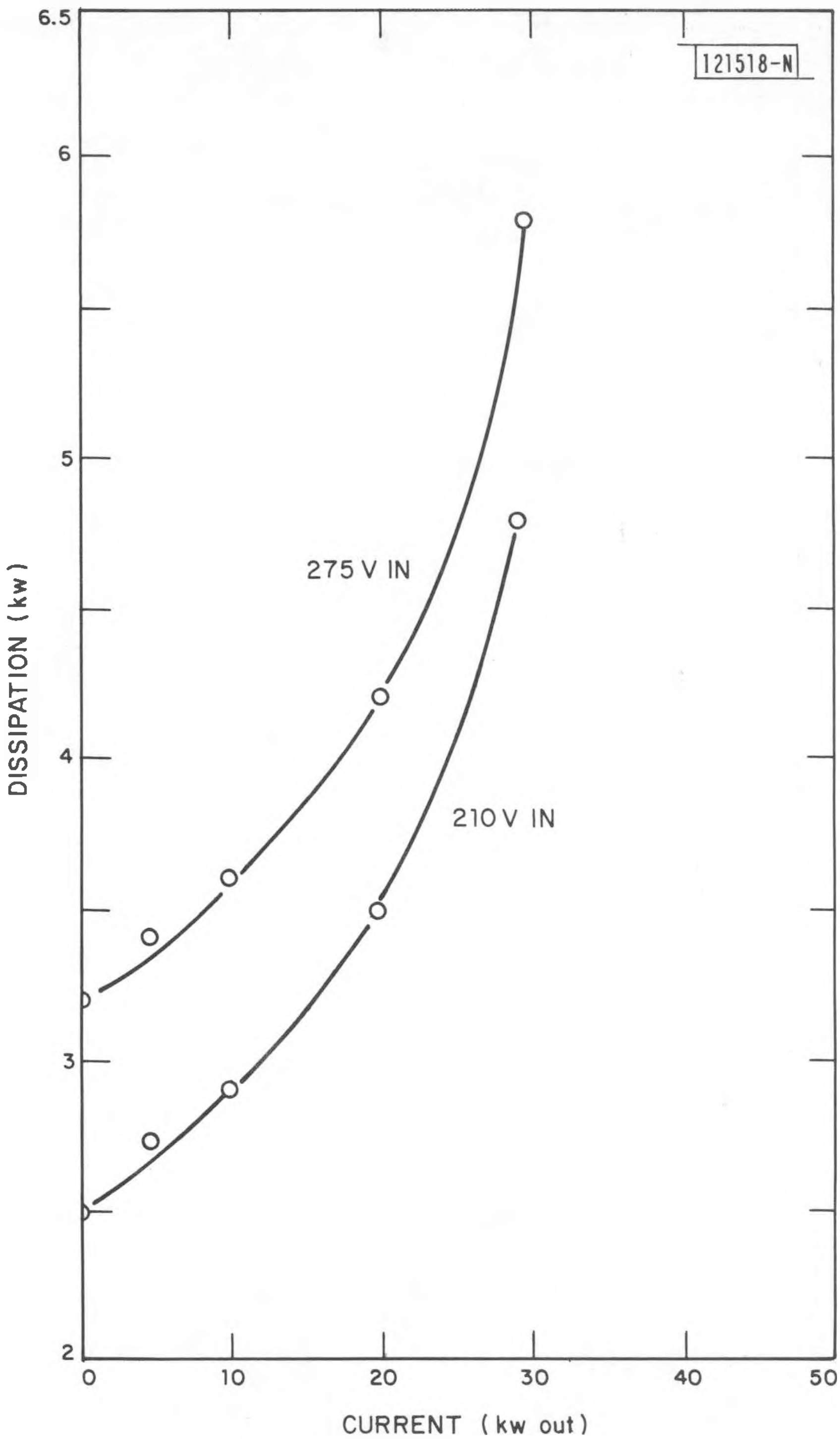


Fig. 1-14 Cyberex inverter MIT/LL 19 Oct. 1979
EEL model 240/50 IFBl, serial number 9794.

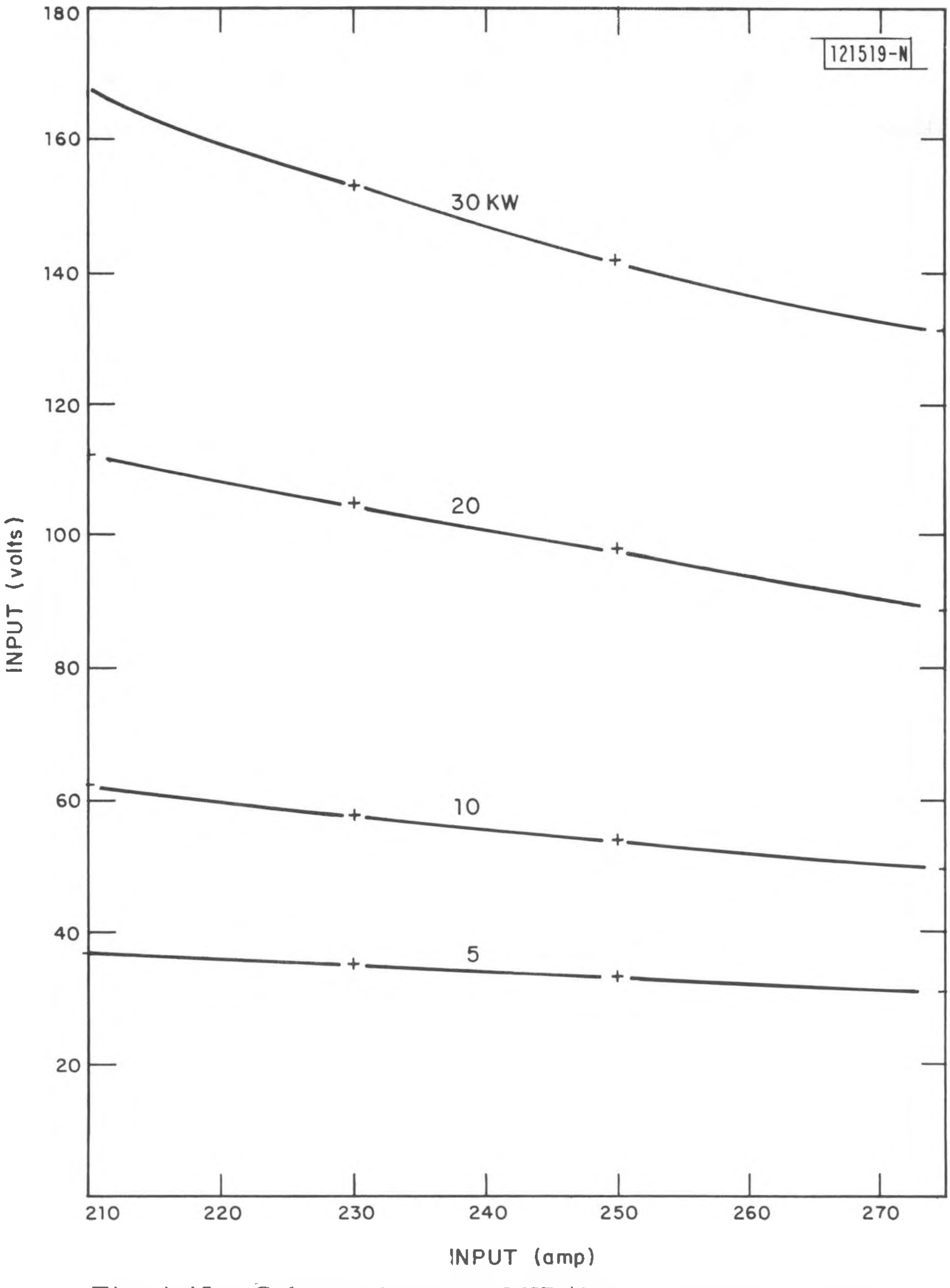


Fig. 1-15. Cyberex inverter MIT/LL, 19 Oct. 1979 EEL model 240/50 IFB1, serial number 9794.

1.6 Detailed Circuit Descriptions

1.6.1 Power Section

This section contains the power handling components of the inverter. It is comprised of four main SCR's, four antiparallel diodes and four commutation circuits containing four commutation SCR's. These are mounted on the large heat sink assemblies. The commutation circuits are used to force the transfer of load current from one main SCR to another. The operation sequence is to fire an auxiliary SCR which initiates the commutation process and a predetermined time later to fire the main SCR to which the load current will transfer. The four power switch assemblies are electrically arranged in a classical bridge configuration which supplies power to the output transformer located at the bottom of the cabinet. The logic boards, located in the card cage in the center of the unit, generate the proper gating signals so that the filtered transformer output is a low distortion, regulated, sine wave.

1.6.2 Reference Oscillator RD 5957

The reference Voltage Controlled Oscillator is comprised of unijunction transistor Q201 and associated circuitry. The oscillator frequency is nominally 720 Hz and is controllable by a current injected at Pin 25 (see Figure R01). The frequency is appropriately divided to produce a 60-Hz square wave at Pin 23. Pins 21 and 22 are used only in three-phase systems so the associated circuitry has not been mounted on the printed circuit board.

The carrier oscillator is unijunction transistor Q207 and associated circuitry. Its frequency is slightly higher than 1200 Hz (see Figure R02). Counter IC 207 divides this to 600 Hz and IC 208 is an integrator used to produce a triangle output. The level is set using R 237 and the waveform observed at TP1 is seen in Figure R03. IC 209 is used as an inverter to produce the inverted triangle. It is observed at TP2 and adjusted at R270.

Fig. RO-1 Reference VCO, C201 Voltage

2V/Div, 0.5 MS/Div, 720 Hz

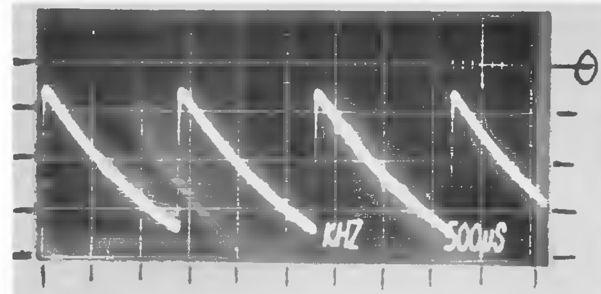


Fig. RO-2 Carrier Oscillator, C202 Voltage

2V/Div, 0.2 Ms/Div, 1200 Hz

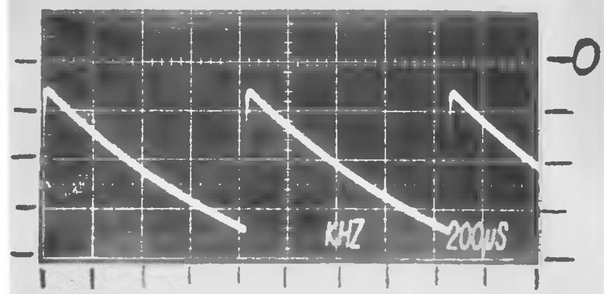


Fig. RO-3 Carrier Frequency Triangle TP1

0.5V/Div, 0.2 MS/Div, 1200 Hz

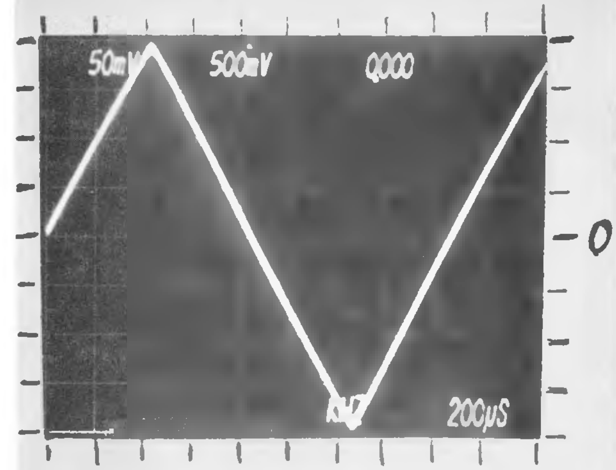
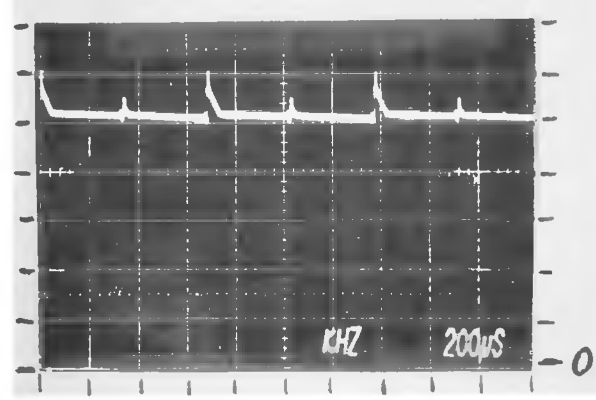


Fig. RO-4 +48 Volts Unregulated

10V/Div, 0.2 MS/Div, 240V Input



REFERENCE OSCILLATOR
MODULE WAVEFORMS

MIT/LL 10-17-79

IC 206 is used to level shift, invert and amplify the unregulated +48 volts at Pin 20 (see Figure R04). The output at Pin 19 controls the delay time between firing an auxiliary SCR and the incoming main SCR.

1.6.3 SYNC Module with Crystal Reference C20339

This board contains a reference crystal oscillator, an automatic switch to an external frequency reference, if available, and a phase detector. The phase detector output is used to control the reference voltage-controlled-oscillator on the reference oscillator board.

IC 607 is a crystal oscillator (120 KHz) buffered by IC 603 (see Figure SM1). IC's 610 through 612 divide by 1000 and IC 616 divides by two to derive a 60-Hz reference square wave (see Figure SM2). If an external frequency reference is applied at Pin 13, it is routed through IC's 601, 603, 619 and 604 to control switch transistor Q601. If there is no external frequency reference, the internal crystal generated reference controls Q601.

IC 604 is configured to be a unity gain inverter when Q601 is conducting and to be a unity positive gain buffer when Q601 is off. A sample of the inverter output frequency is applied to IC 605. If the reference and the inverter output differ in phase by 90^{o}, the output of IC 605 is zero and no amplified correction current is applied via Pin 9 to the reference controlled oscillator. If the phase relationship changes, a correction voltage is generated which corrects the phase (frequency) of the inverter and thus, "locks" it to the reference (either external or internal).

1.6.4 Modulation Index Control RD 5219

The basic function of this board is to generate a variable pulsewidth modulated signal in response to the difference between the desired and actual sinusoidal inverter output amplitude.

The reference 60-Hz square wave enters at Pin 13. Its spectrum is shown in Figure MI-1. IC's 301, 302 comprise an active low-pass filter to produce a resultant

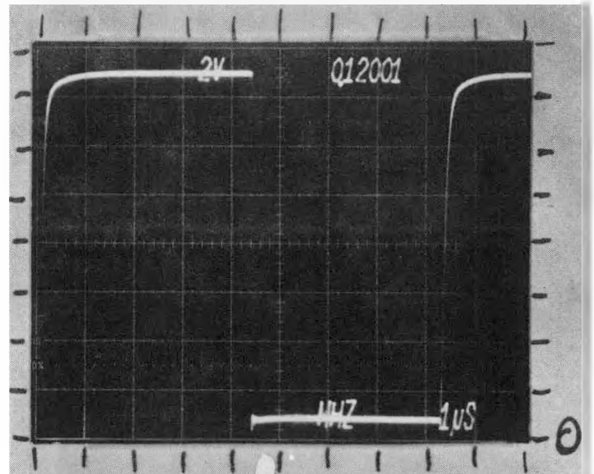


Fig.SM-1 Crystal Oscillator Output IC 610 Pin 14

2V/Div. 1 μs/Div, 120 KHz

MIT/LL 10-18-79

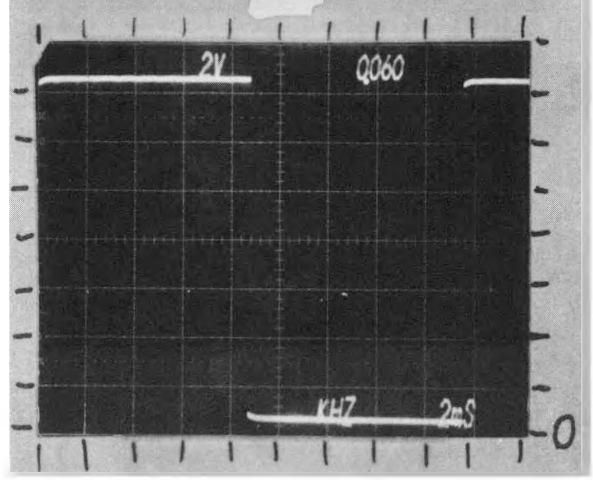


Fig. SM-2 Reference Frequency IC 619 Pin 12

2V/Div, 2 MS/Div

MIT/LL 10-18-79

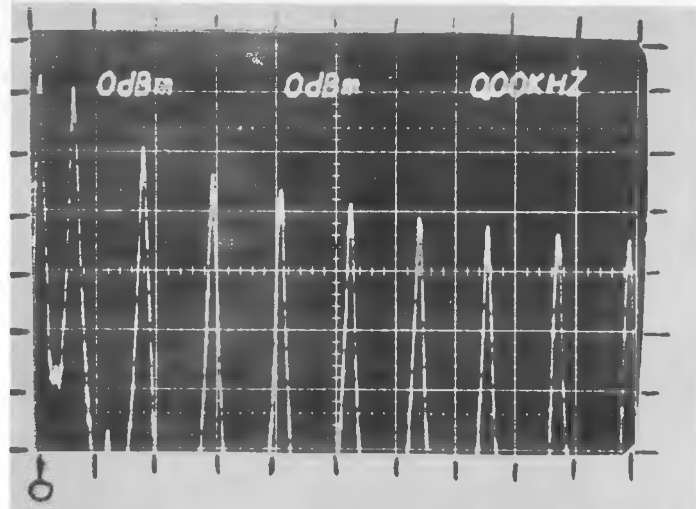


Fig. MI-1 Input Spectrum, Pin 13
10 db/Div, 100 Hz/Div

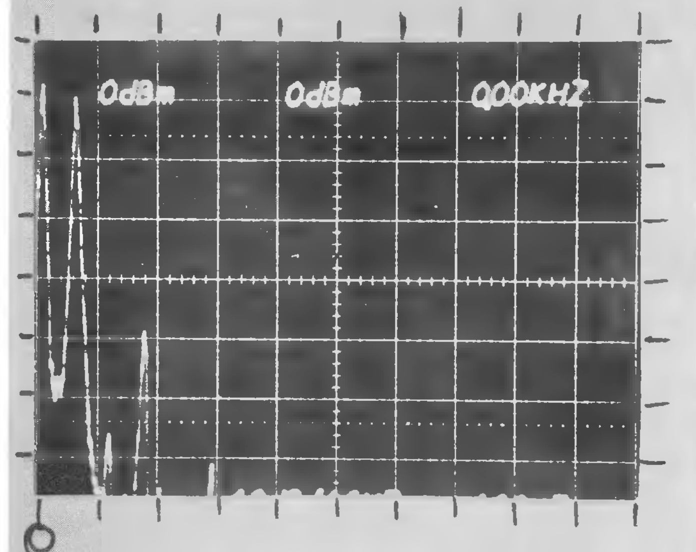


Fig. MI-2 Reference Sine Wave
IC 302 Pin 10
10 db/Div, 100 Hz/Div

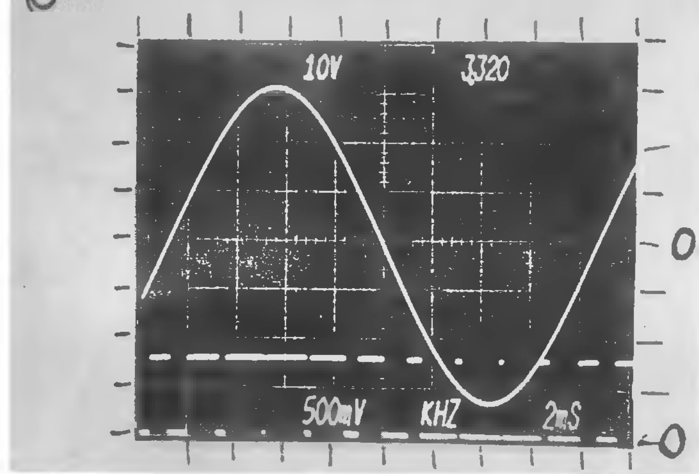


Fig MI-3 Reference Sine & TP1
Voltage
Upper 0.5V/Div
Lower 10V/Div, 2 MS/Div

MODULATION INDEX CONTROL
MODULE WAVEFORMS

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fundamental with spectrum as shown in Figure MI-2. Note that the third harmonic is 40 db down or 1% of the fundamental.

The emitter of Q302 is the summing point for all error signals. A positive voltage at this point reduces inverter output. A positive startup signal at Pin 14 forces the inverter to turn-on with low output voltage and as the startup signal decreases, the inverter output "walks in." IC 307 produces an error signal proportional to the difference between the voltage reference on R358 and the rectified inverter voltage output entering Pin 22. IC 308 produces an error signal proportional to the difference between the current reference on R370 and the rectified inverter output current sample and this voltage can override the voltage regulator. R368/C324 and R356/C323 are required for feedback loop stability. The inverter current limit generally protects against output short circuit, but if a short is applied when the output voltage is near zero, current limit will not activate quickly enough (because of R368/C324) and the DC input fuse may be blown.

The combined error signal controls the reference sine amplitude via the analog multiplier IC 303/304. IC's 305 and 306 compare the sine wave to the triangle waves to produce two PWM signals at Pins 8 and 9 (TP1, TP2). Figure MI-3 shows the reference sine wave and the resulting PWM at TP1.

1.6.5 Gate Drive Control RD 7133

Inputs to this board are the two PWM signals from the modulation index control board and the derived DC bus voltage signal from the reference oscillator board.

The DC bus voltage signal is used to control the time delay between firing an auxiliary SCR and firing the incoming main SCR. This is done in order to adjust the commutation circuit energy as a function of DC input voltage to the inverter so that efficiency is maximized over a wide range of DC input voltage. IC 405 is a monostable multivibrator. Time delay decreases approximately 1μs for every 10 volts increase in bus voltage and is nominally 72μs at 260 VDC. The delay can be observed at TP2 and is shown in Figures GD-1 and -2.

The PWM signal enters at Pin 9 and, after buffering and low-pass filtering, can be observed at TP1. A representative signal is shown in Figure GD-3 and the spectrum in GD-4. Notice that the third harmonic is 36 db below the fundamental (more than in the reference sine wave) and that there are strong components at

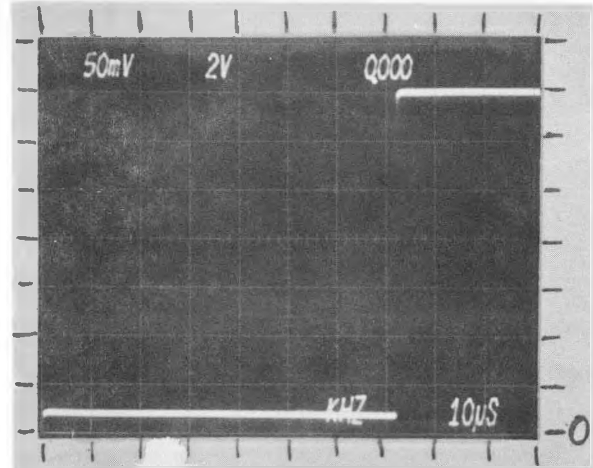

Fig. GD-1 TP2
2V/Div, 10 μs/Div

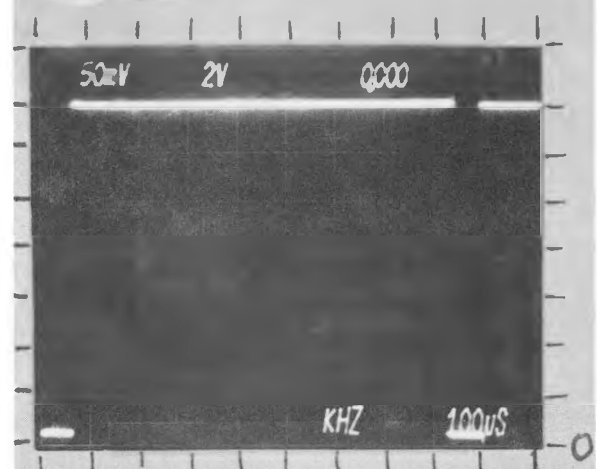

Fig. GD-2 TP2
2V/Div, 0.1 ms/Div

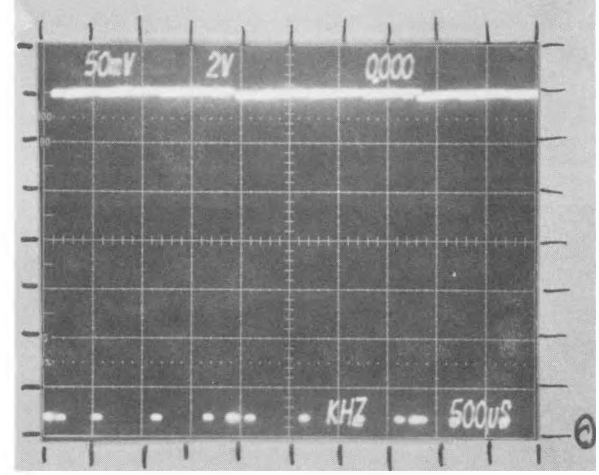

Fig. GD-3 TP1 Test Toggle Switch On
2V/Div, 0.5 Ms/Div

GATE DRIVE MODULE WAVEFORMS

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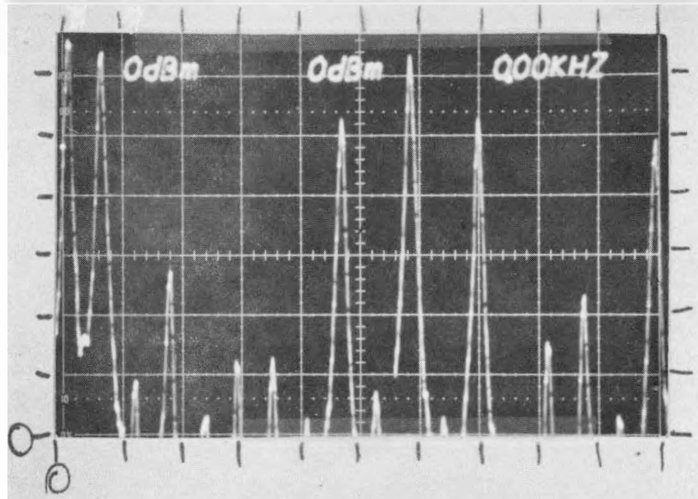

Fig. GD-4 TP1 Spectrum, Test Switch On

10 db/Div, 100 Hz/Div

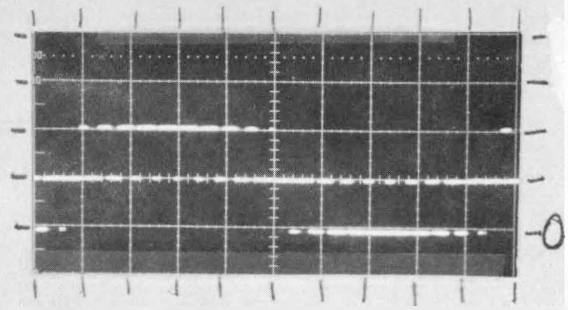

Fig. GD-5 TP1, Sum of Both GD Modules

10V/Div, 2 Ms/Div

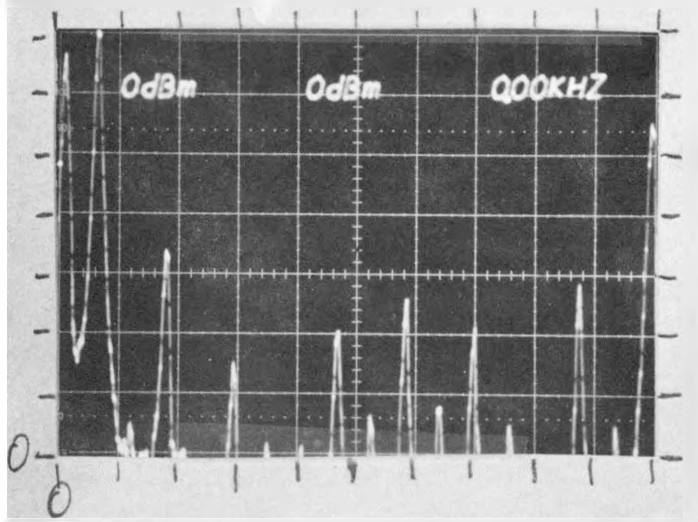

Fig. GD-6 TP1, Sum, Spectrum

10 db/Div, 100 Hz/Div

GATE DRIVE MODULE WAVEFORMS

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480, 600 and 720 Hz. The two PWM drive signals have the same fundamental (60 Hz) but contain carrier frequencies which are 180^{o} out-of-phase so that there will be cancellation if they are added. If the two PWM signals are added (as they are in the power section), the signal appears as in Figure GD-5 with spectrum in Figure GD-6. Notice that the carrier components have been reduced by 45 db. Components at twice the carrier frequency still remain in the original proportion to the fundamental at 15-db down. The low-pass filter formed by the output transformer leakage inductance and output filter capacitors, attenuates the carrier components an additional 10 db and the double-carrier frequency components by 20 db.

1.6.6 Logic Power Supply RD 5816

All power for the logic and gate drivers is derived from this power supply. Input is unregulated DC bus and the output is regulated plus and minus 15 volts and unregulated 48 volts which are distributed to the logic boards. Unregulated 25 volts is also supplied to the gate firing circuits. Nominal operating frequency is 1500Hz which is set by T-502.

1.6.7 Alarm Circuits C9794-4, 5, 8

There are two classes of alarm, those powered by the inverter AC output and those powered by the DC bus input.

The DC powered alarms are low air flow and overtemperature. This overtemperature alarm appears 10^{o}C <u>before</u> the DC breaker trip assembly shuts the inverter off because of overtemperature. Either condition energizes K23 and the appropriate indicator light.

The AC powered alarms are output AC voltage low, output AC voltage high, and frequency out-of-tolerance. These control K21, K22 and K601, respectively, from which the appropriate indicators are controlled.

1.6.8 Common Alarm (see Figure 1-16)

Contacts on the alarm relays are placed in series and maintain K10 energized if operation is normal. If TB10-5 and -6 are closed (TB10-4 and -5 open), then

1. there is AC output within limits and
2. temperature is below 50°C and
3. air flow is normal and
4. frequency is within tolerance.

If TB10-5 and -6 are open (TB10-4 and -5 are closed), then

1. AC output voltage is low or missing or
2. AC output voltage is high or
3. temperature is over 50°C or
4. air flow is low or
5. frequency is out-of-tolerance or
6. K10 or T11 is defective.

Check the five alarm indicators on the front panel.

1.6.9 DC Breaker Trip Assembly

The breaker release winding must be energized before the main DC circuit breaker can be turned on. This requires S10 to be on, TB10-8 be connected to TB10-9 (external enable), and K20 to be energized. Turning S10 on also precharges the input filter capacitor bank. (See Figure 1-17).

K20 is energized by Q201 when the input DC is above the undervoltage trip level. Power is supplied to K20 through R301 and 302 which is removed if Q101 is on (overvoltage condition) or if TS20 indicates overtemperature.

Warning! If an attempt is made to turn on the DC circuit breaker without energizing the release winding, the breaker will trip. The breaker contacts close momentarily during the trip, connecting the DC source to the uncharged input filter capacitors. Battery fuses or capacitor bank protection fuses may be blown.

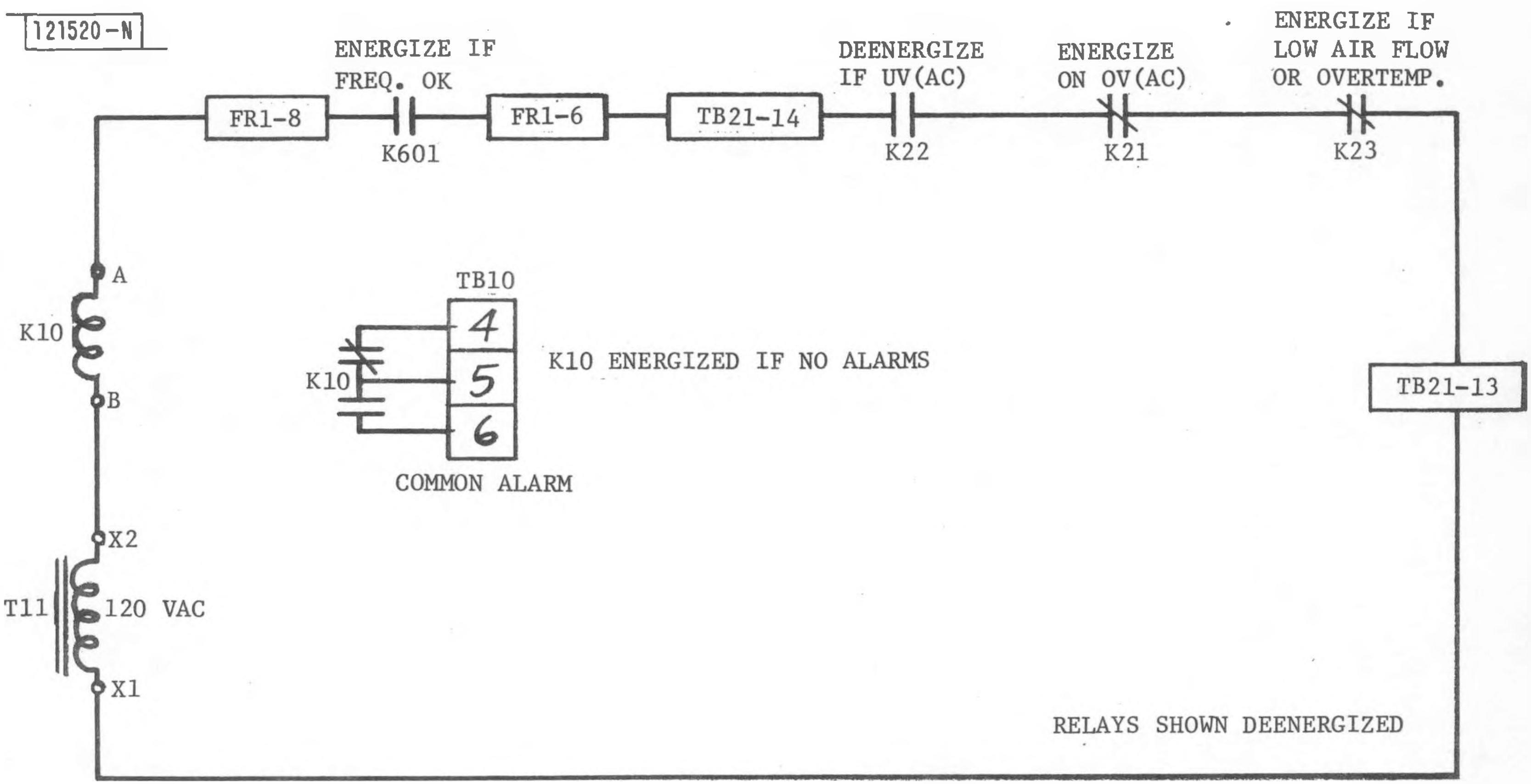

Fig. 1-16 Simplified Schematic Diagram of Cyberex Common Alarm Circuitry

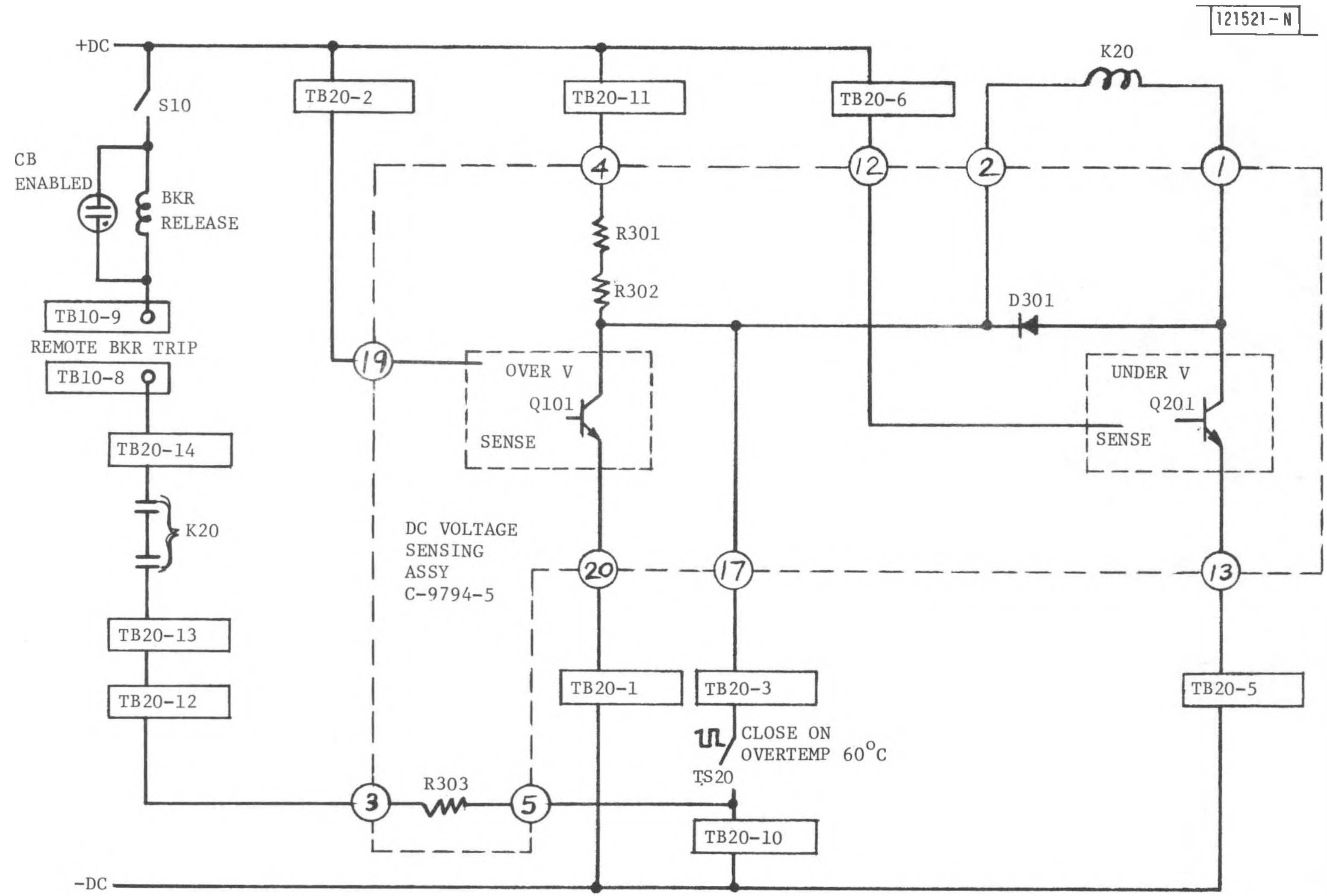

Fig. 1-17 Simplified Schematic Diagram of Circuit Breaker Trip Circuitry

Fig. 1-17. Simplified schematic of circuit breaker trip circuitry.

1.6.10 Under/Overfrequency Sense RC 5624

This board senses an out-of-tolerance inverter output frequency. It is independent of the inverter frequency determining circuits. The circuit compares the inverter output period to crystal oscillator generated periods, one smaller by 1% and one greater by 1% than the nominal specified inverter output frequency.

IC 601/603 square up and buffer the inverter actual output frequency. IC 609/614 divide by 20 and drive IC 615 multivibrator which provides a system reset pulse.

IC 607 is a crystal oscillator (120 KHz) buffered by IC 603. Counter chain IC 610 through IC 613 and IC 616 provide a menu of reference periods which can be chosen by the jumpers. IC 619 output is two pulses, one 1% less and one 1% greater than nominal period. IC 614 is disabled within the tolerance range but complements if a clock arrives outside of the tolerance band. IC 614 acting through IC's 608, 605 and 620 de-energize relay K601 when an out-of-tolerance frequency condition is sensed.

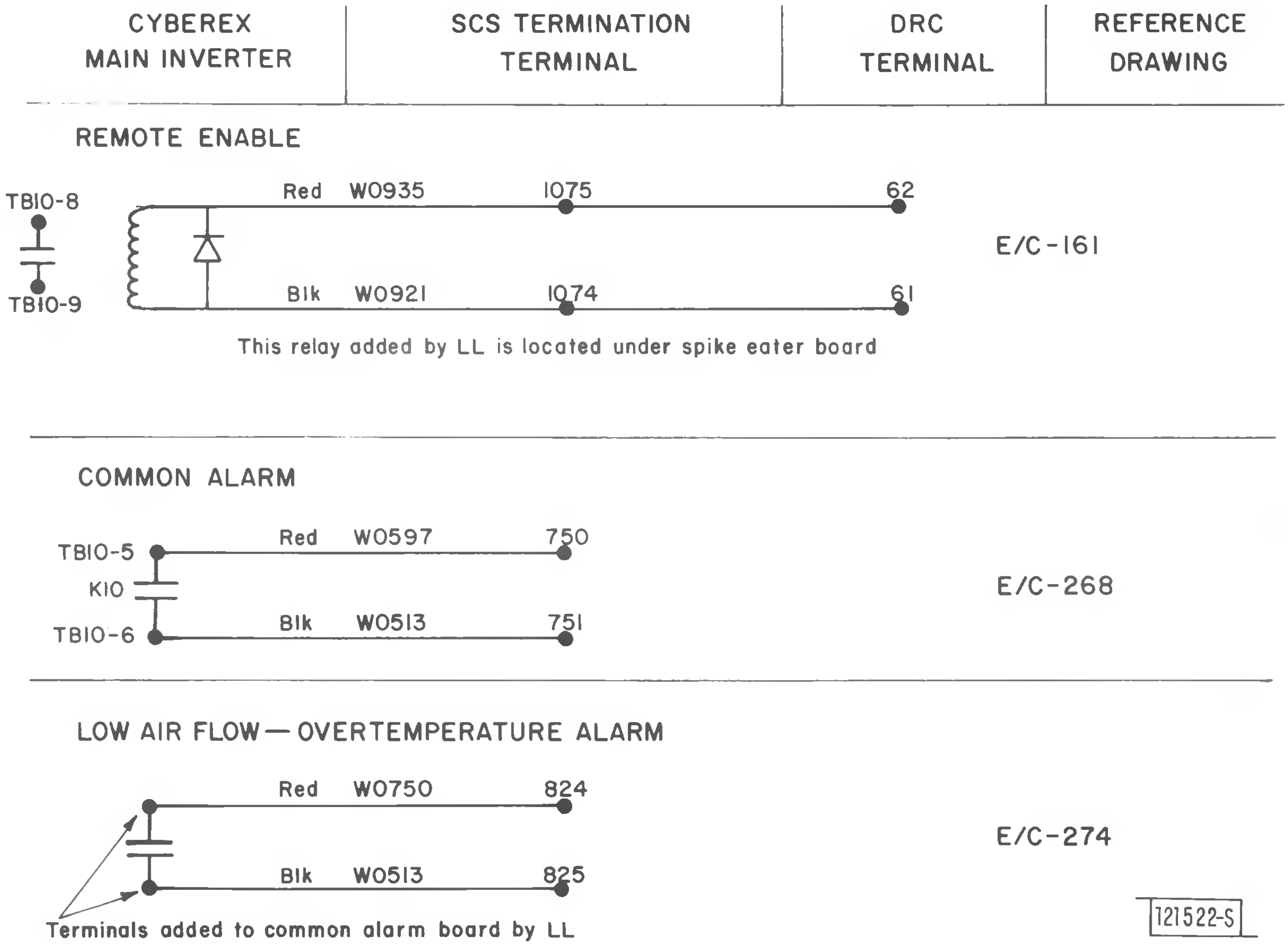

Figure 1-18. Cyberex MI Interface Wiring to ACU.

1.7 Manufacturer's Instruction Manual/Schematics*

The Cyberex instruction manual which is attached, includes the following material:

Inverter description

Table of Contents

Corrections

Installation and operation procedures

Adjustment procedures

Schematic diagrams and parts lists shown in the Table of Contents

Additional blue-line schematic diagrams included are as follows:

C-9794-1 Outline and Mounting Dims. 50 KVA Inverter (LL Dwg. No. C-75700)

C-9794-2 Schematic, Inverter Power Stage (LL Dwg. No. C-75701)

B-9794-3 Wiring Diagram, 1 Phase Inverter Logic (LL Dwg. No. B-75702)

C-9794-4 Alarm Wiring (LL Dwg. No. C-75703)

C-9794-5 DC OV/UV Sensing Assy. (LL Dwg. No. C-75704)

C-9794-8 Schematic, AC Voltage and Dual Sensor Assy. (LL Dwg. No. C-75705)

A-9794-9 Schematic, DC Breaker Trip Assy. (LL Dwg. No. A-75706)

B-9794-13 Wiring Diagram 4 Fan Assy. (LL Dwg. No. B-75707)

*Provided only in site manuals.

1.8 Photographs (Black and White in printed report)

The major components of the Cyberex inverter are shown in Figures CP1-1 through CP1-22.

LIST OF CYBEREX FIGURES

*Provided only in site manuals.

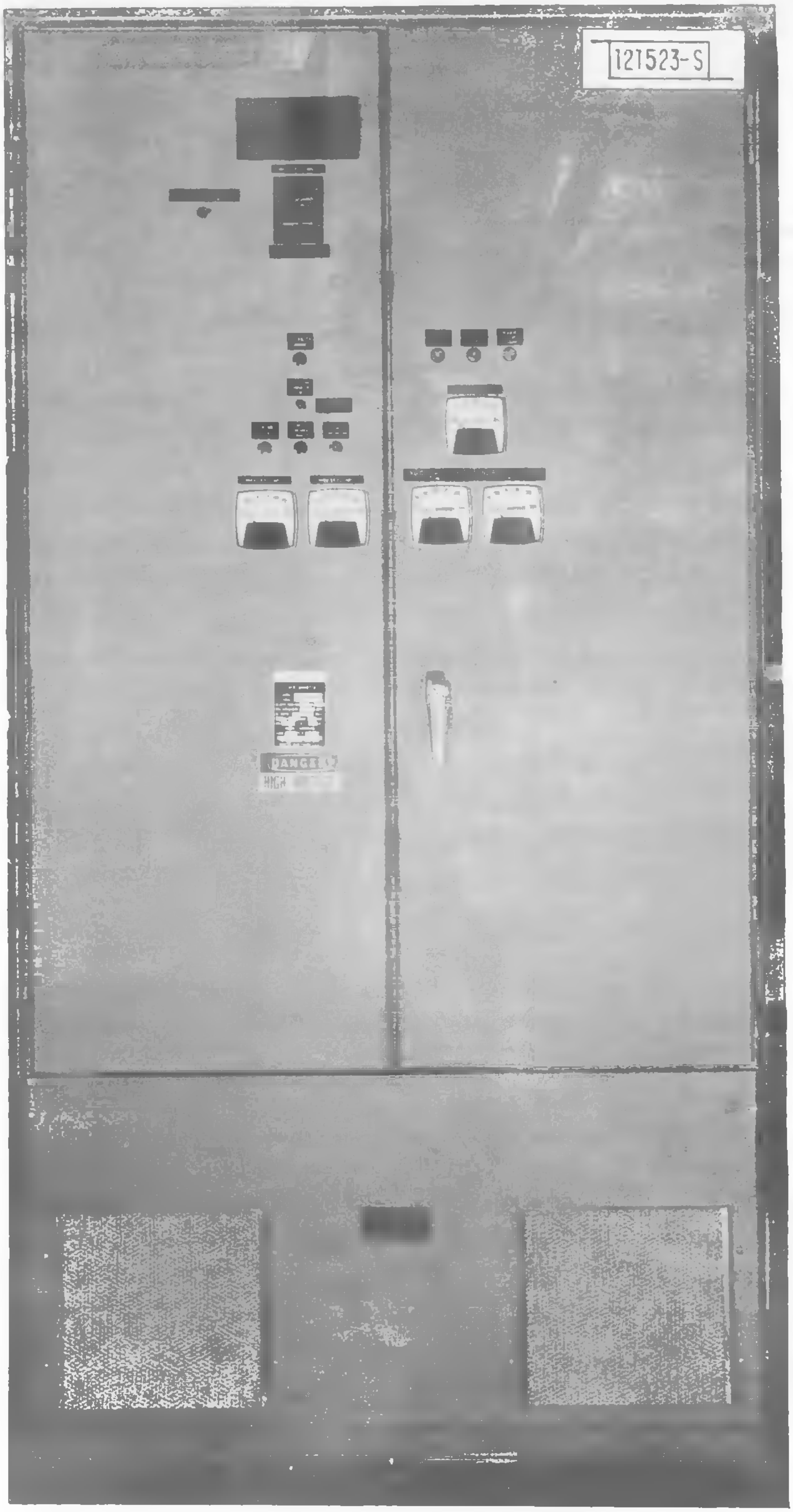

Fig. CP1-1. CYBEREX front view closed.

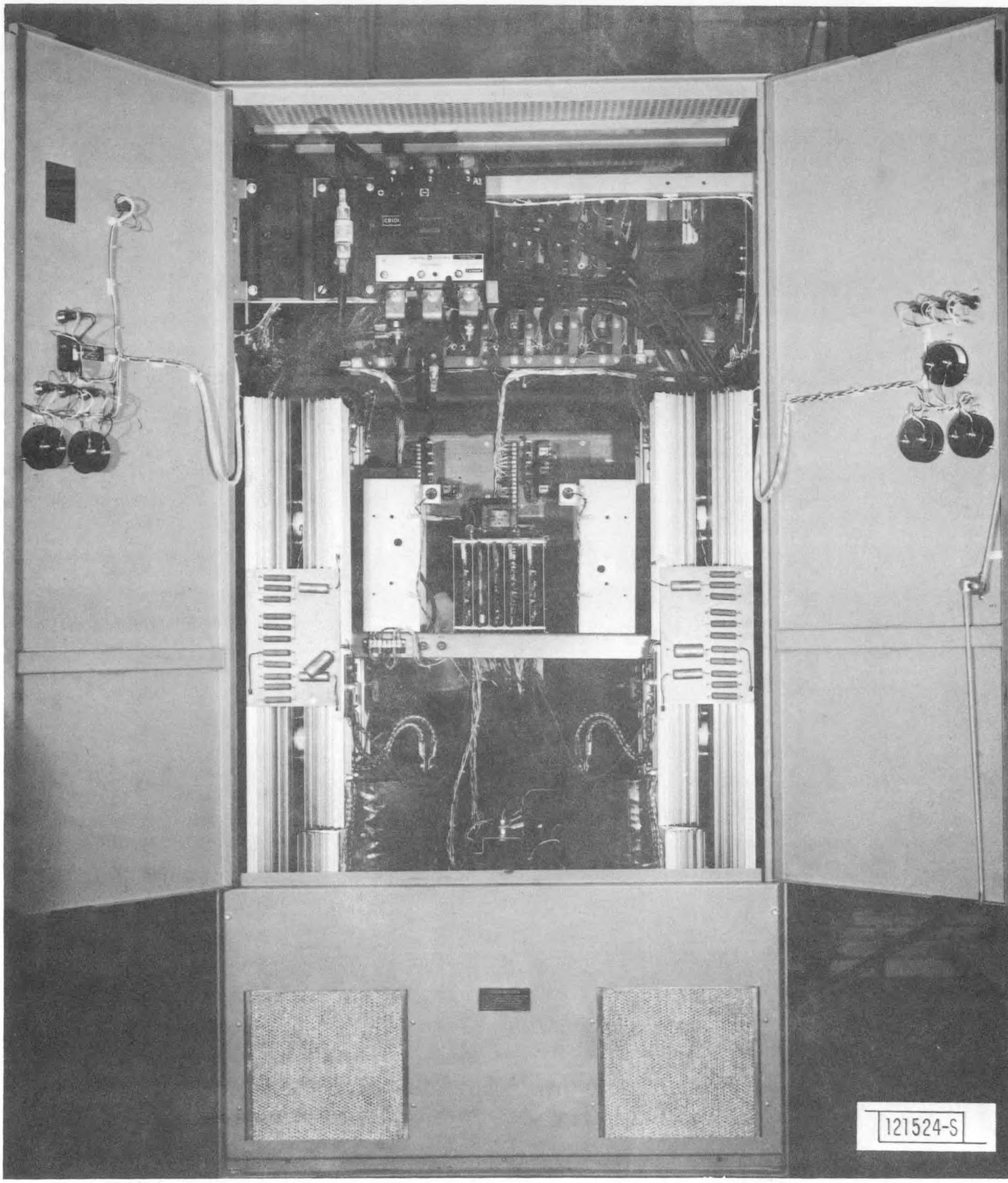

Fig. CP1-2. CYBEREX front open.

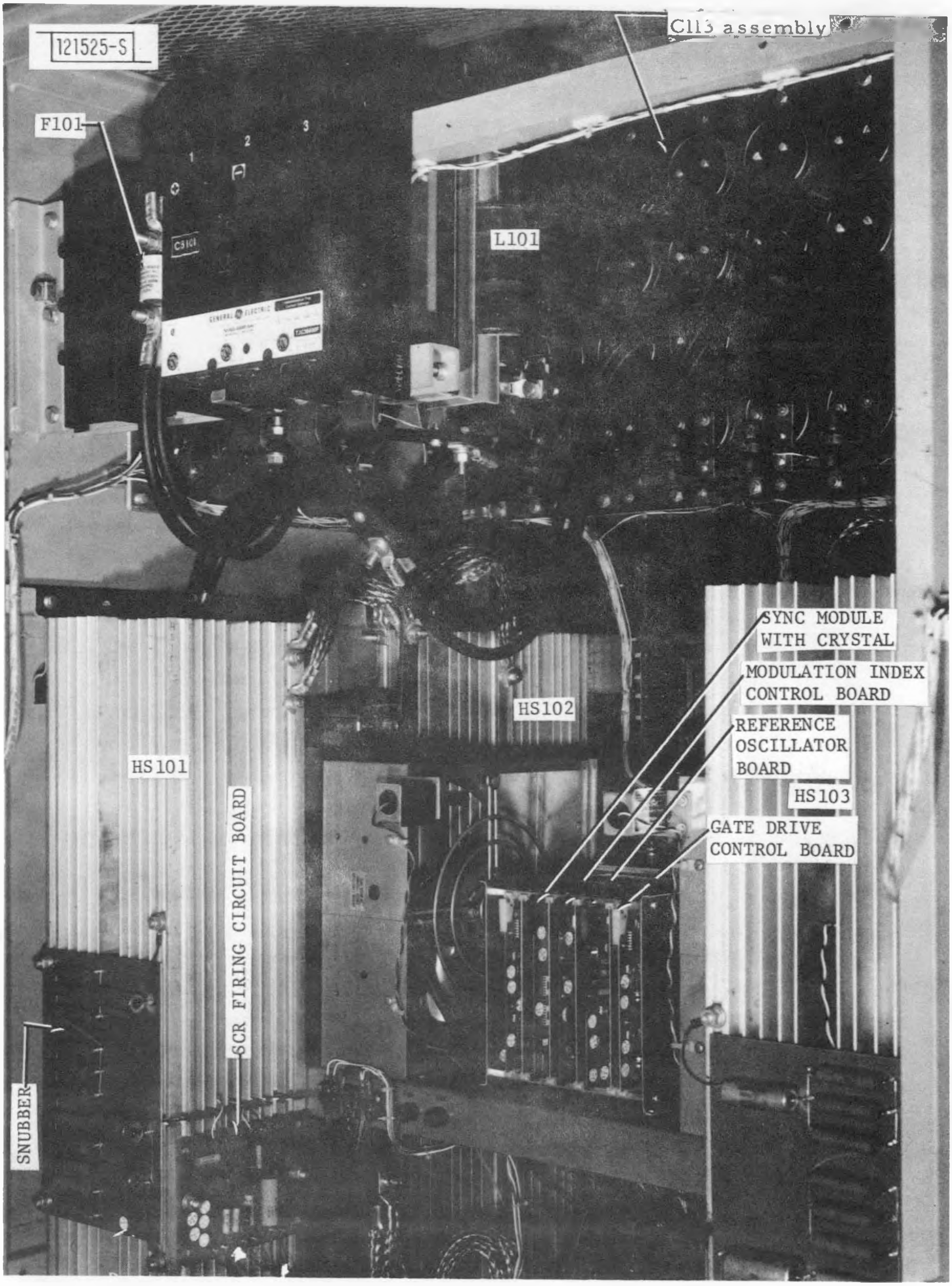

Fig. CP1-3. CYBEREX front top left.

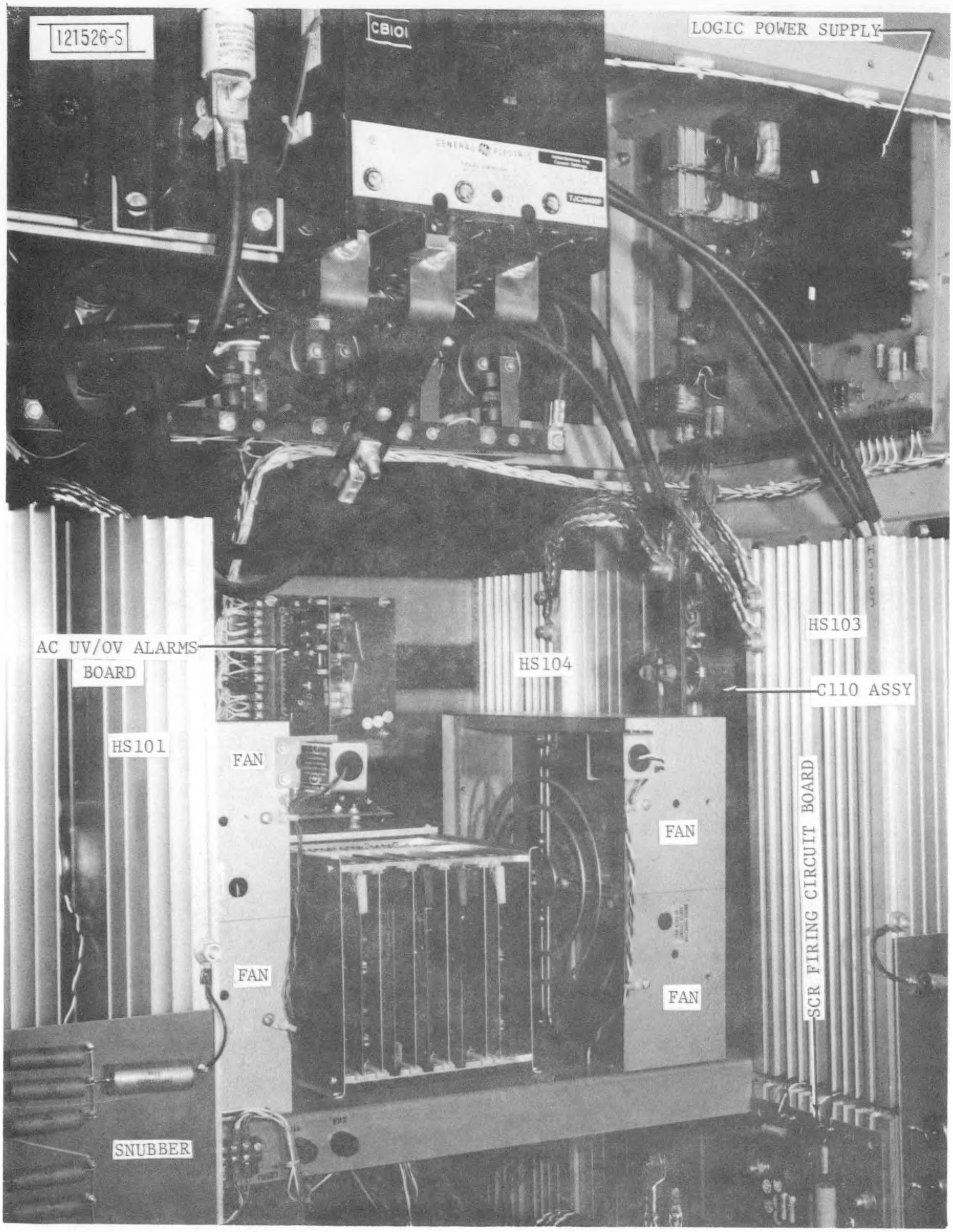

Fig. CP1-4. CYBEREX front top right.

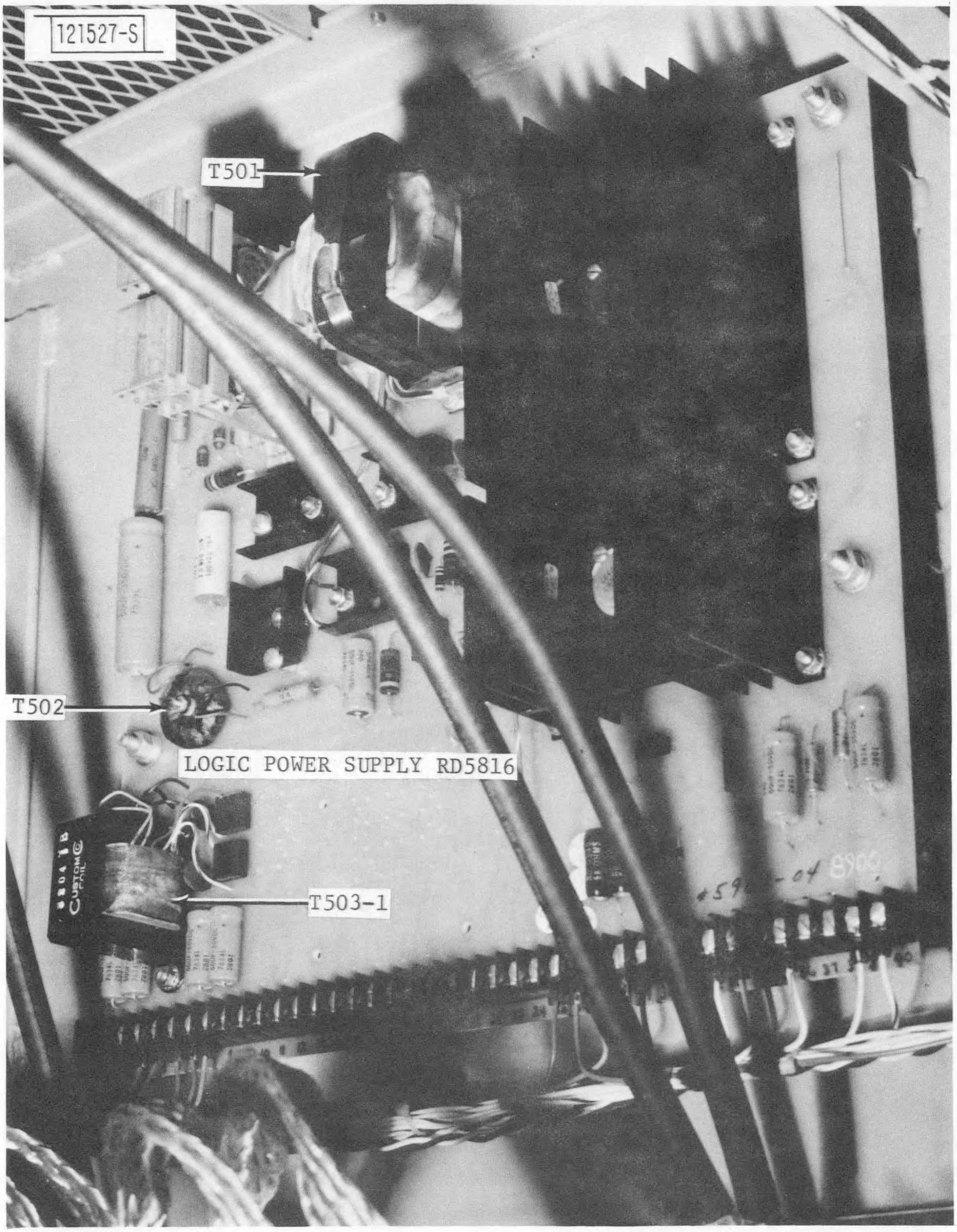

Fig. CP1-5. CYBEREX front top right detail.

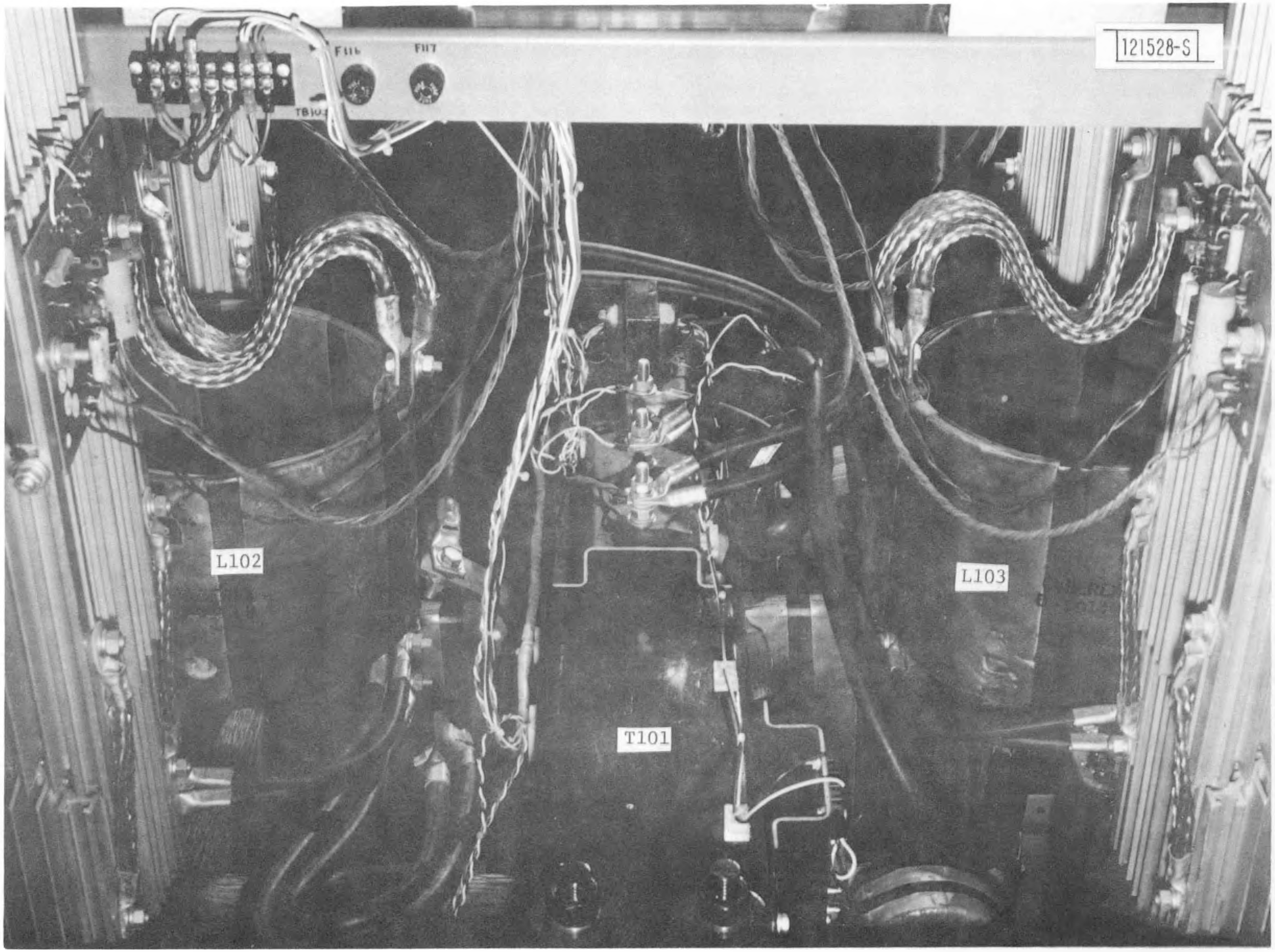

Fig. CP1-6. CYBEREX front bottom.

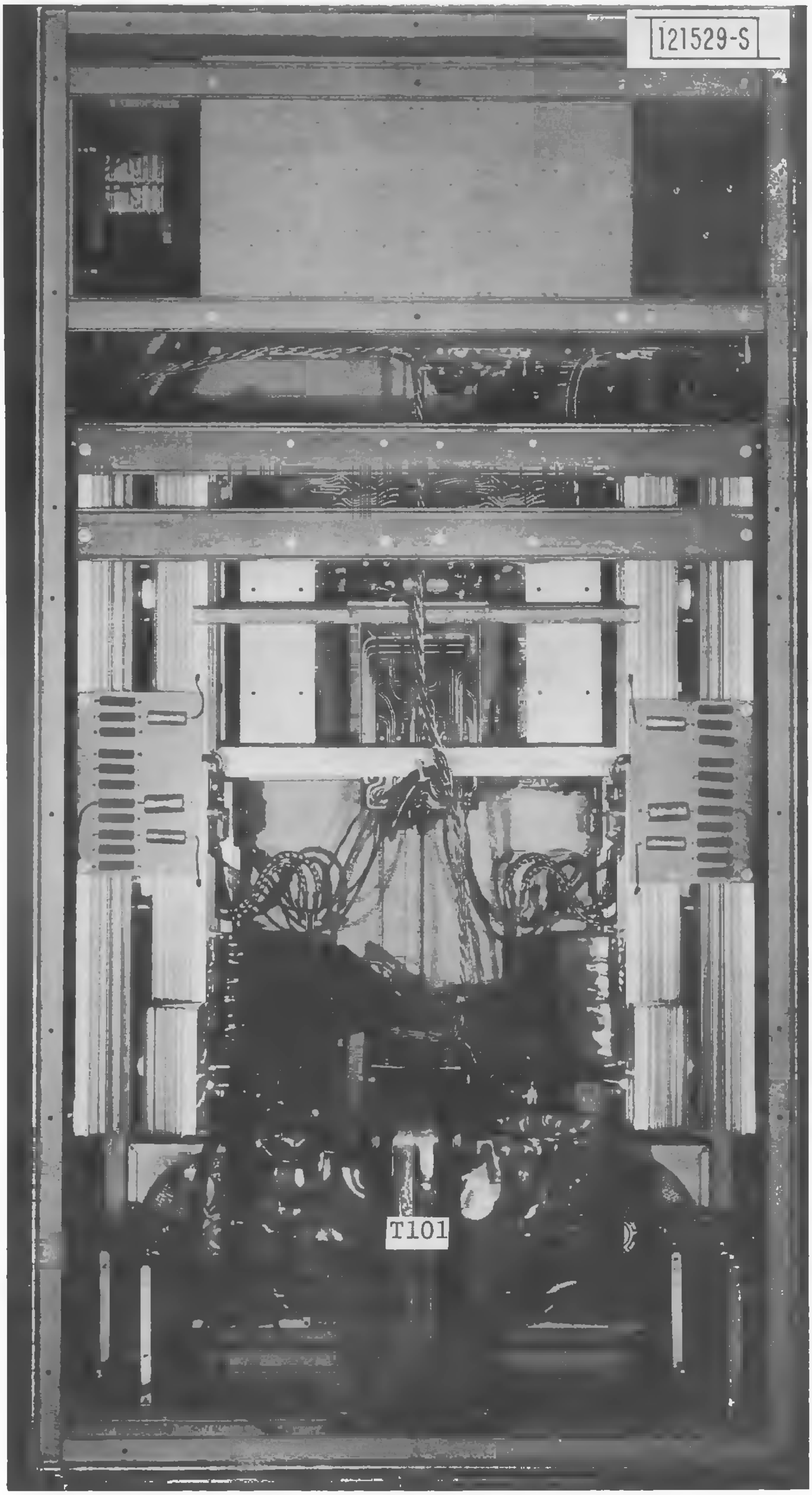

Fig. CP1-7. CYBEREX rear.

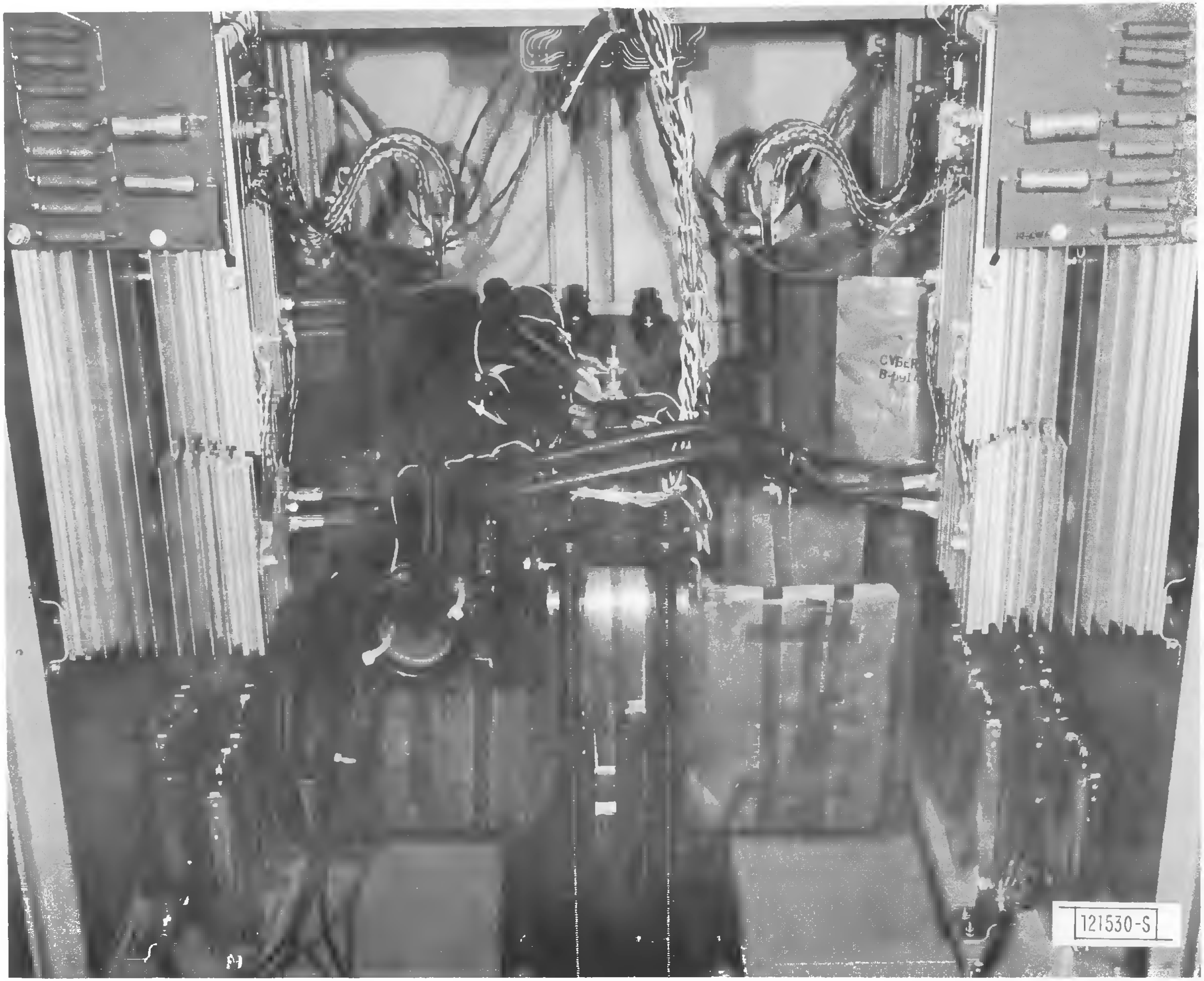

Fig. CPl-8. CYBEREX rear bottom center.

1.9 Fuse Change Procedure for F101

Extreme caution must be taken whenever the main fuse F101 has to be checked or changed.

1. Shut down the main inverter by the normal procedure on its front panel.
2. Turn off the main inverter dc input switch, Unit 202.
3. Turn off the main inverter ac output breaker, Unit 204.
4. Measure on each end of the fuse F101 to chassis ground with a voltmeter (VDC High Scale) making sure no voltages are present at this point.
5. With the same voltmeter on the same scale, measure from terminal #4 CB101 to chassis ground.
6. With no voltage present the main fuse is now removed and checked out on the ohms scale (low range). Measuring the fuse in the circuit is often misleading and not appropriate. Refer to Fig. CPL-3 or CP1-4 for fuse and circuit breaker location.

2.0 NOVA - UNINTERRUPTIBLE POWER SYSTEM FOR NBNM

2.1 General

The UPS system is to be used at Natural Bridges National Monument (NBNM) to provide critical power for the control and data gathering systems of the 100-KWp photovoltaic power system.

2.2 System Description

The UPS is comprised of a 5-KVA inverter, a static switch, and under/over-voltage trip circuits. The model 5K60-240Z002 is manufactured by NOVA Electric Manufacturing Company of Nutley, New Jersey. The inverter provides regulated 120-VAC 60-Hz single-phase output from a variable DC input voltage in the range of 200 to 300 volts. Efficiency is 89% at full load with distortion less than 5%. The static switch assembly normally connects the load to the inverter but can switch the load to the backup utility power whenever the inverter output fails or is otherwise insufficient.

2.3 Control and Monitor

The inverter must be supplied with an enable input of 24 VDC to allow turn-on of the main circuit breaker. If at any time this input is removed, the breaker will turn off. If the DC input voltage is less than 205 V or exceeds 290 V the circuit breaker will also be tripped. Reset must be accomplished locally at the unit.

The external monitor outputs are

1. Form "C" contacts for position of static switch. Relay coil is energized when load is on inverter. (K1)
2. Form "C" contacts for sync alarm. Relay coil is energized when both sources are present and inverter is synchronized to utility power. The coil can also be energized when the inverter has failed and backup power is available so it must be interpreted with Item 3 below. (K3).
3. Form "C" contacts for inverter output present. Relay coil is energized when inverter is present after CB3. (K5)

4. Form "C" contacts for UPS output present. Relay coil is energized when output is present. (K4) See section 2.8 for connections.

2.4 Acceptance Tests

The system was acceptance tested at NOVA in Nutley, New Jersey, on 16 March 1979. Voltage, current, and distortion data was taken at various DC input voltages and AC loads using equipment supplied by NOVA. On-site calculations showed the system to be approximately 89% efficient at full load and nominal input voltage, including the losses in the static switch. DC under- and over-voltage trip operation was verified and then defeated to demonstrate inverter operation at 200 V and at over 300 V. Static switch operation was verified as the inverter DC circuit breaker was operated.

Explanations were supplied on the static switch operating modes and options. At this time it was determined that the loss of sync auto retransfer inhibit circuit would not allow system turn on if the backup utility power was not available. The inverter would operate but the static switch would not put the load on the inverter because of the loss of sync retransfer inhibit operation. Since it was desirable to retain this provision, the decision was made to add a relay to force the switch to the inverter position if the backup utility power was not available. This would allow cold system start-up at the site but would still retain auto retransfer inhibit with loss of sync.

2.5 In-House Testing (18 July to 15 August 1979)

The UPS was provided with DC power and loaded with a variac controlled 5 KW of cone heaters. Suitable calibrated instrumentation was used. Table 2-1 presents the measured data which is plotted in Figures 2-1 and 2-2. Figure 2-3 shows a typical output waveform.

The UPS was next supplied with a backup utility connection and loaded with a lighting load of approximately 2 KW. Ventilation was blocked so that the unit would run hot and the unit was left to run. Internal heat sink temperatures were monitored to preclude overheating and 55^{o}C was the maximum observed temperature. After 3 hours operation, the in-

TABLE 2-1 NOVA 5K60-240Z002 S/N 2472-1 TEST DATA

MIT/LL 18 July 1979 TBE - EEL

V_{IN} VDC	I_{in} ADC	P_{in} WATTS	I_{out} AAC	V_{out} VAC	P_{out} WATTS	Eff. %	Diss. WATTS	% Harmonic Distortion 2nd	3rd	4th	5th	7th	9th	TOTAL
215	1.72	369.8	0	120	0	0	369.8	1.5	3.5	1.5	0.5	1.2	.6	
			10											
			20											
			30											
			40											
230	1.70	391	0	120	0	0	391	1.5	3.4	1.6	0.55	1.0	.8	4.27
	6.51	1497.3	10	119.5	1195	79.8	302.3	1.5	3.2	1.5	0.34	1.4	.55	4.14
	12.20	2086	20	119.5	2390	85.1	416	1.5	3.1	1.5	0.85	1.7	.2	4.21
	17.7	4071	30	118.5	3555	87.3	516	1.5	2.8	1.2	1.4	1.7	.32	4.05
	23.2	5336	40	118.0	4720	88.4	616	1.5	2.4	1.0	2.10	1.2	.68	3.91
245	1.68	411.6	0	120.0	0	0	411.6	1.5	3.4	1.4	1.5	1.0	.90	4.45
	6.2	1519	10	119.5	1195	78.6	324	1.5	3.2	1.5	1.1	1.2	.74	4.24
	11.5	2817.5	20	119.5	2390	84.8	427.5	2.0	3.2	1.5	.55	1.8	.50	4.50
	16.7	4091.5	30	119.0	3750	87.2	521.5	1.5	3.0	1.2	.65	2.0	.05	4.14
	22.0	5390	40	119.0	4760	88.3	630	1.5	2.8	1.0	1.4	1.8	.40	4.06
260	1.68	436.8	0	120	0	0	436.8	1.5	3.8	1.5	2.5	.75	.95	5.16
	6.0	1560	10	119.5	1195	76.6	365	1.5	3.5	1.5	2.0	1.1	.85	4.76
	10.8	2808	20	119.5	2390	85.1	418	1.5	3.3	1.5	1.2	1.6	.72	4.46
	15.9	4134	30	119.0	3570	86.3	564	1.5	3.3	1.5	.50	2.2	.30	4.54
	20.6	5356	40	118.0	4720	88.1	636	1.5	3.0	1.0	.65	2.0	.05	4.08
280	1.67	467.6	0	120	0	0	467.6	1.5	3.8	1.5	3.2	.30	.80	5.47
	5.70	1596	10	119.5	1195	74.8	401	1.5	3.5	1.5	3.0	.85	.85	5.21
	10.2	2856	20	120	2400	84.0	456	1.5	3.5	1.5	2.2	1.4	.80	4.92
	15.0	4200	30	119.5	3585	85.3	615	1.5	3.4	1.5	1.4	2.0	.60	4.73
	19.5	5460	40	118.5	4740	86.8	720	1.5	3.4	1.0	.55	2.2	.30	4.48

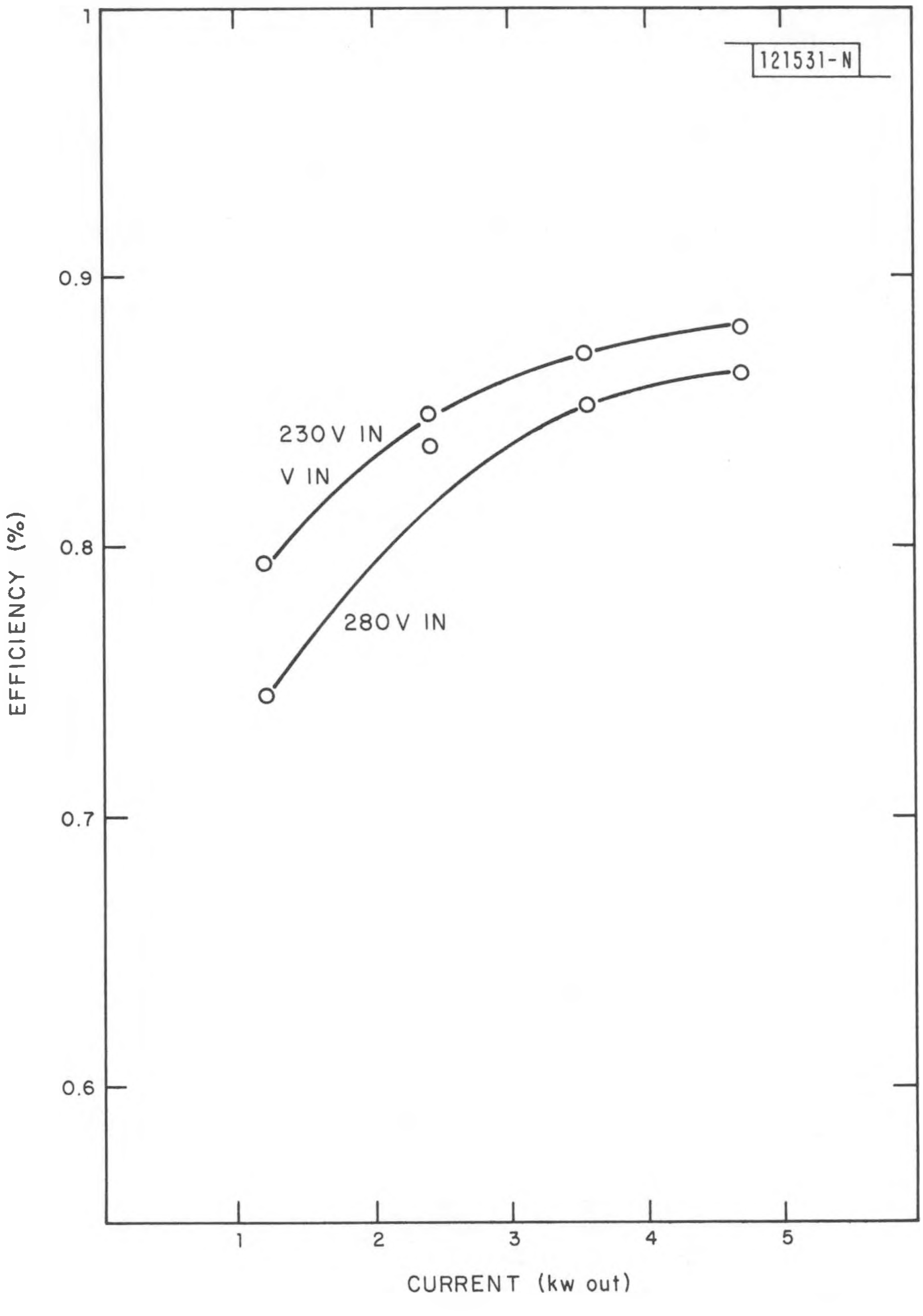

Fig. 2-1. NOVA UPS serial number 2472-1, MIT/LL, 18 July 1979 EEL.

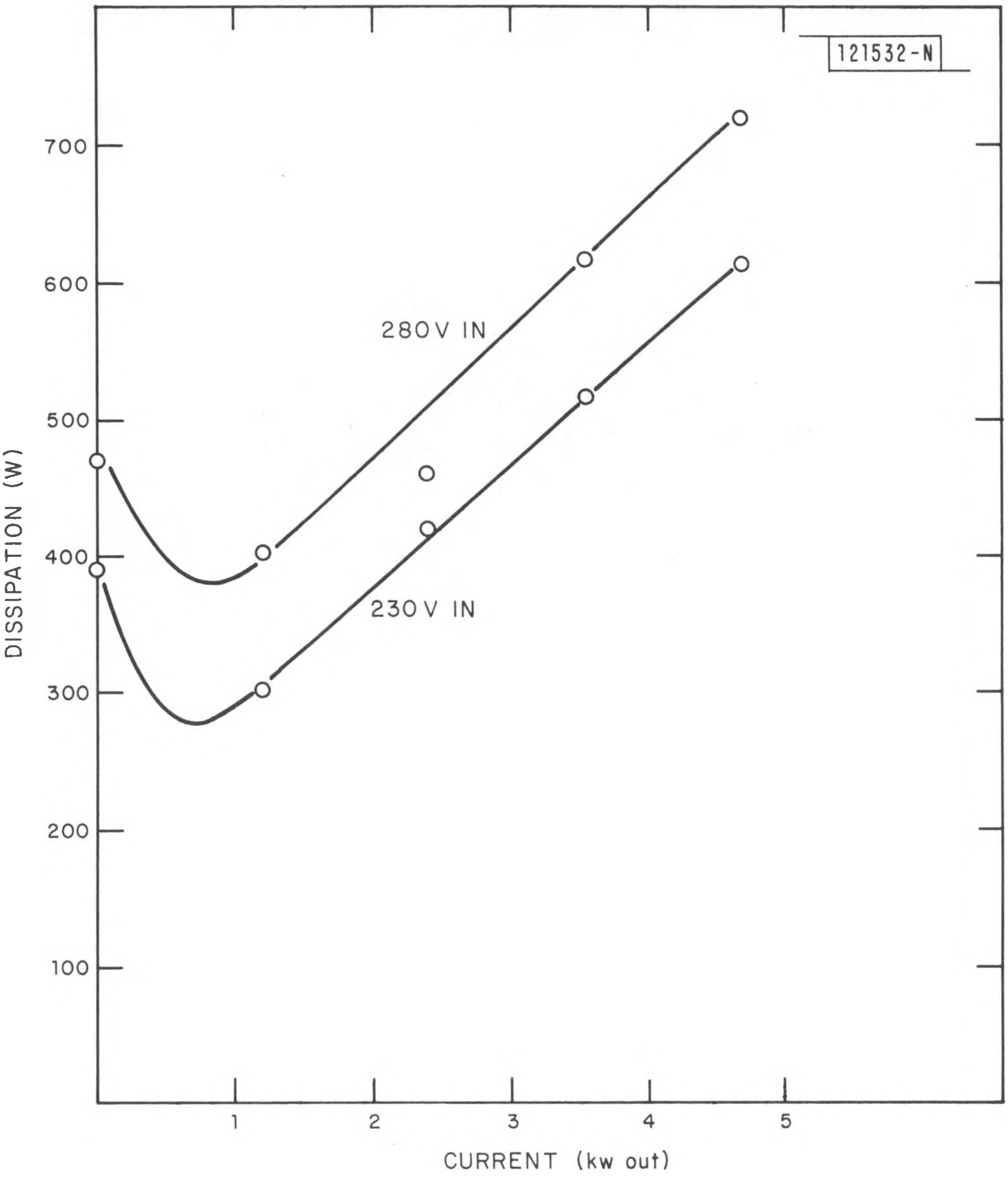

Fig. 2-2 NOVA UPS serial number 2472-1, MIT/LL, 18 July 1979 EEL.

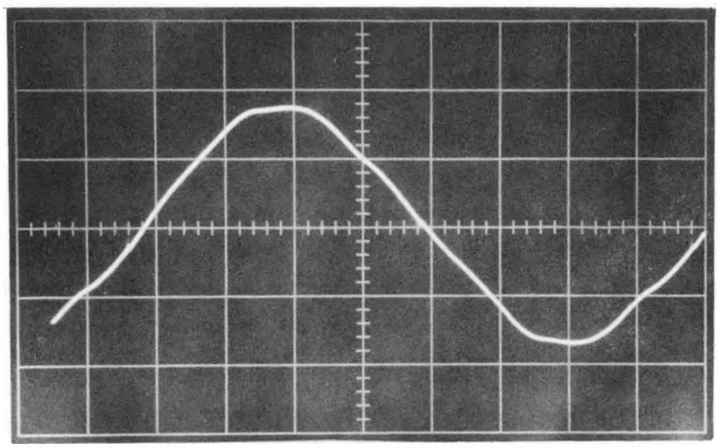

Fig. 2-3 NOVA typical output waveform
Load I = 20A
Vert. 100V/DIV
Horiz. 2ms/DIV

verter DC circuit breaker tripped. The static switch operated so that there was no load power interruption. Breaker reset and subsequent inverter turn on was sometimes successful, sometimes not. Many theories were advanced, including transient under-or over-voltage conditions caused by the DC power supply being used. The use of latching duplicate external under-and over-voltage detectors did not shed light on the problem. A circuit breaker trip coil signal detector did verify that the circuit breaker was being tripped by the UV/OV circuit. The problem was eventually traced to a defective electrolytic capacitor in the UV/OV detector circuit. This circuit was rebuilt using higher-quality components. The original intermittent problem was solved but it was not possible to reliably turn the inverter on. The under-voltage sensing is done after the circuit breaker and as the voltage comes up after breaker turn-on, the under-voltage circuit tripped the circuit breaker. A one-second UV trip inhibit was added and there were no more problems.

The UPS was run with the above mentioned 2-KW load for five, 8-hour days with no further problems.

2.6 Subsequent In-House Work (November through December 1979)

Additional alarm relays were added to provide information to the power system control about presence of AC out of the inverter and out of the static switch. Placement of these extra relays prompted a review of the UPS physical layout which led to the discovery that the auto-retransfer inhibit on sync loss was not wired on the static switch control board. Further review of the schematic uncovered the fact that the out of sync relay driver circuitry was not compatible with the inhibit circuit. A 120V DC relay was used in the out-of-sync alarm and this was controlled by a high-voltage transistor, the failure of which might cause static switch control board failures. The manufacturer has now abandoned the high-voltage relay approach and recommended a replacement board which carries a relay and requires some internal unit rewiring. Since the board in our unit had been thoroughly inspected in-house and had proved reliable in operation, it was decided not to exchange it. A suitable low-voltage relay and driver were built into the unit at the time the extra alarms were added.

During the course of testing the newly installed alarms, an unacceptable turn-on output overshoot was discovered. This has been corrected by slowing the turn-on (increase of R25 on inverter control board).

The first attempt to operate on the intended system battery was unsuccessful. The inverter DC circuit breaker was called upon to open a short circuit caused by inverter malfunction. The result was a flame from the panel-mounted circuit breaker which melted one meter, removed some paint, and covered the area with soot. The problem was caused by over and undershoot of voltage out of the inductor input filter. This "ringing" was not apparent at the factory because a low impedance was not used as a source for testing although it is claimed that the unit operates on batteries in many field installations. The unit was successfully operated after the internal logic power supply was modified by the addition of capacitors.

The 50-KVA power system main inverter was connected as backup utility to the UPS and DC battery power was supplied to both. Static switch operation was verified but inverter instability was noted when load was abruptly put on the inverter during retransfer. The problem was due to oscillation of the input filter because of negative resistance presented by the inverter. Although more sophisticated stabilization methods are available, shunt resistor damping across the inductor was adequate and expedient since time was pressing. This solution would probably solve the turn-on problem also but the logic power supply modification was not removed.

During transfer of the load to the 50-KVA inverter, indication of current limit operation was observed. In excess of 110 amps would be required to activate the current limit, but this could not be observed because it happened when the inverter DC breaker was turned off and was not observed every time. It was surmised that a short spike of current circulated between the inverters as the static switch operated in a "make-before-break" manner. The addition of 60-μH line inductance between the 50-KVA inverter and the static switch appears to have solved the problem and inherent wiring inductance at the site will probably prevent occurrence of the problem at the site.

2.7 NBNM UPS System Detailed Circuit Description

2.7.1 Overall Block Diagram (D75667)

The UPS system contains three main components

1. A 5-KVA DC-to-AC inverter. The inverter operational input range is approximately 200 to 300 VDC. The output is 120 VAC single-phase capable of at least 42 amps output. The inverter is phase locked to the backup utility power source when it is available, otherwise the inverter runs at a nominal 60 Hz.
2. The static switch which can transfer the load between backup utility power and inverter.
3. The under/over voltage trip which is used to disconnect the inverter from the DC source when this source is out of the acceptable operating range. This is accomplished by tripping circuit breaker CB2. An external enable relay (24V) must be energized to prevent trip of CB2. (K6).

When backup utility is not present, the load will be switched to the inverter even if the inverter voltage is out of tolerance. Switch state is indicated by K1 which is energized when the load is on inverter. K3 is energized when both utility and inverter are present and phase lock is accomplished. K5 is energized when inverter output is present at the output of CB3, and K4 is energized when power is available out of the static switch.

The front panel of the UPS has metering of the inputs and outputs and indicator lights. DS101 (green) indicates inverter output before CB3. DS1 (red) indicates that the load is on the backup utility power.

2.7.2 Inverter (D75669)

SCR 101, 102, 103 and 104 form a classic bridge inverter which supplies a "quasi" square waveform to the primary of transformer T101. L101 and 102 in conjunction with C 101, 102, 103 and 104 are used for SCR commutation and T 102 and 103 and associated diodes form an energy recovery circuit to reuse energy trapped in the commutation circuits. L 103, 104, and 105 and associated capacitors form a low pass, and trap, filter to provide low-distortion sinusoidal-inverter output.

The inverter control board, A 101, controls the firing of the power SCR's via T 107 and T 108, based on output voltage feedback via T 105, and output current feedback via T 104.

2.7.3 DC-to-DC Converter (B75673)

This converter supplies regulated 12 V to the inverter control board and to the UV/OV board. Input voltage to the converter is the DC system bus voltage which can vary from 180 to 350 volts.

When Q1 and Q2 are turned on, energy is stored in T1. The base windings are phased such that if Q1 and Q2 are on, they will remain on. When current rises sufficiently, the voltage drop across R7 removes base drive from Q2. Both Q1 and Q2 now turn off and the stored energy is transferred to C3 via D5 at which time Q1 and Q2 turn back on. Regulation is accomplished by turning off Q2 before it would normally turn off. Q3 removes Q2 base current when D6 conducts thereby regulating the output at approximately 15 V. D2 and D3 return the energy in T1 leakage inductance to the input supply and prevent breakdown of Q1 and Q2.

2.7.4 Inverter Control Board (D75672)

The control board is comprised of:

1. Voltage-controlled oscillator with phase-lock circuitry
2. Compensated voltage error amplifier
3. Under/overvoltage shutdown, soft start, and current limit
4. Pulsewidth modulator and power switch sequencing

IC1 is a voltage-controlled oscillator with frequency adjustment at R9. The frequency can be controlled via R8. A frequency-doubling technique is used to generate a time-shifted sync reference signal.

Two comparators (IC10) are used to alternatively reset passive integrating networks ($\tau \sim 4.7$ ms) near the zero crossings of the input reference signal. Drawing number C75674 illustrates the waveforms to be found at the marked points on the schematic. A is the reference signal. The waveforms resulting from the halves of the reference signal are added at B and compared to 7 volts (plus or minus) to produce at D a square wave nominally delayed 90 electrical degrees from the reference. The delay adjustment range at R39 is 40° to 110°. IC2 is an exclusive "or" gate used as a phase sensitive detector, which produces a DC output signal proportional to the phase difference between the delayed reference signal and the inverter output. With no sync present, the output at F is a 60-Hz square wave with average value 6 volts. If the voltage-controlled oscillator frequency is adjusted with no sync signal, then phase lock will occur at 90° to the delayed sync when an external reference signal is present. The overall phase relationship is thus 180°, or nominally in phase with the external reference and at the same frequency.

The inverter output voltage sample is rectified by CR2 and CR3 and applied to the compensated error amplifier IC3 via output voltage adjustment R21. The voltage-controlled oscillator output at G is integrated to produce a 120-Hz triangle waveform H. The analog error voltage and the triangle are compared at IC4 to produce the pulsewidth modulated waveform J. The maximum and minimum pulsewidth waveforms M and N are used to ensure that waveform J is not allowed to become static under any condition of inverter operation. The lead bridge power pole waveform P follows K on the falling edge of J. The trailing bridge power pole waveform R follows P on the rising edge of J. A low signal on external shut off via C6 can remove the clock from the lead power pole and stop inverter operation. The trailing flip flop removes inverter output by assuming the same state as the leading flip flop at the next edge of J.

IC7 forms an under and overvoltage detector which inhibits inverter operation below 160 volts and above 360 volts. An output current which exceeds the setting at R26 will also instantly turn off the inverter. This is not a linear current limit. Restart of the inverter after removal of a shut down condition is in a controlled manner. The inverter "walks" in as C13 is slowly charged through R25.

2.7.5 Static Switch System (C75670)

The static switch system is comprised of three high voltage to low voltage transformers, two bidirectional static switches and a switch control board.

Power for the control board is derived from T302 and T303 so that if power is available from either backup or inverter, the control board will be powered. T301 provides a low-voltage sample of the inverter output. The switch control board turns on either SCR301 and SCR302 to connect the inverter to the output or SCR303 and SCR304 to connect the backup utility power to the output. The switch control board has appropriate input control signals and output status signals.

2.7.6 Static Switch Control Board (D75731)

A low-voltage sample of the inverter output is full-wave rectified by CR 2/3 and compared to a small positive voltage reference. C3 is discharged every 8.3 ms near the zero crossing, generating a rising sawtooth at U3 pins 8 and 11. The references at U3 pins 9 and 10 are set such that the output voltage at U3 pins 13 and 14 has transitions at the 45° and 135° points on the half-cycle waveform (every 4.16 ms). The output of U4 pin 4 is a 100-μs negative pulse which turns on Q2 via Q1. The input to Q2 is a buffered version of the rectified inverter voltage, thus Q2 samples the inverter voltage and holds it on C8 at two points each half cycle, approximately $\pm$ 45° away from each zero crossing. The input to U12 pin 11 is arranged to be high during normal operation but to drop within 1 ms after complete loss of inverter voltage. The output of U12 at pin 13 instantly discharges C8 in the sample-and-hold circuit and C10 in the sync alarm circuit. A sync alarm is not generated if the inverter has failed but the backup supply is present. U12 pins 4, 6, and 9 are applied sequenced references with R21 adjusted so that with nominal inverter output voltage, U12 pins 7 and 8 fall halfway between the voltages at pins 6 and 9. If the inverter sampled-and-held voltage deviates by more than ± 19% from nominal, U12 pins 1 or 14 will cause the load to transfer to backup utility if this condition persists for longer than 35 ms. If the sampled signal is 45% below nominal, transfer is almost instantaneous via U12 pin 2. Notice that waveform updates are taken every 4.16 ms. The U12 pin 13 signal mentioned above is necessary to provide instant (1 ms) transfer on complete loss of inverter output.

U11 pins 3 and 4 form a memory element which controls the SCR driver transformers via U10. U13 and U14 provide delay after recovery of the inverter signal, after which the U11 memory is reset causing autoretransfer back to the inverter (if sync-alarm is not low). The separate 5-second delay inhibits transfer operation during the time of the inverter transient response to the suddenly reapplied load.

The loss of sync circuit is a classic exclusive "or" gate with low-pass filter and threshold adjust R26. The signals are applied in phase. At these conditions, the average output at U4 pin 10 is close to zero. The output will vary linearly with phase difference and when the threshold is exceeded, U7 pin 14 will go to zero. Loss of either input signal will also cause an alarm condition but diode CR17 inhibits the sync alarm if the inverter input is lost. A diode prevents the occurrence of the pulse used to start the timers if the sync alarm is low. This inhibits the autoretransfer operation which is initiated when the inverter input is again within voltage specifications.

Inputs to the static switch control board are:

1. Manual transfer which forces the static switch to backup utility power when this signal is low.
2. Reset which forces the static switch to inverter power when this signal is low. If both manual transfer and reset are low the static switch chooses inverter power, in other words reset takes precedence.

Outputs from the switch control board are:

1. Position signal which when high, indicates that the static switch is on backup utility power and when low, indicates that the static switch is on inverter power. Grounding this output does not affect switch operation.

2. Sync alarm indicates when low that both supplies are available but that the inverter phase lock circuitry has failed or that the inverter is on but utility backup has failed. When high this signal indicates that both supplies are available and the inverter is synchronized or the inverter has failed but backup utility is available.

Grounding this output will inhibit the autoretransfer operation.

2.7.7 Under/Overvoltage Trip (C75668)

Q1 and Q2 are turned on respectively if under or overvoltage condition is detected. Q3/Q4 inhibits circuit operation until 1 second following application of power. Normal operation is with both relays de-energized. A trip signal grounds TB2-6 which trips the input circuit breaker. The delay is required to allow reliable initial system power up.

2.8 Nova UPS Alarm and Control Connections (See Figures 2-4 and 2-5)

TB3	Designation	Description
1	No connection	
2	Sync Alarm N.O.	The relay coil is energized and this terminal is connected to terminal 3 when both inverter and backup AC inputs are available to the static switch and the inverter is synchronized to the backup power. This relay can also be energized if the inverter has failed and backup utility power is available.
3	Synch Alarm K3-C	This is the common terminal of the sync alarm relay and is used as a status indicator in conjunction with terminals 2 and 4. These terminals are isolated from the UPS circuits. Power for the detector circuit and relay coil is available if either inverter or backup utility power is present. Note: the sync alarm is meaningless and should be ignored unless both inverter and backup utility power are present.
4	Synch Alarm N.C.	This terminal is connected to terminal 3 when inverter and backup AC power is available and the inverter is not synchronized to the backup utility power. Terminals 3 and 4 are also connected if the system is unpowered.

5	Position Signal N.O.	The relay coil is energized and this terminal is connected to terminal 6 when the static switch has connected the load to the inverter.
6	Position Signal K1-C	This is the common terminal of the position indication relay and is used in conjunction with terminals 5 and 7. These terminals are isolated from the UPS circuits. Power for the relay coil is derived from the switch control board which derives power from the inverter or backup utility power.
7	Position Signal N.C.	This terminal is connected to terminal 6 when the static switch has connected the load to the backup utility power or if the system is unpowered.
8	No Connection	
9	No Connection	
10	No Connection	
11	Enable +	This is the positive terminal of the inverter enable relay K6. 24V DC must be applied before the DC input circuit breaker can be turned on. Removal of voltage will trip the circuit breaker.
12	Enable -	Negative side of applied enable voltage. These terminals are isolated from the UPS circuits.
13	No Connection	

14	No Connection	
15	Inverter Output	The relay coil is energized and this terminal is connected to terminal 16 when AC power is available from the inverter and CB3 is on.
16	Inverter Output K5-C	This is the common terminal of the inverter output presence relay and is used in conjunction with terminals 15 and 17. These terminals are isolated from the UPS circuits. Coil power is provided directly from the AC voltage.
17	Inverter Output	This terminal is connected to terminal 16 when the inverter output is not available or CB3 is off or tripped.
18	UPS Output N.O.	The relay coil is energized and this terminal is connected to terminal 19 when AC power is available at the output of the static switch.
19	UPS Output	This is the common terminal of the UPS output presence relay and is used in conjunction with terminals 18 and 20. These terminals are isolated from the UPS circuits. Coil power is directly from the AC power.
20	UPS Output	This terminal is connected to terminal 19 when power is not present at the output of the static switch.

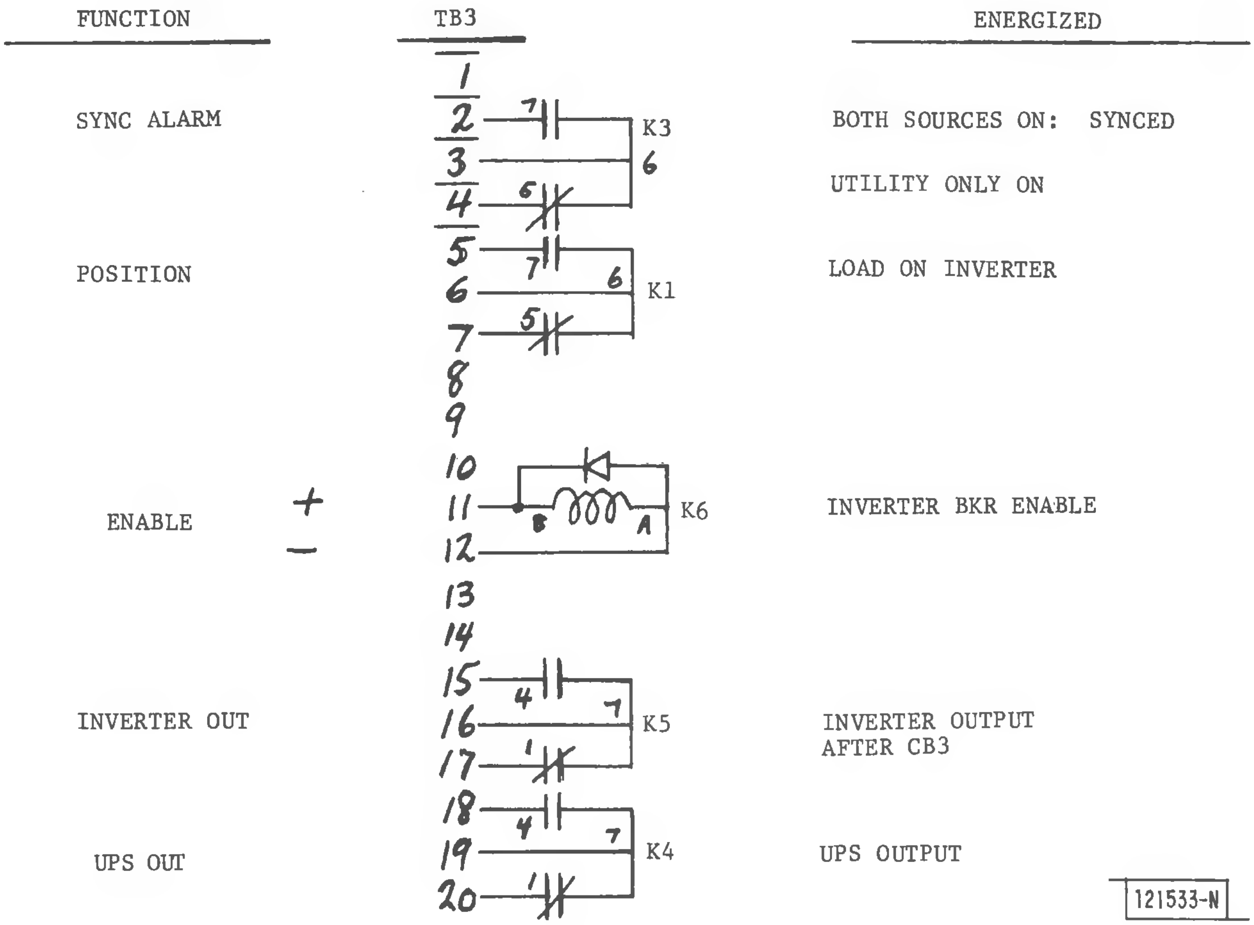

Fig. 2-4. NOVA UPS alarm and control.

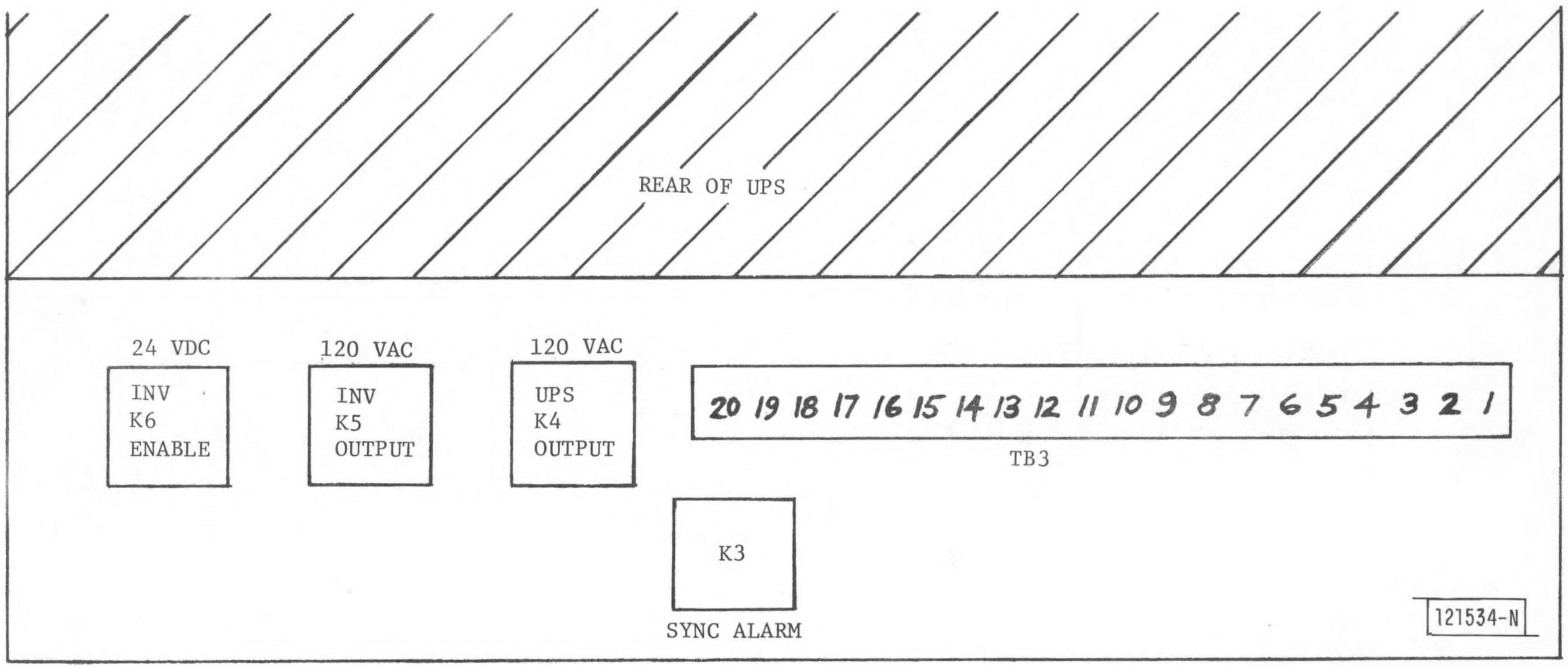

Fig. 2-5. NOVA inverter alarm box (top view) 11 Dec. 1979 EEL.

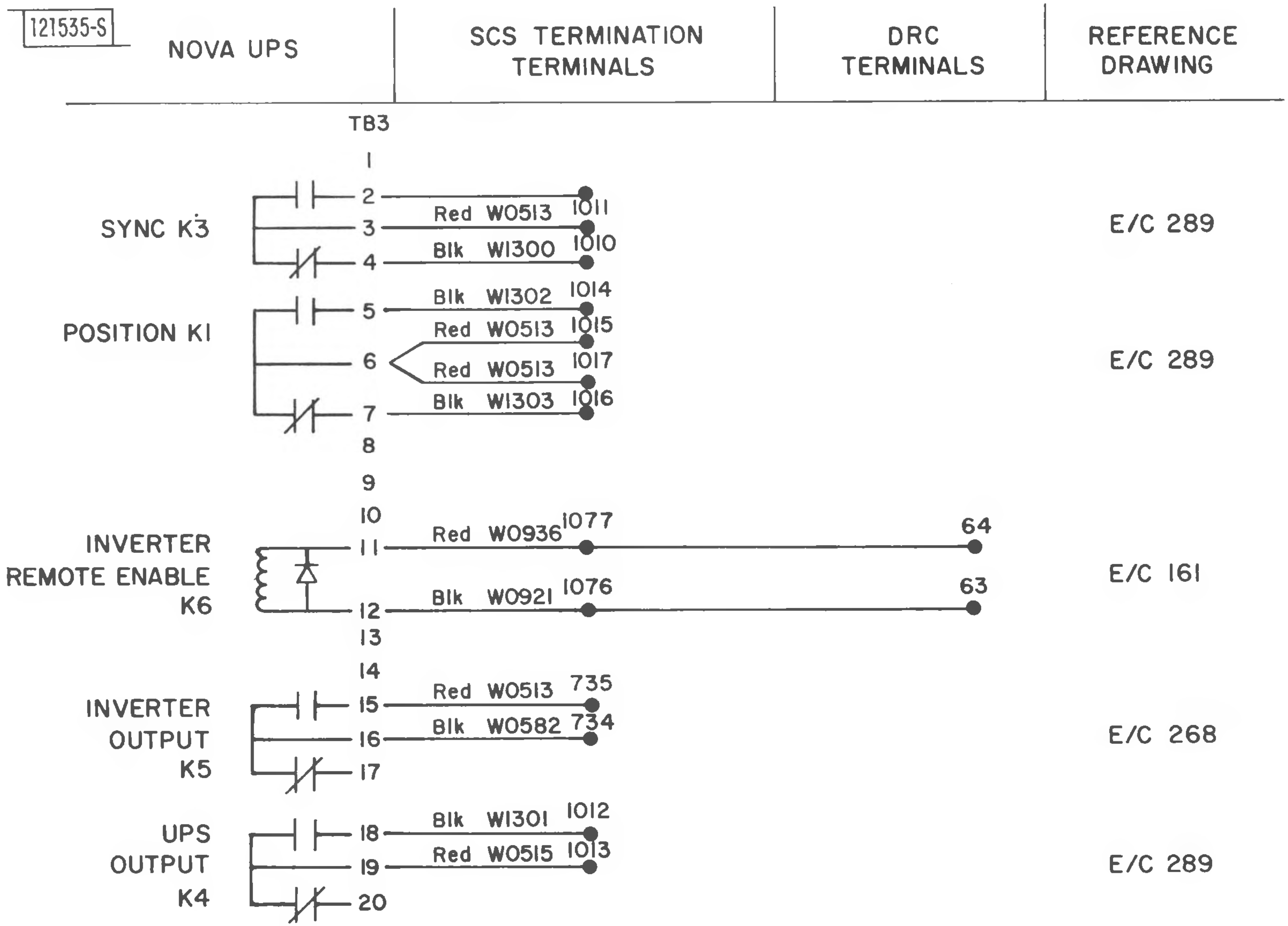

Figure 2-6. UPS Inverter Interface Wiring to ACU

2.9 Manufacturer's Instruction Manual

The NOVA instruction manual which is attached, includes the following material:

*Table of Contents

Inverter specifications

*Installation procedures

*Theory of Operation

*Adjustment and calibration procedures

*Troubleshooting, Repair and Testing procedures

*Site copies only

SPECIFICATIONS

General:

The TAURUS^{tm} series of power inverters is a family of rugged, reliable, high efficiency DC to AC inverters, designed to deliver regulated sinewave power. The TAURUS^{tm} power inverter will provide full rated output continuously.

Model: 5K60-240Z002

Description: Single Phase Sine-wave Inverter

Specifications:

Input Voltage: 200-280 VDC 320 OK V.B. 8-2-79 ESL

Maximum Input Current: 28 amps

No Load Input Current: 3 Amps

Output Voltage: 120

Output Current: 42

Output Frequency: 60 Hz.

Frequency Regulation: .5 % for line and load

Frequency Temperature Coefficient: 0.01% per °C

Voltage Regulation: ± 1%

Transient Response: Less than 50mSec (no load to full load)

Efficiency: 90 % at full load

Maximum Harmonic Distortion: 5%

Load Power Factor: 0.7 lead or lag

Operating Ambient Humidity: to 95% (non-condensing)

Phase and Frequency Lock with 60 Hz. AC input

Circuit Protection:

Reversed input polarity

Short circuit

Automatic output current limited

Input circuit breaker with shunt trip
Inverter output circuit breaker
Input under voltage protection (195 VDC shut off point)

Input over voltage protection (300 VDC shut off point)

Thermal Protected; 105° C shut off for the inverter)

Physical Characteristics:

Weight: 325 lbs. (147.7 kg.)

Size: 34.75 H x 17" W x 24" D (88.3H x 43.2W x 61.0D CM)

Cooling: Natural Convection

Options:

Transient Filter
Input Voltmeter, Ammeter
Output Voltmeter, Ammeter

Solid state switch with automatic reset
(Switch Input: 120 VAC 60 Hz)

Load normally supplied by the inverter.
Transfer inhibit relay when utility is not present.
Out of phase alarm contact.

2.10 NOVA Schematics*

Schematic diagrams included here for the NOVA inverter are as follows:

D75667A Schematic Diagram, UPS NOVA 5K60-240Z002,
UPS SN2472-1 NBNM

D75668 Schematic Diagram, Over/Under Voltage Trip Board
205 & 290 volt UPS, SN 2472-1 NBNM

D75669 Schematic Diagram, Inverter, UPS
UPS SN2472-1 NBNM

D75670A Schematic Diagram, Single Pole Static Switch, UPS
UPS SN2472-1 NBNM

D75671 Schematic Diagram, Solid State Static Switch Control Board,
UPS SN2472-1 NBNM OBSOLETE

D75672 Schematic Diagram, Inverter Control Board,
UPS SN2472-1 NBNM

B75673 Schematic Diagram, DC-DC Converter Board C275/12, Inverter
UPS SN2472-1 NBNM

C75674 Waveforms, Inverter Control Board
UPS SN2472-1 NBNM

D75731 Replaces D75671

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*Site copies only.

2.11 <u>Photographs</u> (Black and White in Printed Report)

The major components of the NOVA inverter are shown in Figures CP2-1 through CP2-13.

LIST OF NOVA FIGURES

*Site copies only.

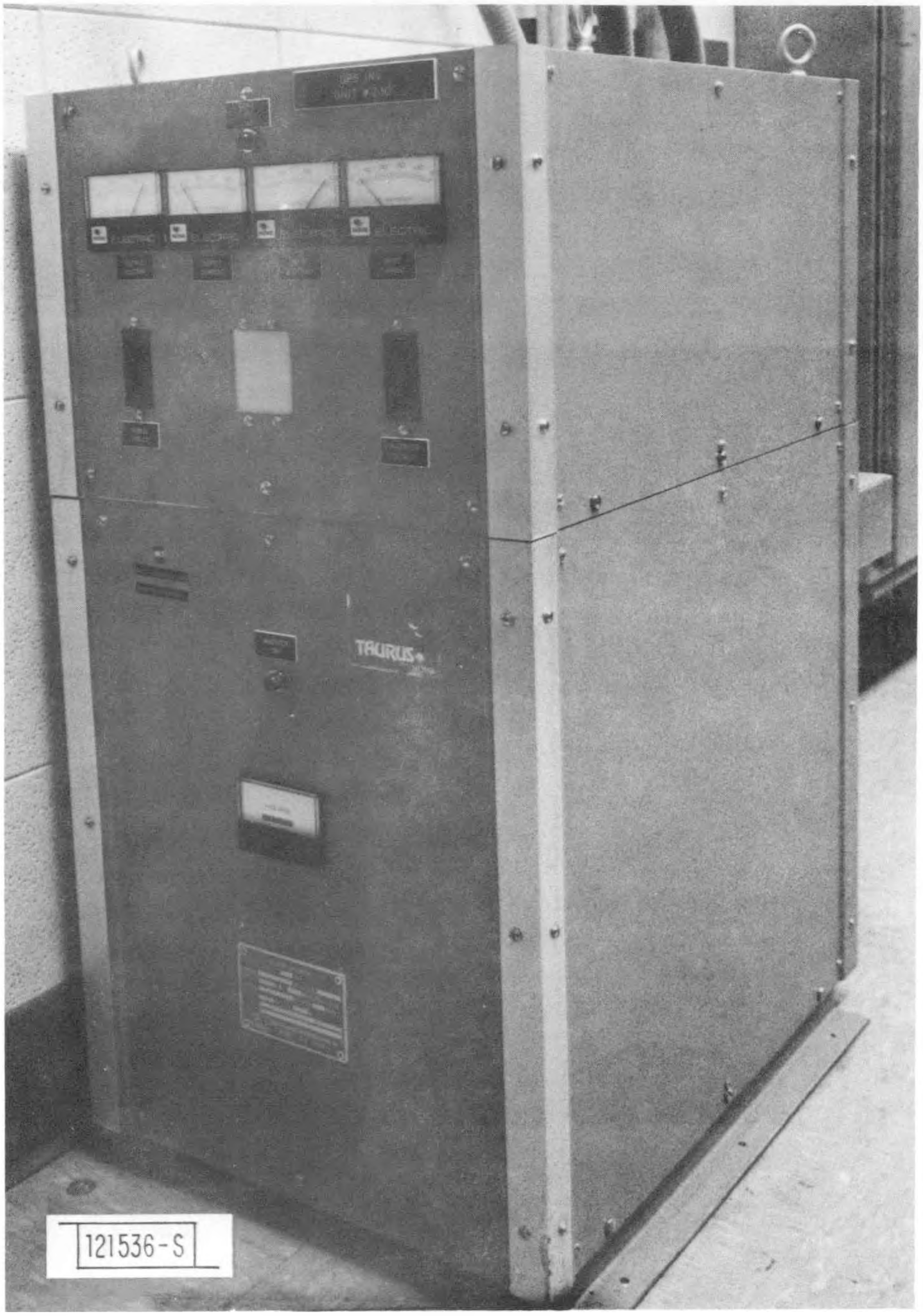

Fig. CP2-1. NOVA front view.

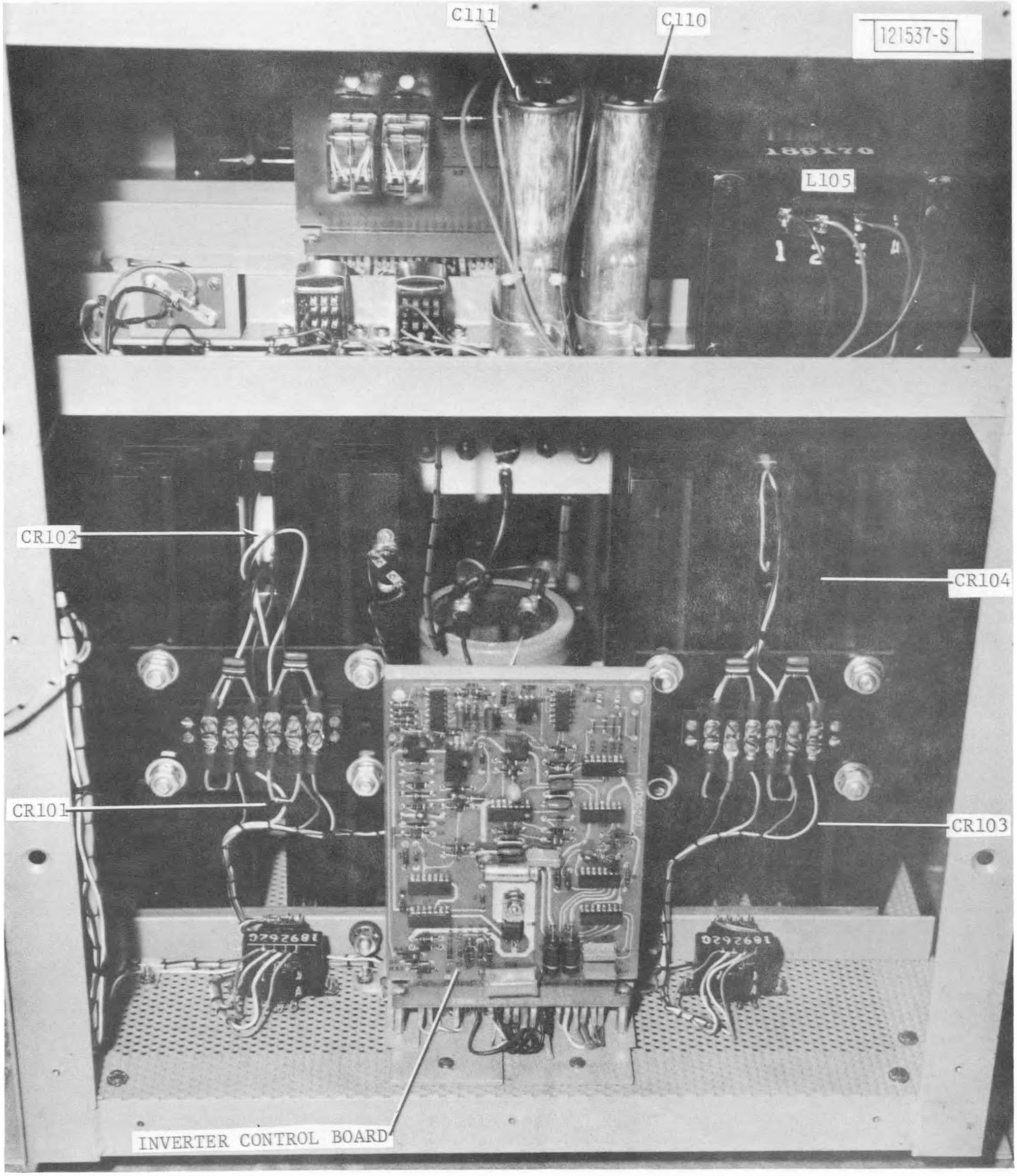

Fig. CP2-2. NOVA UPS front view.

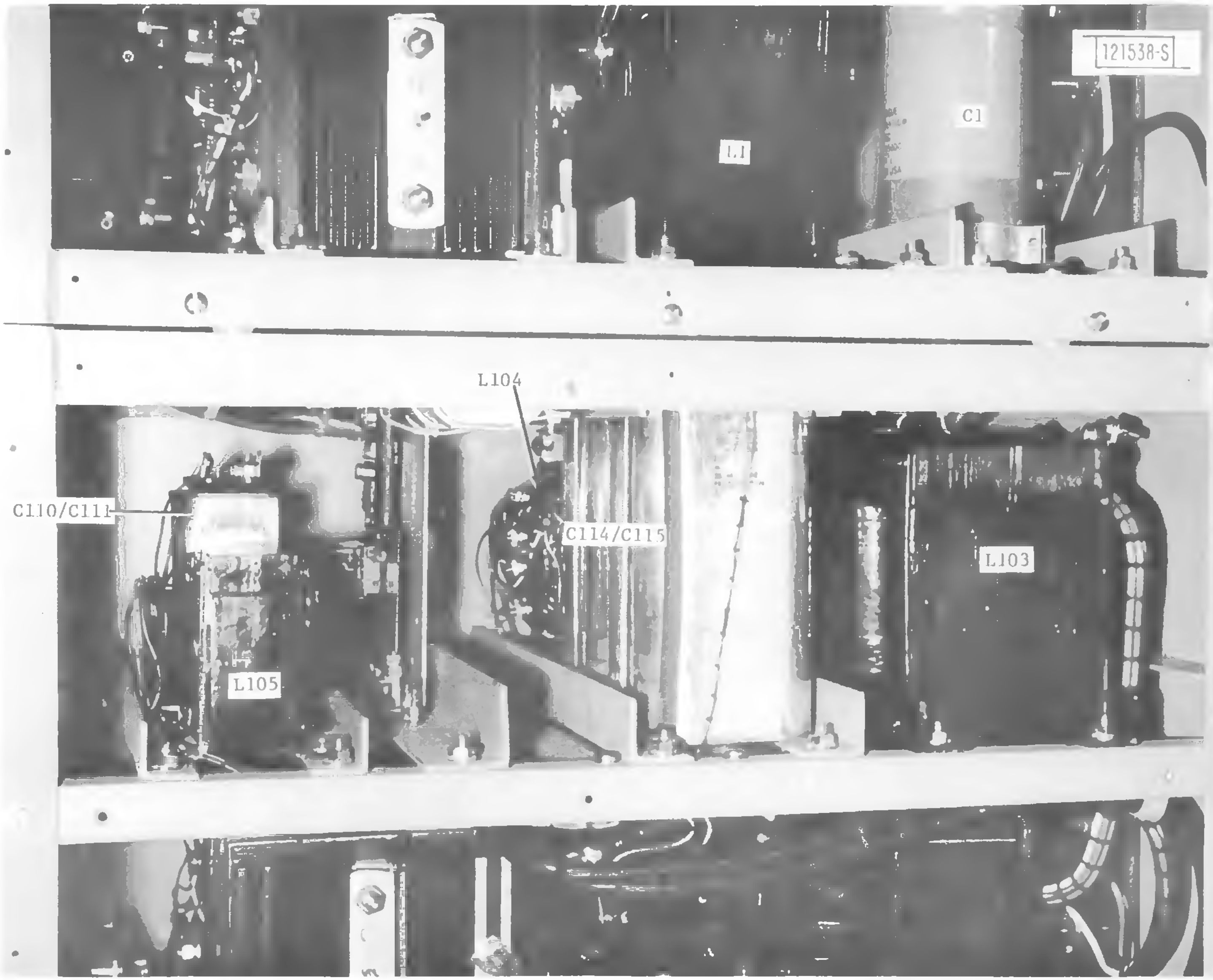

Fig. CP2-3. NOVA right middle.

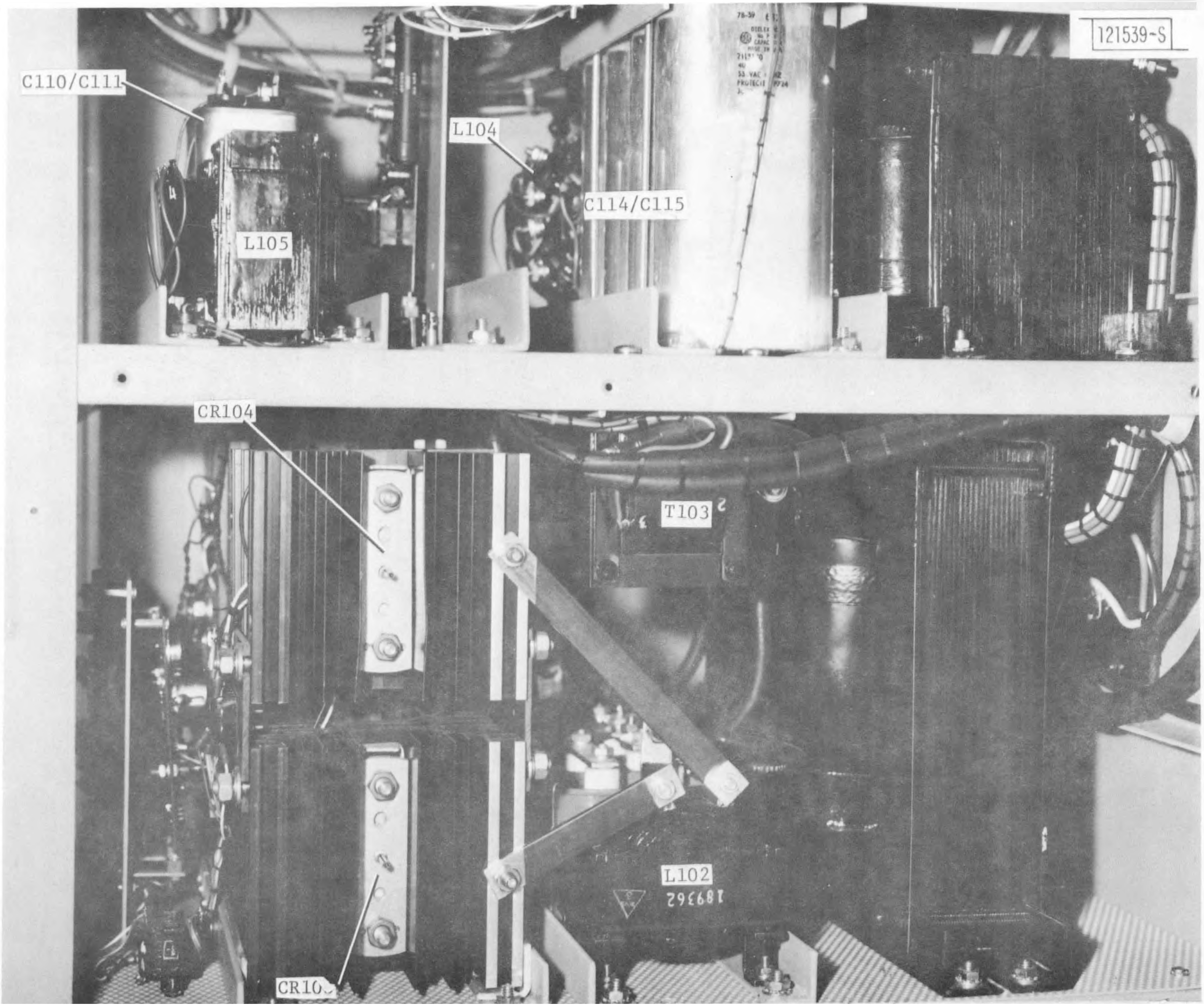

Fig. CP2-4. NOVA right bottom.

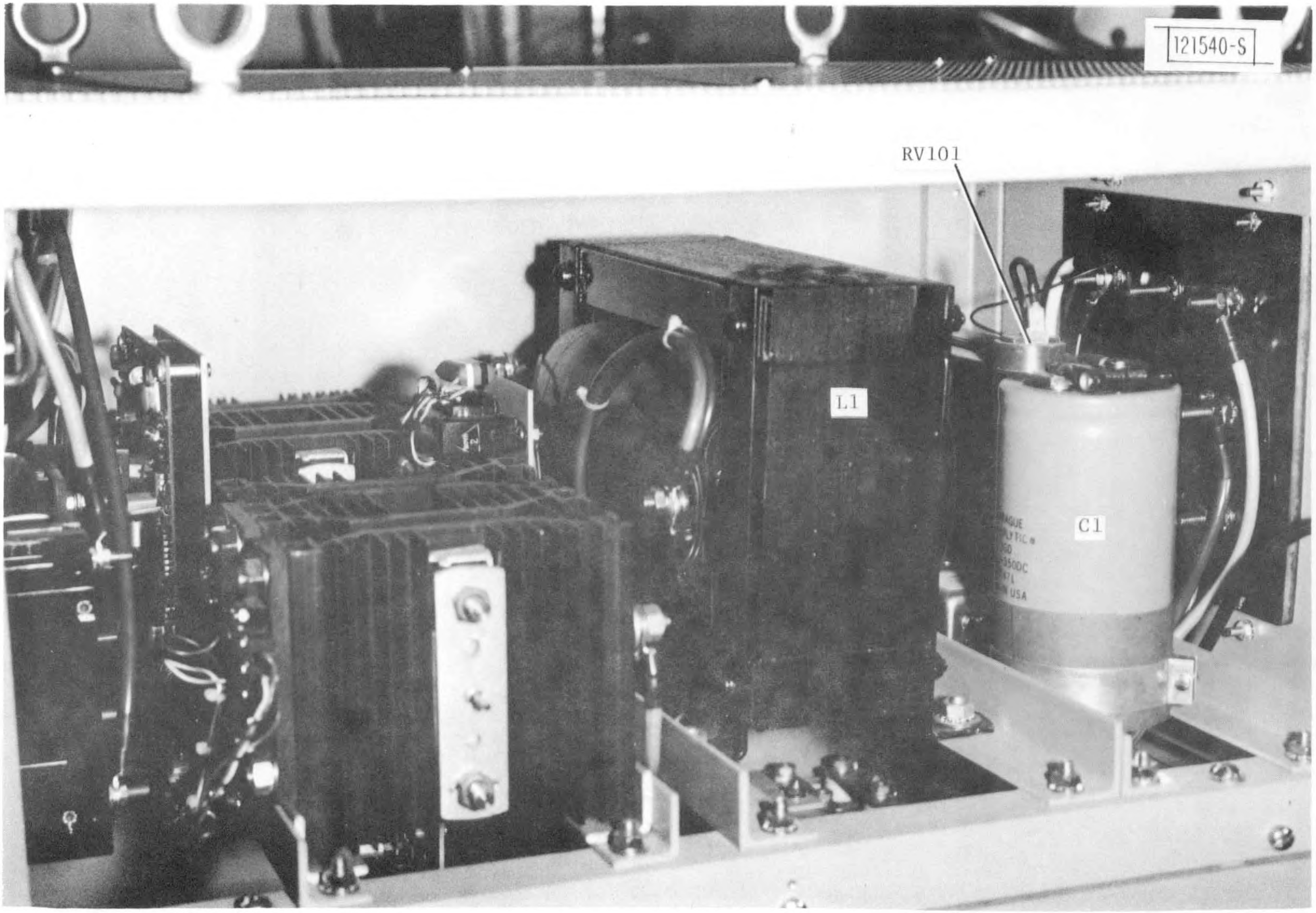

Fig. CP2-5 NOVA right top.

3.0 RATELCO BATTERY CHARGERS

3.1 Specifications

The salient electrical requirements per charger were the following:

Output Voltage Limit	200-290V adjustable 0.5% regulation
Output Overvoltage Protection	275-300V adjustable Latched triac short to Standby. Recovery by charger off-on sequence.
Standby Voltage	190V maximum, no load.
Output Current Limit	No damage from short circuit, automatic recovery. No adjustment.
Output Current Ripple	<30A P-P into battery
Input Current Limit	55-110A adjustable ±5% regulation
Input Voltage	240 VAC, 1Φ, ±5% ±10% no damage
Input Frequency	60Hz ±2% ±5% no damage
Efficiency	>85% at input power limit
Power factor	>90% over 75-100% of input power limit
Input Current Distortion	<15% third, < 5% higher harmonics
Warrantee	Parts and materials at factory for two years.

3.2 Acceptance Testing

On September 1979, acceptance tests were run at the Ratelco facilities in Seattle, Washington.

Both chargers were set up for test. Ratelco engineers stated that the units were identical electrically, so preliminary tests were done to convince us and then detailed testing was only done on S/N 10798. The instruments were supplied by Ratelco and we did not verify their accuracy. Table 3-1 shows the data taken on S/N 10798. The measurements were all done at nominal line voltage of 240 VAC. After the first two measurements, it was noted that power factor was below the specified 90% and decreasing as output voltage was lowered. The unit has been optimized for use as a standard catalog item of 240V/100A which would normally be used above 260V. Power factor below 260V output could have been improved with different turns on the transformer, but since transformer changes were impossible at that point, capacitors were added to the AC input. This produced about 3% improvement. The product of P.F. and efficiency was .778 at 220-VDC output. Since this product is really the item of interest and the specification product was .765, the units were accepted as is. This allows total chargers output to be 38.5 Kw from a generator of 50KVA capability.

AC input voltage and current were observed visually and P.F. and current distortion looked good. The Ratelco engineer stated that current distortion met specifications.

Table 3-2 is S/N 10797 measured input AC amps vs. DC amps output. Below 1-amp output the charger draws increasing current and the power factor approaches zero. Since the charge failure alarm (CFA) senses input current, it cannot be set for less than 35A output current and still indicate complete loss of output. The adjustment range is only 6-10 amps but the units would be shipped and changes made at LL to increase the adjustment range.

No load output voltage was measured with triac control fully on. It was approximately 190 VDC at 240 VAC input and 200 VDC at 252V AC input on unit S/N 10798. This does not meet our specifications of 190V but is acceptable because the specifications had a built-in cushion.

Other Observations:

1. Input current limit adjustment range was measured. Low end was 49A; high end was said to be 150A, not checked. The unit cannot be harmed because the transformer primary is designed for 160A and secondary is

VDC	ADC	PDC KW	VAC	AAC	PAC KVA	PAC KW	POWER FACTOR	EFFICIENCY %	COMMENTS
260	83.1	21.62	240	110	26.39	23.38	88.5	92.4	
240	82.8	19.88	240	105	25.10	21.50	85.6	92.5	
239.8	86.1	20.65	240	106	25.44	22.48	88.3	91.1	120 μf added
260	81.6	21.22	239	104.1	24.88	23.00	92.4	92.2	120 μf added
220	90.0	19.8	240	106	25.44	21.50	84.5	92.1	120 μf added
220.3		14.78	240	75	18.00	16.23	90.0	91.1	120 μf added
260.2	59.1	15.38	239	75.1	17.94	16.75	93.4	91.8	120 μf added

Table 3-1 S/N 10798 6 September 1979 Ratelco Charger

OUTPUT ADC	INPUT AAC
0	40
1	9
5	9.3
10	15.3
20	26.7
30	37.9
40	49.4
50	60.7
60	72.9
70	85.8
100	100.7

Table 3-2. S/n 10797 6 September 1979

Ratelco Charger

designed for 150A and input and output protective devices are 150A.

2. Front panel voltage adjustment has a 200-290V range.

3. Internal overvoltage latch shut-down is set at 300V and operation verified.

4. Under and overvoltage alarms were checked on both units and a bad relay was replaced. Hysteresis is fixed too large and will be modified at LL.

5. Overtemperature trip thermostat is 100^{o}C and sits on a bracket at the top middle heat sink. The transformer weighs 750 lbs. and has a thermal time constant of 2 hours.

6. Ripple voltage output (resistive load) is less than 1 VRMS except at less than 1-amp load where the unit does strange nondestructive things (low frequency burp less than 10VPP).

7. Remote-standby-run switch can be teased to put unit in a nondestructive full output mode.

8. Remote sense is available and connected to the output terminals. They can be extended if necessary. Unit shuts down if sense leads are open or connected backwards.

3.3 In-house Testing

The two battery chargers were supplied 240V AC from isolation transformers capable of at least 100 amps continuously. One side of this AC source was grounded and a calibrated 100A/50mv shunt was used in this grounded side for observation of waveforms. In addition a current transformer (100:1 range) and 1-amp Weston ammeter was used as a check against the shunt. Agreement was within 0.5% of each other. Input power was measured with an Ohio Semitronics AC watt transducer model PC5 with known calibration and accuracy within 1%. The charger DC outputs were connected together and used to either charge the batteries or run the Cyberex 50KVA inverter or both simultaneously. The negative output leads were grounded through 100A/50mv precision shunts. All shunts used on the DC and AC sides were adjusted to agree within 0.5% of each other so than even if absolute readings were questioned, the efficiency calculations would be correct. Measurements were done when the opportunity was presented during the testing of other parts of the power system, including battery charging.

Table 3-3 shows data taken on charger S/N 10798 and table 3-4 shows data taken on charger 10797.

Table 3-5 shows the charger input current distortion at about 220V, 90A output. Both chargers' input distortion were identical. Figures 3-1 and 3-2 show the actual line currents and phase angles.

A comparison of the acceptance test data and the in-house data suggests that the instrumentation being used by Ratelco for P.F. measurement is in gross error if we trust the LL instrumentation. Since the battery charger use will be mainly at low bus voltage, 40KW DC could be gotten with only about 46 KVA of diesel generator output which is much better than planned.

Table 3-3 Ratelco Battery Charger 10798

VDC	223	236	253	256	280	280	279
IDC	87.0	46.7	47.6	79.0	36.3	8.8	75.2
VAC	232	238	238	234	240	243	237
IAC	96.6	52.2	56.8	96.2	51.0	26.2	96.2
ACKW	20.4	12.0	13.0	21.6	11.0	3.3	22.4
ACKVA	22.4	12.4	13.5	22.5	12.2	6.4	22.8
DCKW	19.4	11.0	12.0	20.2	10.1	2.5	21.0
EFF	.949	.918	.925	.936	.925	.755	.938
P.F.	.911	.965	.964	.959	.896	.51	1.0
EFF x P.F.	.865	.886	.892	.898	.829	.385	.938

TABLE 3-4 RATELCO CHARGER 10797

VDC	222.2	279
IDC	86.9	75.0
VAC	231	236
IAC	97.8	97.2
ACKW	20.6	22.2
ACKVA	22.6	23.0
DCKW	19.3	21.0
EFF	.938	.942
P.F.	.914	.970
EFF x P.F.	.857	.914

Table 3-5 Input Current Spectrum

FREQUENCY	db	%
60	0	
180	-17.5	13.3
300	-31.5	2.7
420	-31.5	2.7
540	-32	2.5
660	-36	
THD		14.1

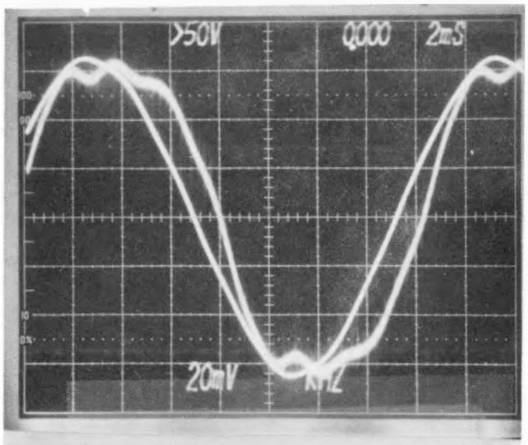

Fig. 3-1 Line Current and Voltage
Charger S/N 10797
242 VDC/88 ADC
235 VAC/101 AAC
100V/DIV, 40 A/DIV

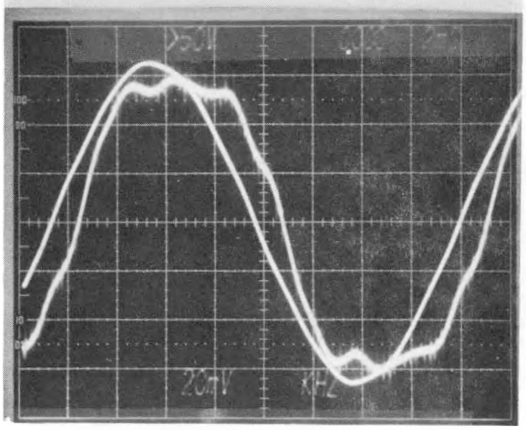

Fig. 3-2 Line Current and Voltage
Charger S/N 10798
235 VDC/90 ADC
235 VAC/101 AAC
100V/DIV, 40 A/DIV

3.4 Modifications

The ac failure alarm sensing was moved from the control board dc supply (XA201 pin 13) (which is controlled by the on-STBY-off switch) to an auxiliary dc supply (TB2 pin 15) so it would indicate presence of input ac and circuit breaker turned on.

The hysteresis was reduced in low-and high-voltage alarms (LVA, HVA) by changing values of R307 and R316 to 100 K. The range of input current limit adjustment was extended to 0 to 100 A by changing R403 to 100 K.

All alarms and external controls were then checked and set. Current limits were set to 60 A for initial Utah operation and CFA were set at 50 A. LVA trip is 210 V and reset at 215 V, HVA trip is 275 and reset at 265 V.

3.5 Battery Charger Ac Interface Control Unit (Unit 214D) Figs. 3-3, 3-4, 3-5)

3.5.1 General

This unit provides the following operational functions:

a. Manually (local) operate chargers without disrupting overall system operation.

b. Control the chargers' ac supply via power contactors K1 and K2

c. Provide overload protection for diesel-powered generator (DPG) (Fig. 3-3).

3.5.2 Unit Description (Fig. 3-4)

The battery charger control unit provides for convenient operational checkout and maintenance of the battery charging system. When the manual (local) operating mode is required, switches S1 and S2 should be placed in the MAN (local) position and indicator lamps DS1 and DS2 are illuminated. The charger(s) are operating. Switch S1 serves as an on/off control for the charger(s) provided the operating controls have been set up correctly. (See Section 3.6 for further information on controls.)

The battery charger(s) are normally operated remotely (system) by the ACU. The switches inside the front cover of the battery charger control unit

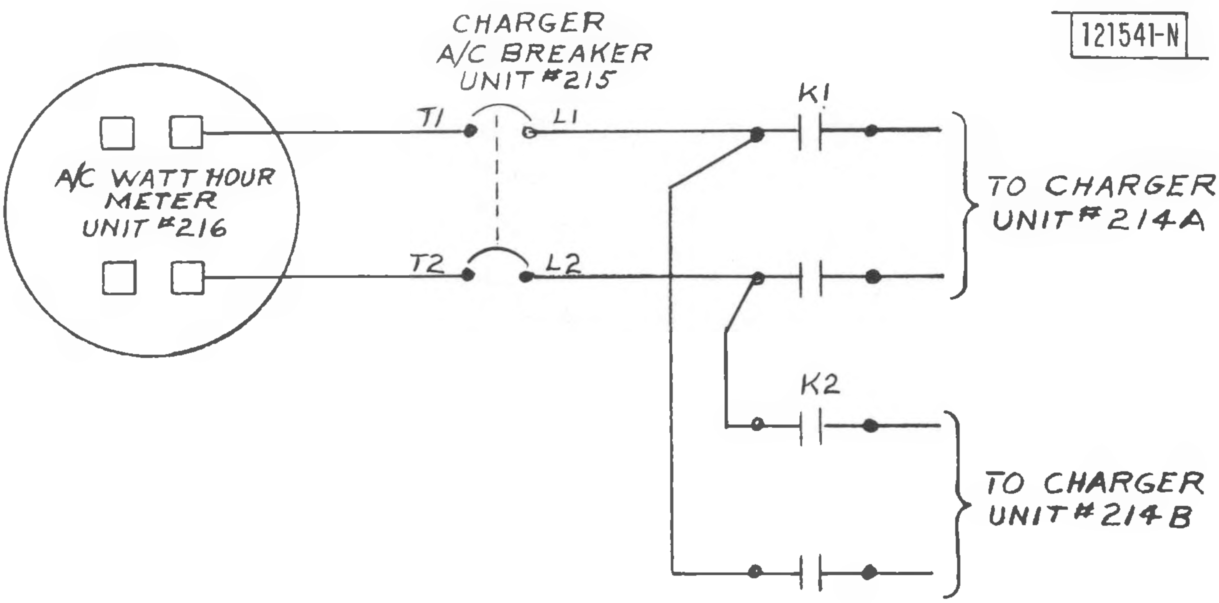

Fig. 3-3. Battery charger control unit AC power ring (LL drwg. C-75720, sheet 2 of 2).

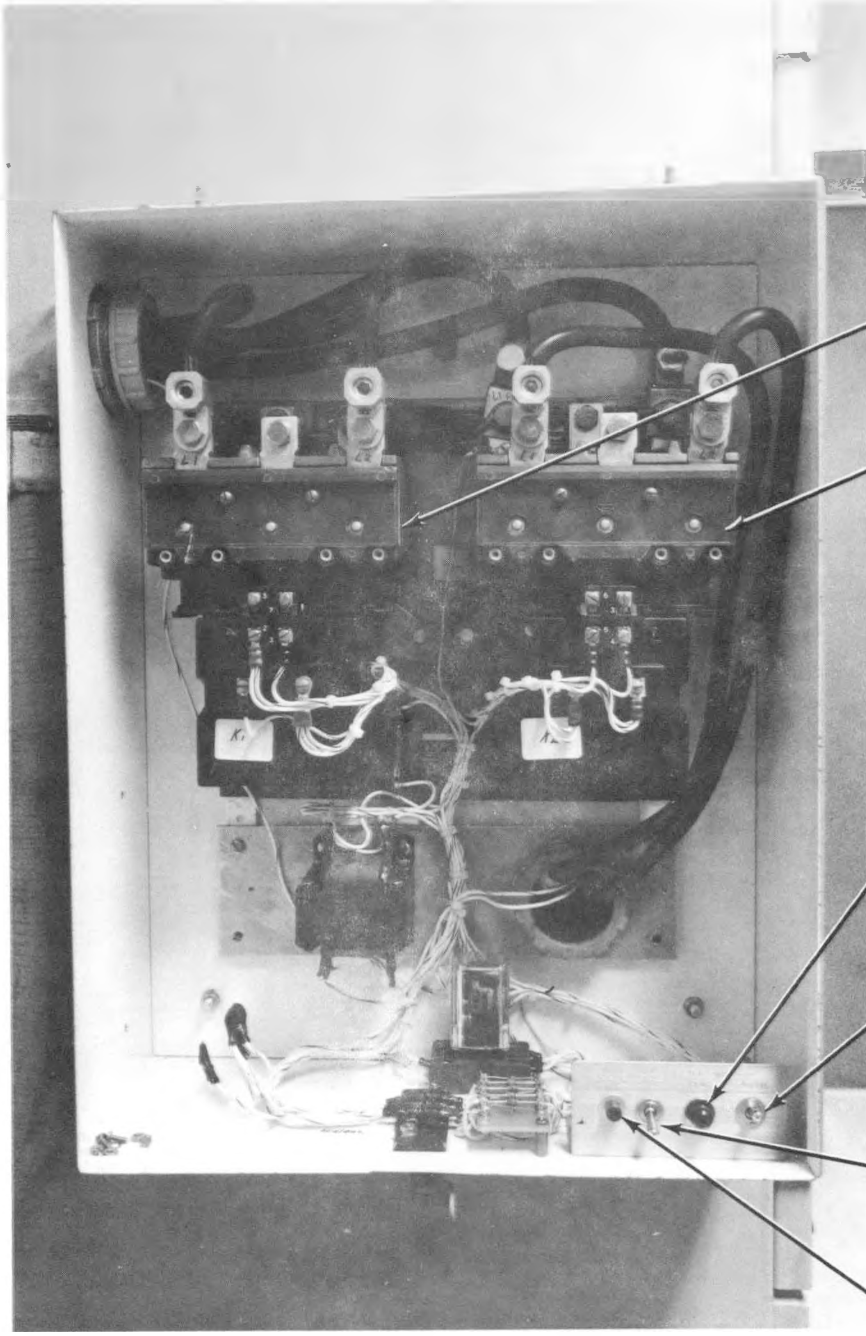

Fig. 3-4. Battery charger AC interface (Unit 214D)

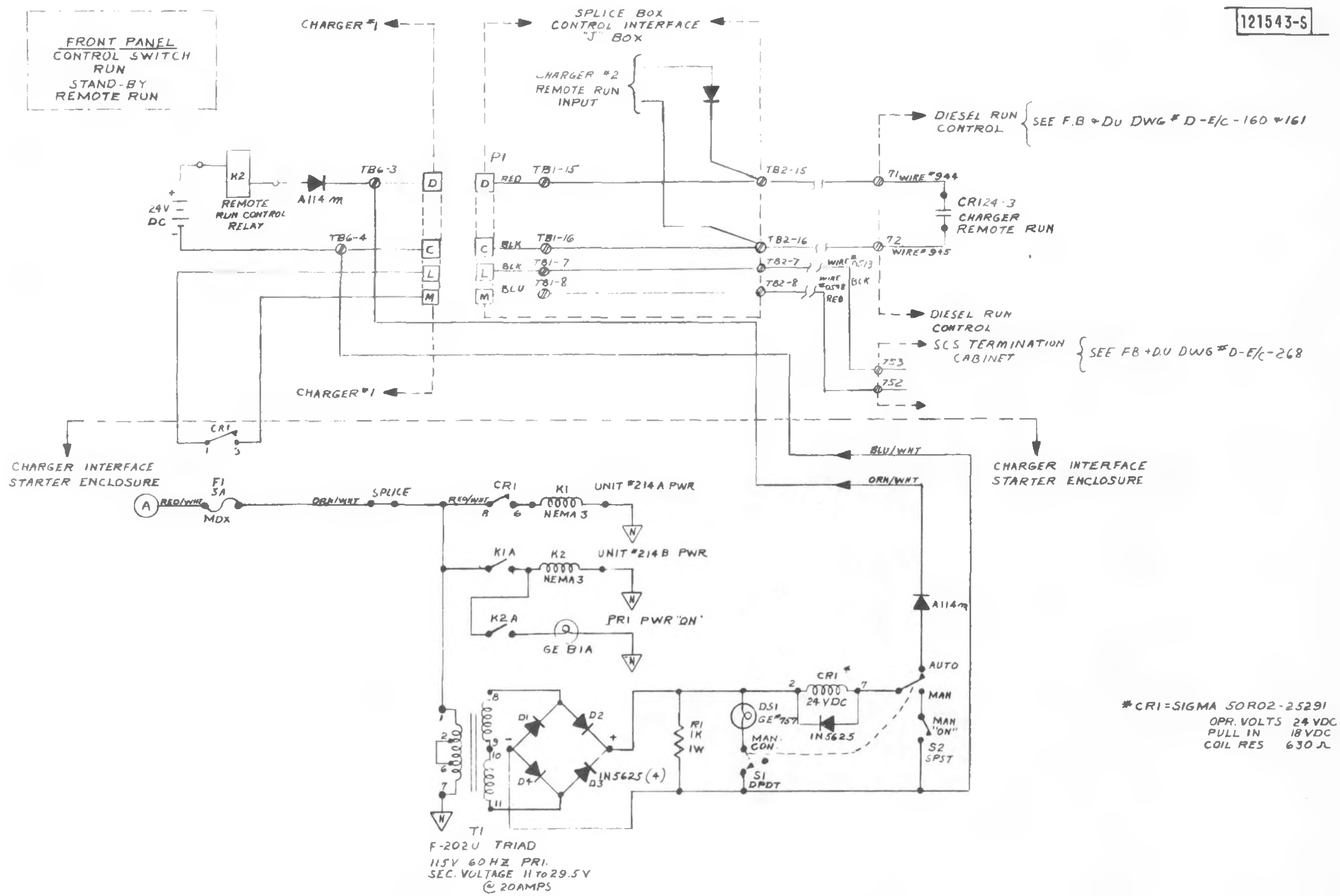

Figure 3-5. Battery charger AC interface schematic diagram
(LL Dwg. No. C-75720, sheet 1 of 2)

should be configured as follows: S1 to AUTO (remote) and switch S2 to OFF (remote). The indicator lamps, DS1 (PRI PWR ON) and DS2 (MAN CNTL), should be extinguished unless the operating system (ACU) has requested that the battery charger(s) be turned on. In this case, only indicator DS1 (PWR ON) lamp is illuminated.

3.6 Ratelco Battery Charger Alarm and Control Connections

(See Figures 3-6 through 3-10) (See Notes)

TB101	Designation	Description
1	Neg. Remote Sense	Negative input lead to the regulating circuitry. It is factory connected to the charger output terminals but may be extended to the battery to provide more precise regulation.
2		No connection.
3	Pos. Remote Sense	Positive input lead to the regulating circuitry. It is factory connected to the charger output terminals but may be extended to the battery to provide more precise regulation.
4	Low-Voltage Alarm C	This is the common terminal of the low-voltage alarm relay and is used as a failure alarm along with terminals 5 or 6. These terminals are isolated from the the charger circuits. Power for the detector circuit and relay coil are derived directly from the DC output bus.
5	Low-Voltage Alarm NO	The relay coil is energized and this terminal is connected to terminal 4 when the charger output voltage is in the normal operating range above the set point (200-250 V adj).

TB101	Designation	Description
6	Low-Voltage Alarm NC	This terminal is connected to terminal 4 when the charger output voltage is less than the set point.
7	High-Voltage Alarm C	This is the common terminal of the high-voltage alarm relay and is used as a failure alarm along with terminals 8 or 9. The terminal is isolated from the charger circuits. Power for the detector circuit and relay coil are derived directly from the DC output bus.
8	High-Voltage Alarm NO	The relay coil is energized and this terminal is connected to terminal 7 when the charger output voltage exceeds the set point (250-300V adj).
9	High-Voltage Alarm NC	This terminal is connected to terminal 7 when the charger output voltage is in the normal operating range.
10	Charge Failure Alarm C	This is the common terminal of the charge failure alarm relay and is used as a failure alarm along with terminals 11 and 12. These terminals are isolated from the charger circuits. Power for the detector circuit and relay coil is from the charger regulator control board. If the charger is in standby mode,

TB101	Designation	Description
		this alarm will indicate charge failure even if the control SCR's have failed allowing the chargers to go to maximum output.
11	Charge Failure Alarm NO	The relay coil is energized and this terminal is connected to terminal 10 when the charger AC input current is above the set point (0-100 A adj).
12	Charge Failure Alarm NC	This terminal is connected to terminal 10 when the charger AC input current is below the set point such as during battery equalize or equipment or wiring failure.
13	Load Share	See Ratelco instructions.
14	AC Failure Alarm C	This is the common terminal of the AC failure alarm and is used to indicate AC input voltage failure along with terminals 15 and 16. These terminals are isolated from the charger circuits. Relay coil power is derived from the auxiliary DC power.
15	AC Failure Alarm NO	The relay coil is energized and this terminal is connected to terminal 14 when AC input power is sensed after the input circuit breaker and power transformer (no set point adjustment).

TB101	Designation	Description
16	AC Failure Alarm NC	This terminal is connected to terminal 14 when AC input power is not present.

TB6	Designation	Description
1	Remote Shutdown	The AC input circuit breaker will be tripped when this terminal is connected to terminal 2. Open-circuit voltage is positive 24 volts DC and shorted current is less than 1 amp. These terminals are isolated from the charger circuits.
2	Remote Shutdown Return	Connected to terminal 4.
3	Remote Run	When this terminal is connected to terminal 4, the charger will run if the front panel switch is in "REMOTE" position and AC power is on. Open-circuit voltage is positive 24-volts DC and shorted current is less than 1 amp.
4	Remote Run Return	Connected to terminal 2.

ALARMS NOTES

(This listing supercedes Ratelco documents if there is disagreement)

1. LVA and HVA differential have been reduced from that indicated in the operating instructions.

2. CFA is activated by input AC current and not by output DC current as indicated in the operating instructions.

3. ACF is activated from the auxiliary DC power supply at TB2-15, not from XA201-13 as indicated in the schematic.

4. Front panel indicator lights are powered from an auxiliary DC supply. If AC power is not available at the unit, the indicator lights will not work but the alarm contacts will reflect the true status. If DC bus voltage is applied from an external source the LVA and HVA in particular will be operative even though AC power is not applied to the charger.

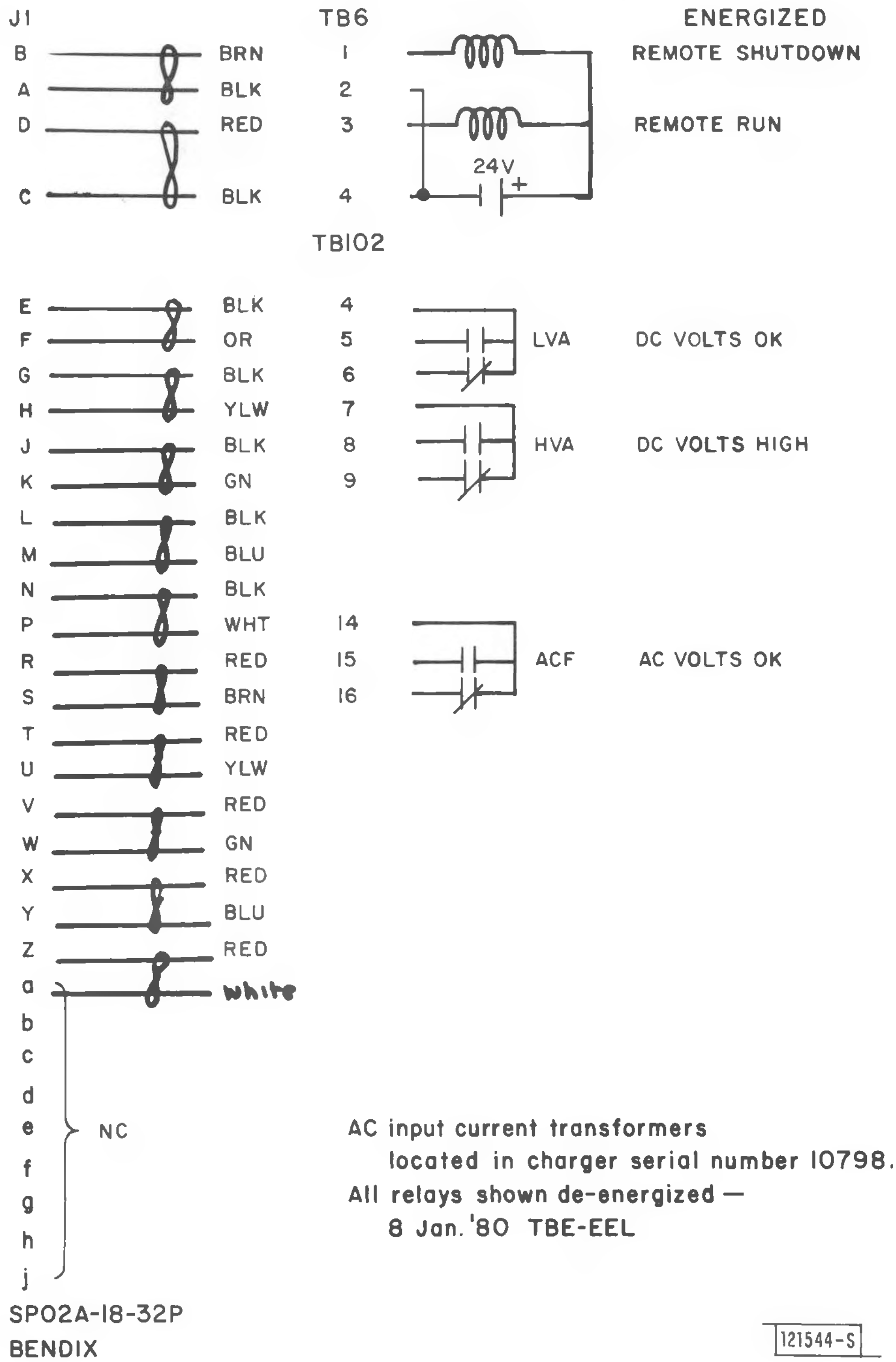

Figure 3-6. Ratelco charger alarm/control connections S/N 10797, 10798

UNIT		UNIT
RATELCO CHARGER S/N 10798		SPLICE BOX
RECEPTACLE		**RECEPTACLE**
SP02A-18-32P		TB1
PLUG	**LENGTH**	**PLUG**
SP06A-18-32S (SR)	12 FT. 0 IN.	

CHANGE LETTER	D'W'N BY	APP'D BY	DATE	CHANGES	REQ. NO.	INTERCONNECTING DWG. NO.
DRAWN FOR				APPROVED BY	**LINCOLN LABORATORY** MASSACHUSETTS INSTITUTE OF TECHNOLOGY LEXINGTON - MASS.	
DRAWN BY			1/8/80	APPROVED BY	CABLE - RATELCO/SPLICE	
CHECKED BY				DATE		
	SHEET 1 OF 2				FILE	CHANGE	DWG. NO. A-

Figure 3-7.

121545-N

J1	Wire	TB1	FUNCTION
A	BLK	14	RMT SD RTN
B	BRN	13	RMT SHUTDOWN
C	BLK	16	RMT RUN RTN
D	RED	15	RMT RUN
E	BLK	4	LVA C
F	OR	5	LVA N.O.
G	BLK	6	LVA N.C.
H	YLW	1	HVA C
J	BLK	2	HVA N.O.
K	GN	3	HVA N.C.
L	BLK	7	TO CR-1 PINS 1&3
M	BLU	8	IN UNIT 214D
N	BLK	9	
P	WHT	10	ACF C
R	RED	11	ACF N.O.
S	BRN	12	ACF N.C.
T	RED		
U	Y		
V	RED		
W	GN		
X	RED		
Y	BLU		
Z	RED		
a	WHT		

Fig. 3-8. Ratelco/splice.

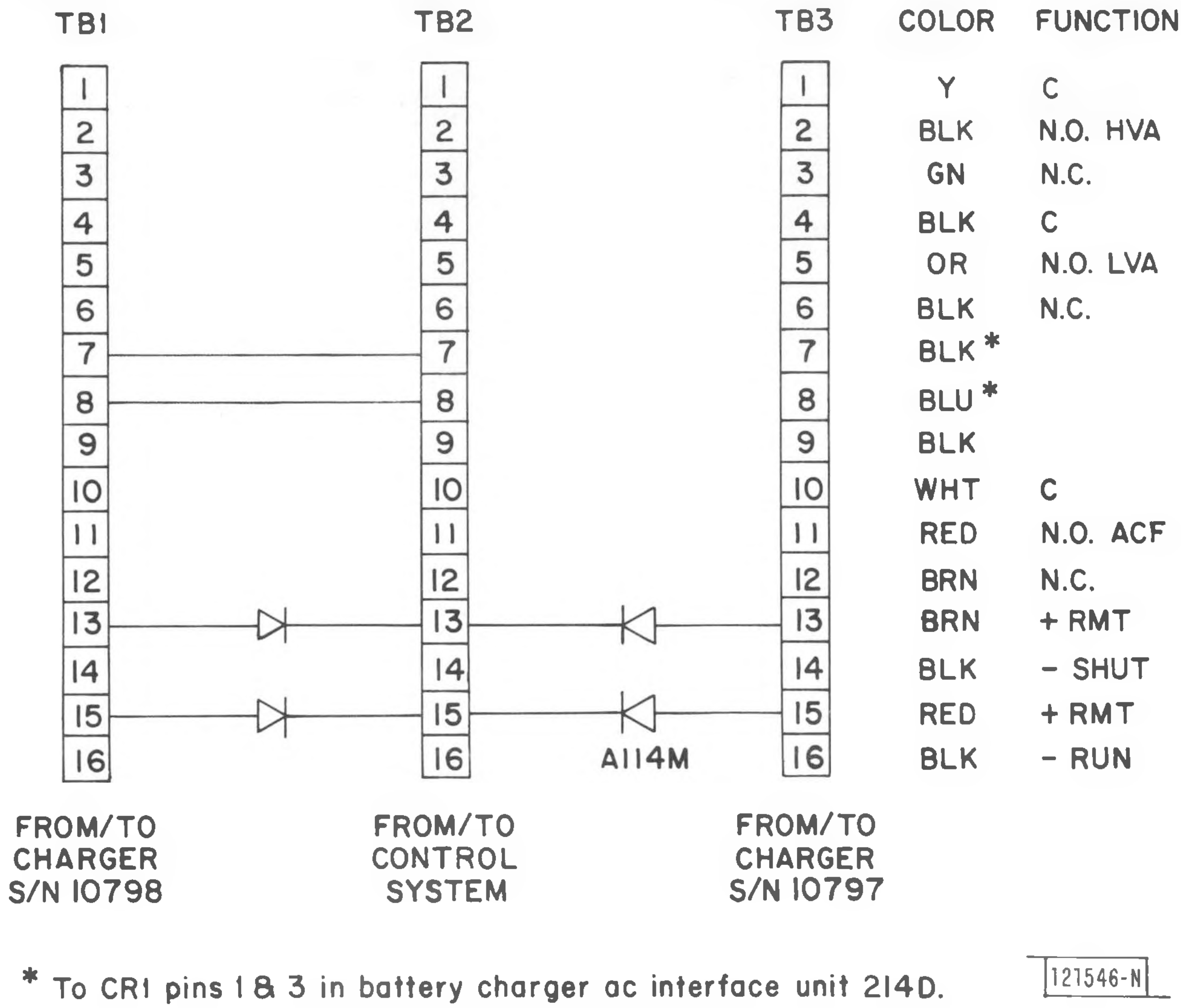

Figure 3-9. Splice box between chargers and control/alarm system.

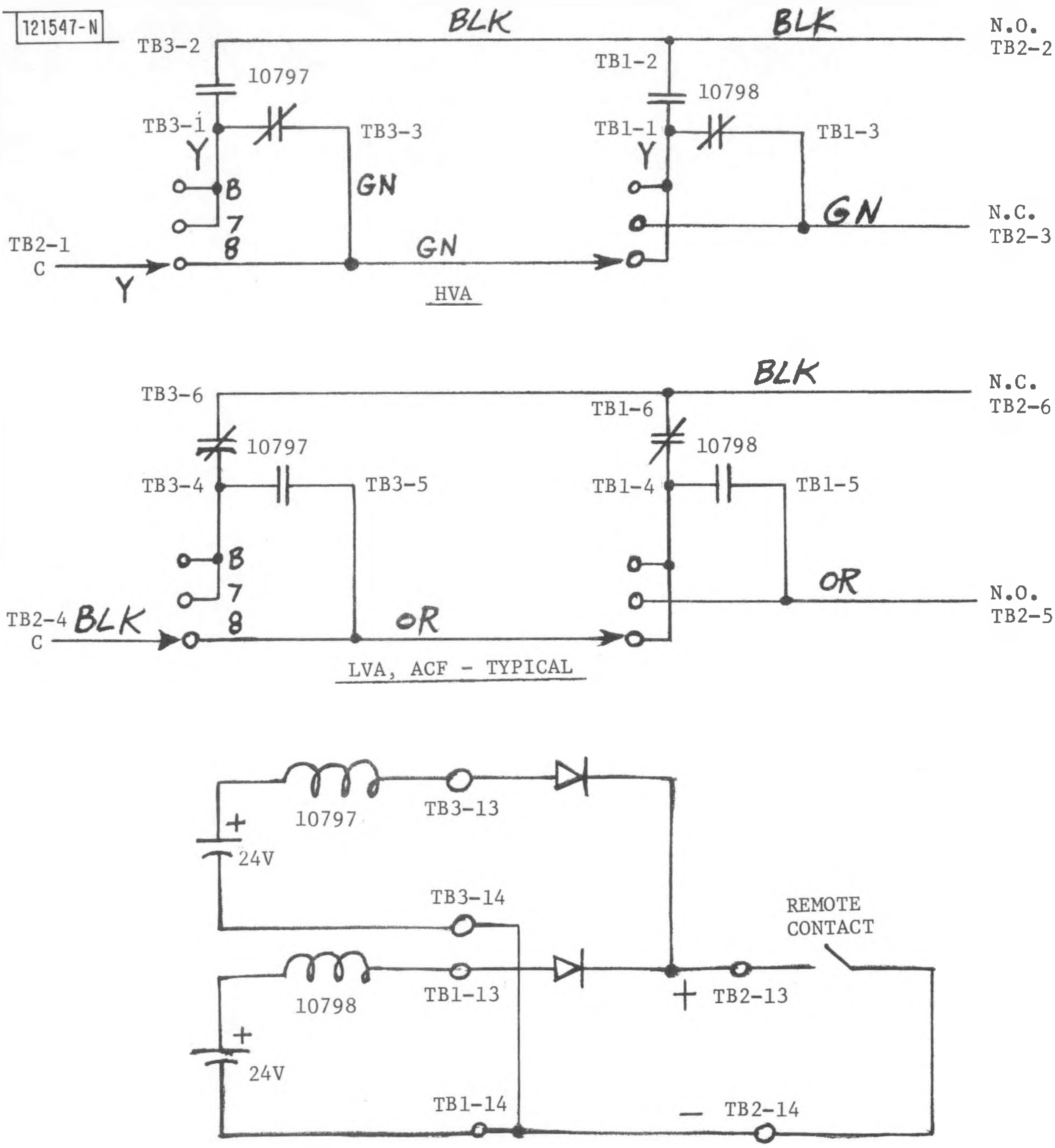

Figure 3-10. Charger alarm control switch located in splice box.

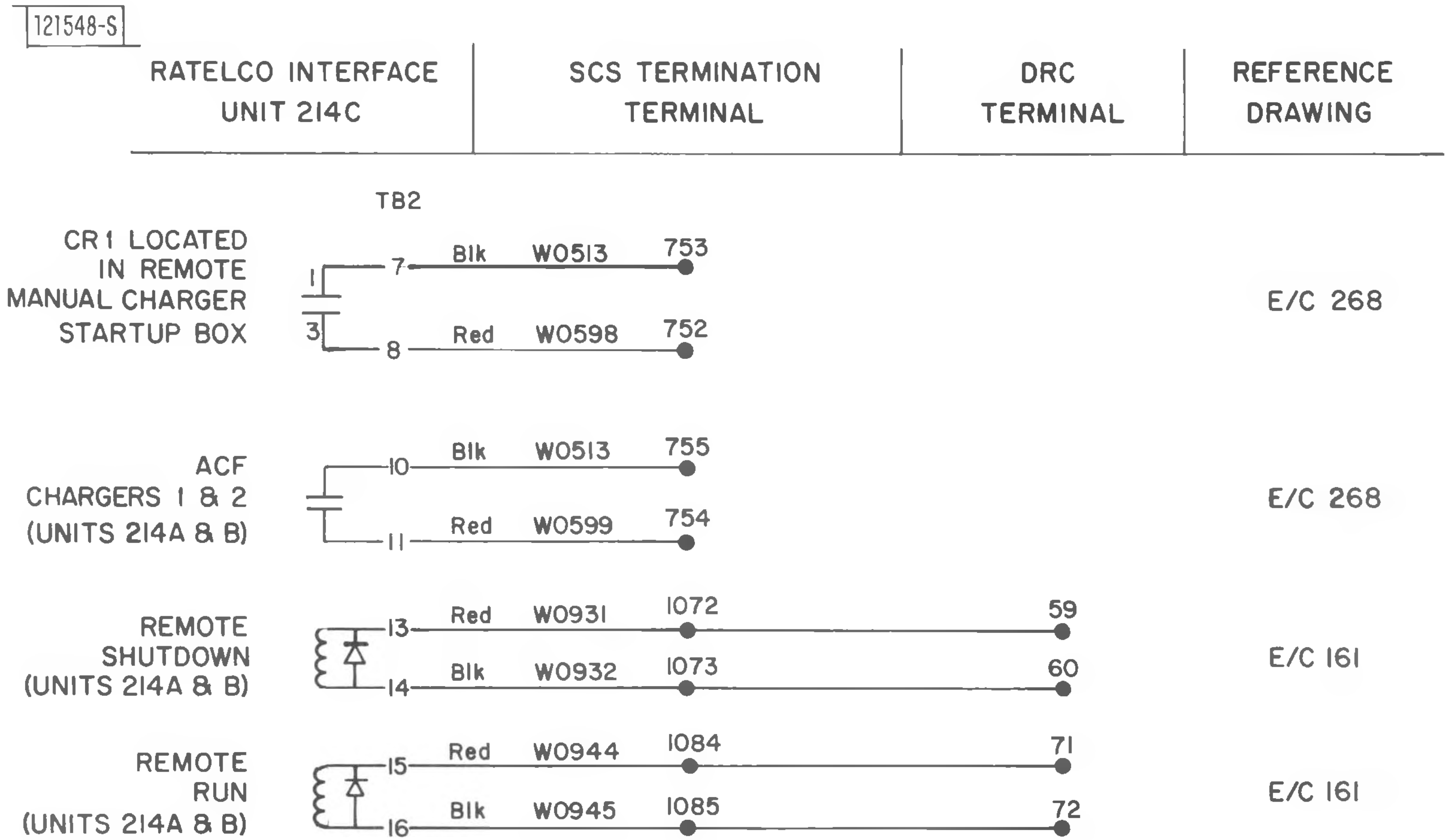

Figure 3-11. Ratelco interface wiring to ACU.

3.7 Manufacturer's Instruction Manual/Schematics*

The RATELCO instruction manual which is attached, includes the following material:

Charger specifications/optional accessories

Warranty information

Table of Contents

Installation and operating instructions

Plant connections circuit descriptions

Theory of Operation

Calibration and adjustment procedures

Troubleshooting guide

Voltage levels and waveforms

Mechanical specification

Parts list and drawings as shown in the Table of Contents

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*Site copies only

3.8 Photographs (Black and White in Printed Report)

The major components of the RATELCO Battery Charger are shown in Figures CP3-1 through CP3-11.

LIST OF RATELCO FIGURES

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*Site copies only

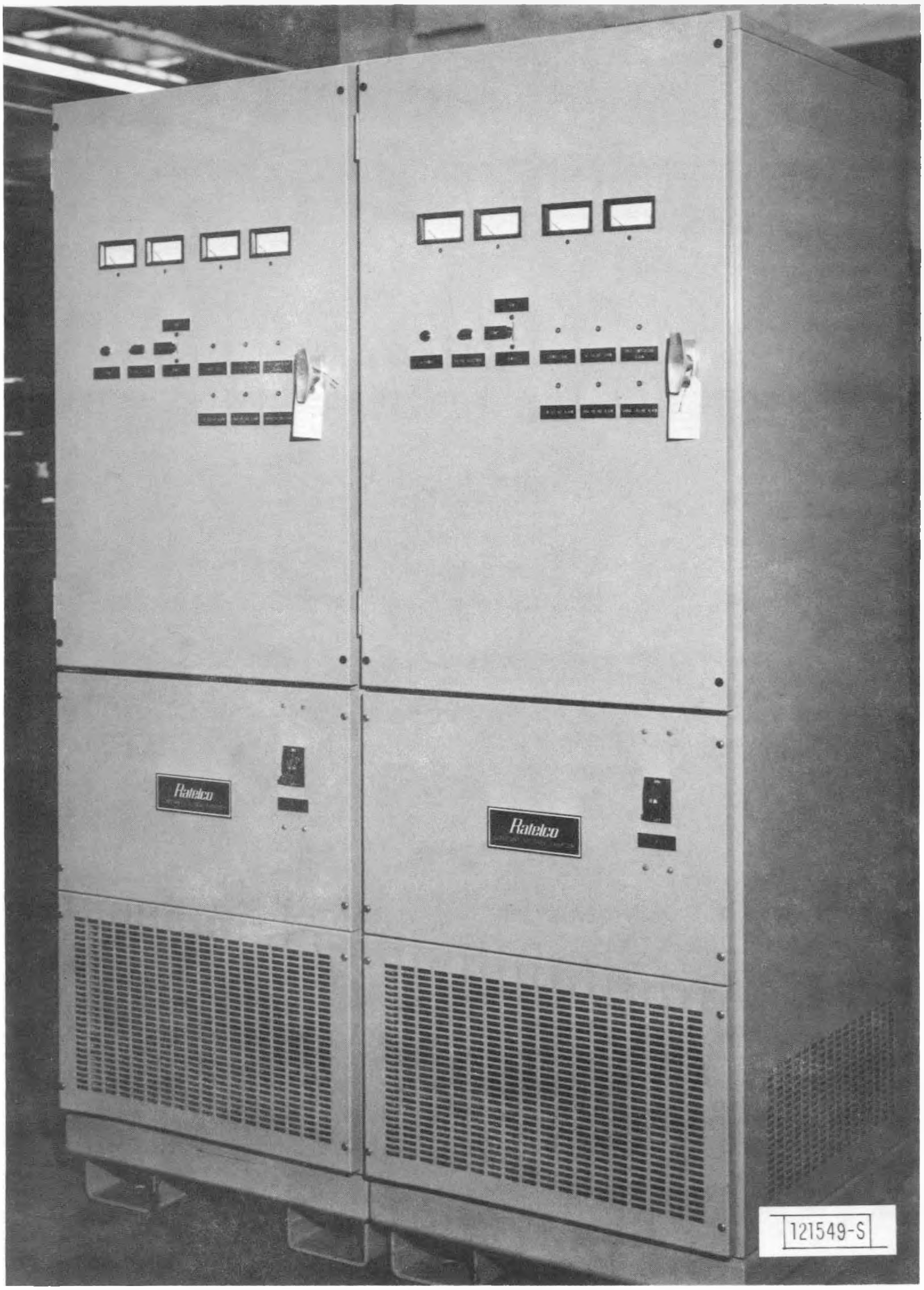

Fig. CP3-1. Ratelco front view, both sides, left 10798, right 10797.

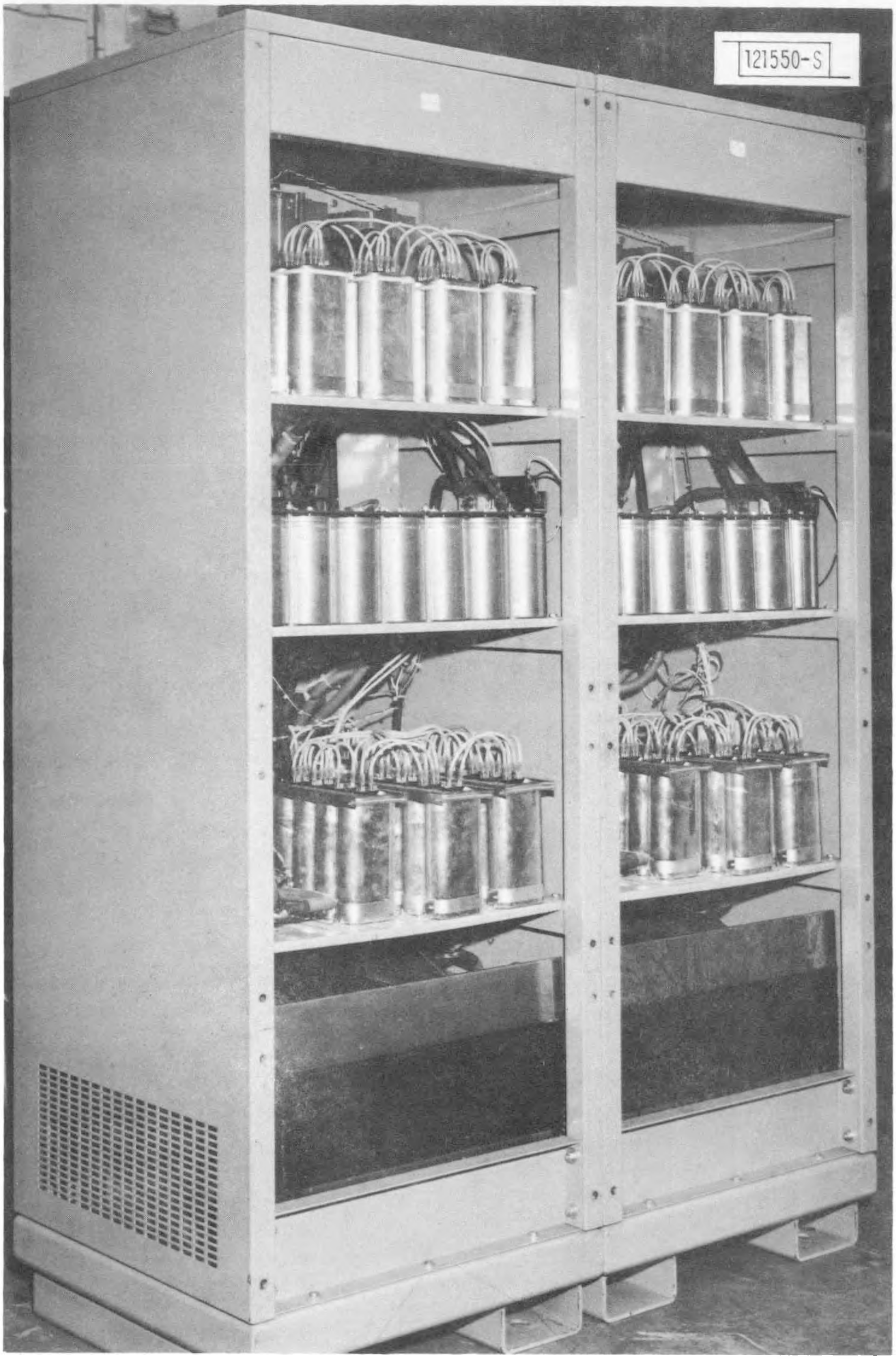

Fig. CP3-2. Ratelco rear view, both sides, right 10798, left 10797.

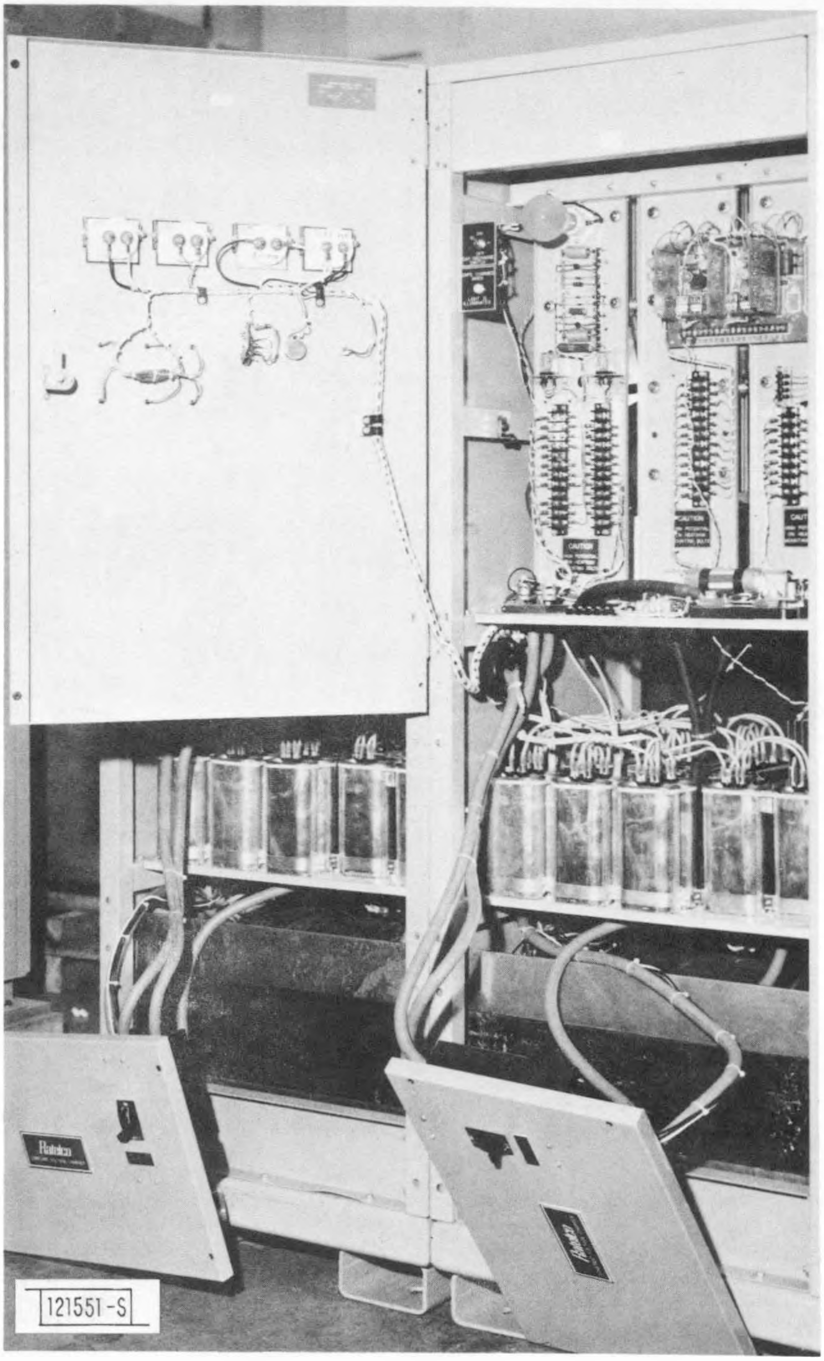

Fig. CP3-3. Ratelco front, 10797 open.

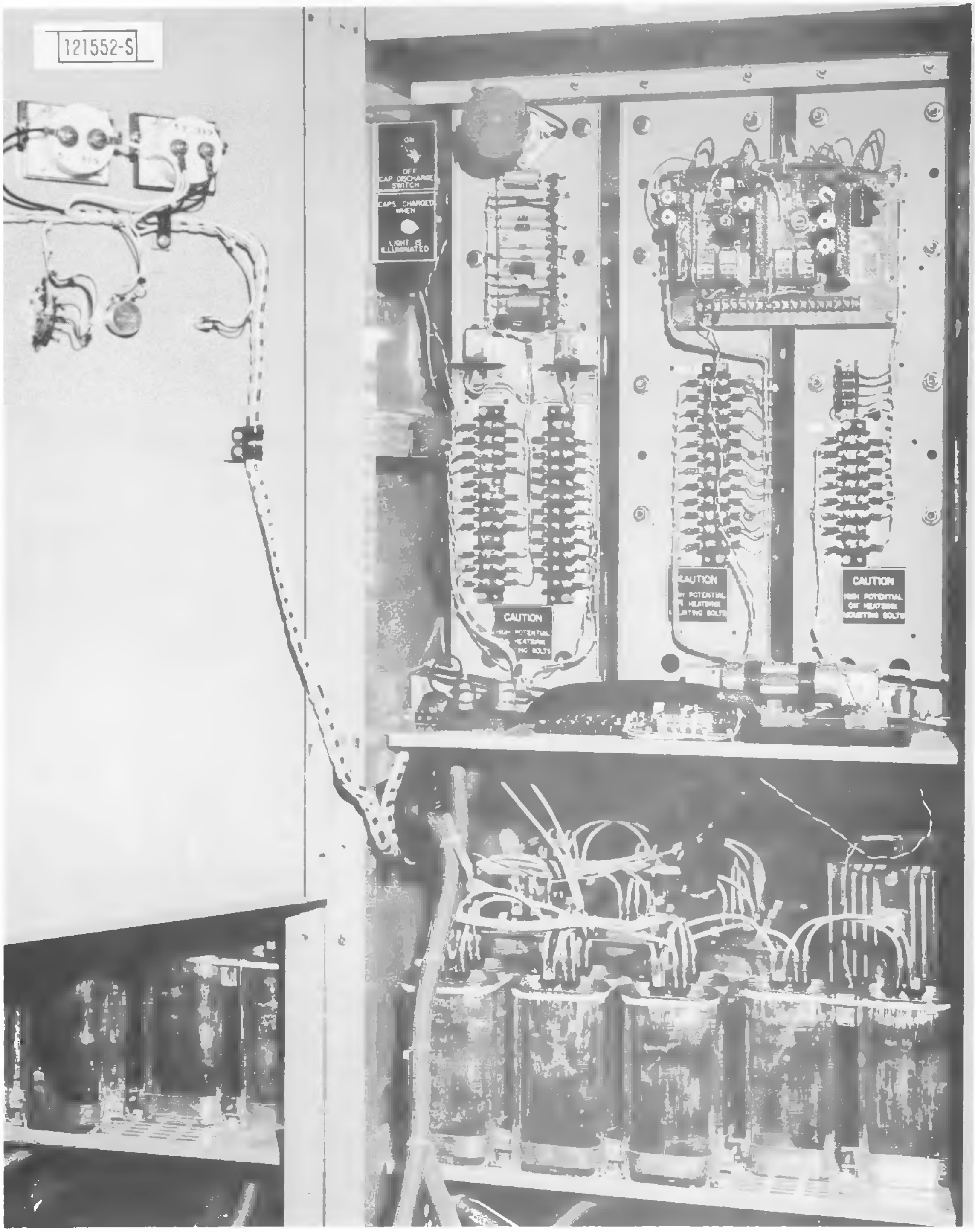

Fig. CP3-4. Ratelco front, 10797 open.

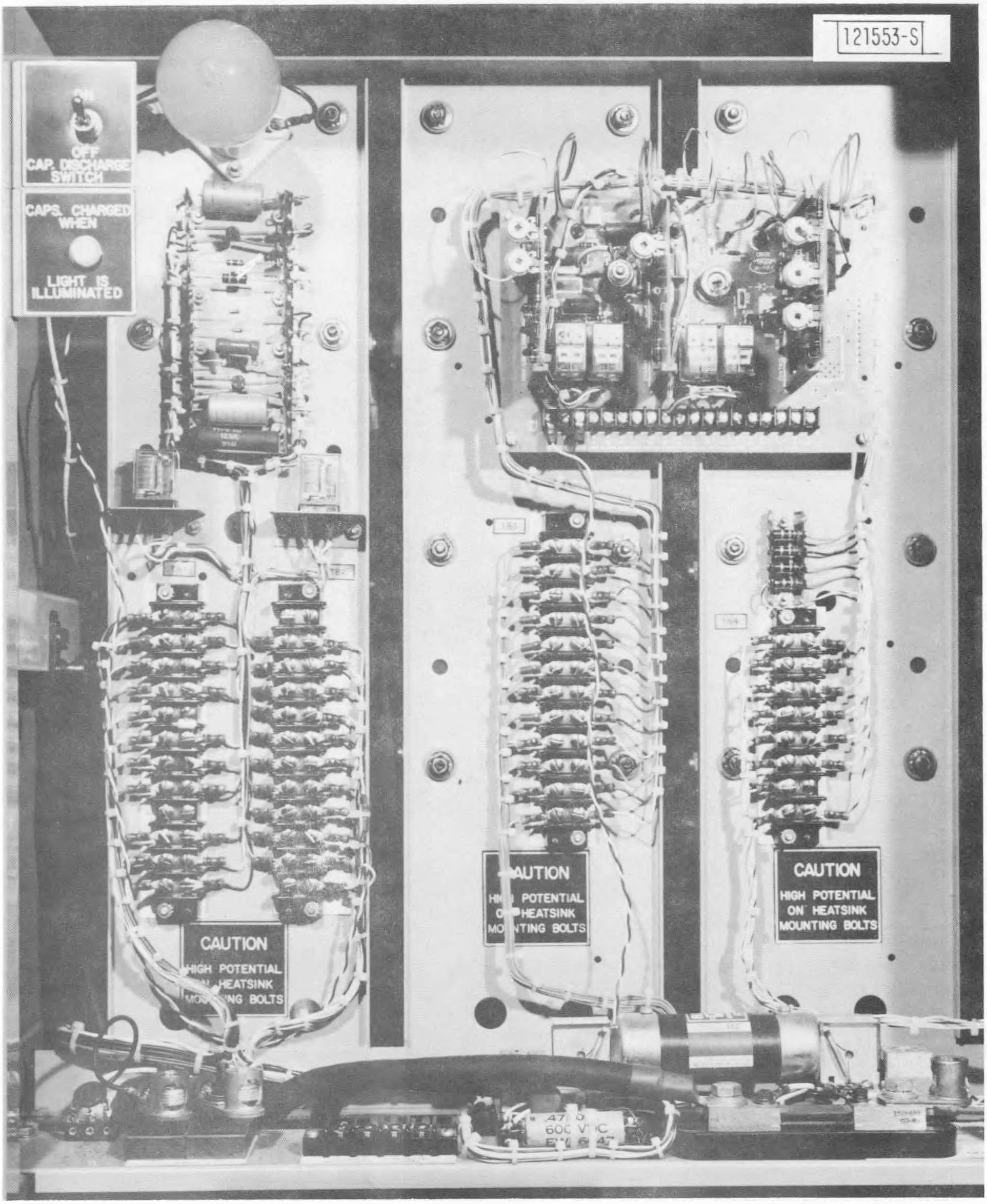

Fig. CP3-5. Ratelco front top 10797.

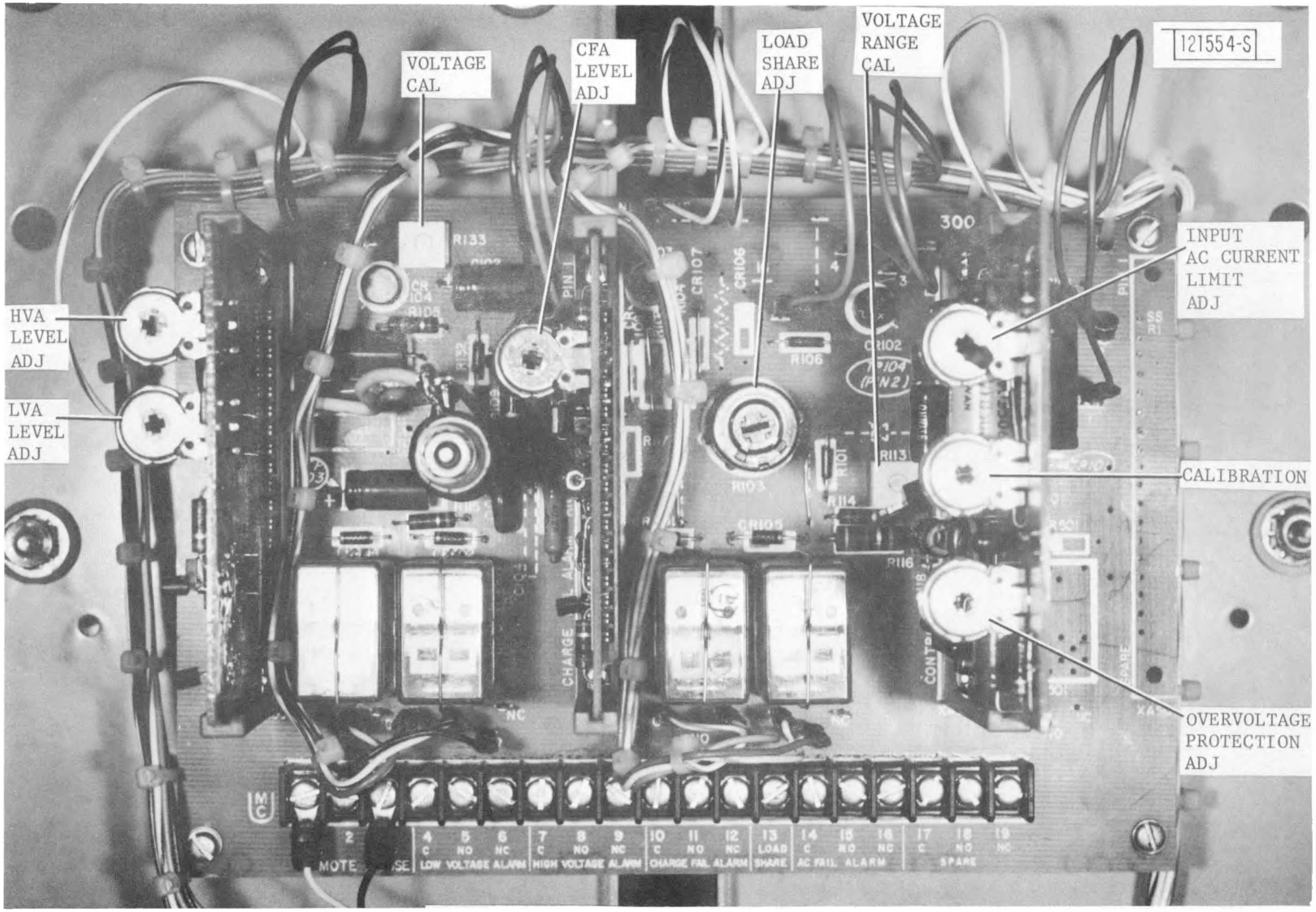

Fig. CP3-6. Ratelco mother board loaded.

3.9 Float Voltage Adjustments

If the need arises and the battery chargers voltage output must be calibrated, the following procedures must be adhered to.

Energize one charger at a time without a load, (turn off Unit 217) and adjust the float voltage control located on the front panel of each battery charger. Refer to Fig. 3-12. The desired voltage level is 280 VDC. The same voltmeter should be used to adjust each charger so they are set at the same voltages. Test points have been provided on the inside door of each charger to facilitate the required measurements.

CAUTION

The diesel power generator may get itself into an overspeed condition and trip its output breaker if the battery chargers are both dropped on line together. They should be walked in, one at a time.

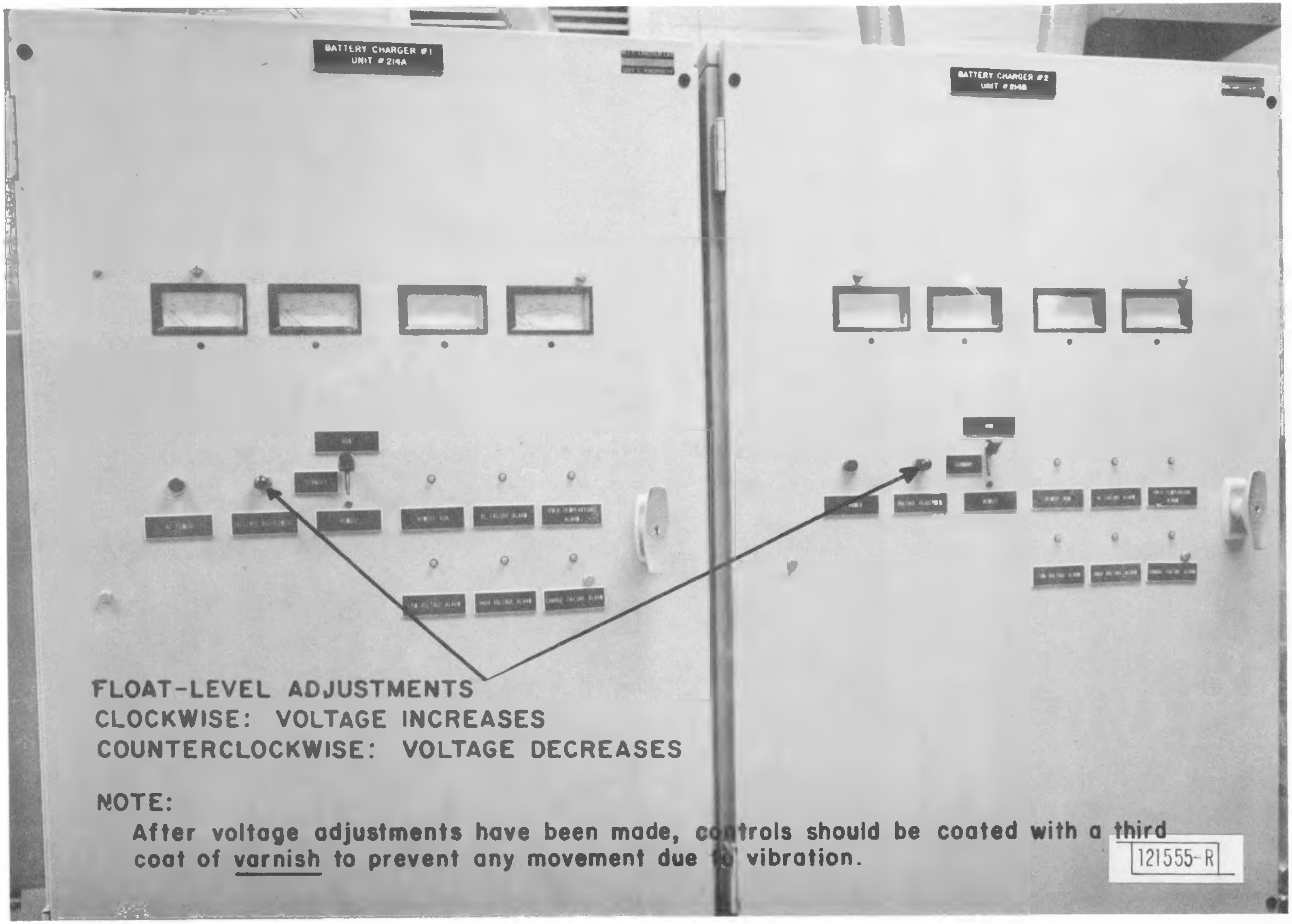

Figure 3-12. Battery charger float voltage adjustments.

4.0 BATTERY SUBSYSTEM

4.1 General

The 100-kWp photovoltaic power system at Natural Bridges National Monument (NBNM), Utah utilizes a 750-kWh lead-calcium battery storage subsystem to keep the Visitor's Center and staff residences supplied with power 24 hours per day throughout the year. The batteries were designed and built by C & D Batteries Division in Plymouth Meeting, Pennsylvania. The design is basically a modification of a fork-lift truck (traction) battery and the batteries will, during periods of low solar insolation, be capable of supplying power to the site for approximately two days before turn-on of the back-up diesel generator is necessary.

4.2 System Description

The battery consists of two parallel strings of 112 series-connected CD-QP160-23 cells. The batteries are packaged in modules of eight cells, two rows of four series cells, such that each module has two terminal voltages of 8 volts each. Twenty-eight modules are series connected to form the total battery. (See Photographs in Section 4.9.0.)

The cells in each module are encased in a steel tray which is coated with a special acid and flame-resistant plastic coating. On the bottom of each module are stand-off insulators which are permanently mounted to prevent shorts to ground and to accommodate the forks of the battery lifting device. Each cell is equipped with three special devices: 1) an air-lift pump to mix the electrolyte and prevent stratification, 2) a hydrogen recombiner to minimize net hydrogen evolution and water losses, and 3) a level indicator to display the electrolyte level to the operator without him/her having to physically open each cell top vent.

The manufacturer's (name plate) rating for each cell is 1760 AH at the 6-hour rate to an end voltage of 1.70 V/cell. The allowable bus voltage range for the total PV system is 210 to 280 V (or, 1.87 to 2.50 V/cell), and the total battery capacity is: 1760 AH x 2 strings = 3520 AH, and 3520 AH x 213 V = 750 kWh. (213 V is the average discharge voltage for the 6-hour rate to 1.70 volts/cell.) The usable capacity is 80% of 750 kWh, or 600 kWh, and the warrantee is given for a six-year life at an average daily depth of discharge of 65% such that at the end of the six years there will be available 600 kWh at a 40-kW drain (approximately 25 hour rate) to an end voltage of 1.87 V/cell, or 210 V total. See Figure 4-1 for the family of discharge curves.

4.3 Control and Monitor

4.3.1 Introduction

Battery control is accomplished by both manually operated (safety) switches and by the microprocessor controller. The system has been designed such that if the microprocessor fails or loses power for any reason, the battery will be automatically protected from over-charge or over-discharge, and the operator will be able to manually control the charge and discharge modes.

4.3.2 Manual Control

The battery can be controlled by the operator by manually turning on the diesel generator to charge the battery or turning off the generator and connecting loads for discharge. The battery can also be totally disconnected from the system via a remote control circuit breaker which has three poles: one on the negative side of the battery and two on the positive side, between the load and the battery, and between the array and the battery. Two other switches further isolate the battery: one fused disconnect switch connected to both the positive and negative end terminals (with two separate fuses on the positive end) and a safety isolation switch located in the middle of the parallel battery strings to separate the battery into two batteries of 112 V (nominal) each. Both of these switches are large knife switches located just outside the doors of the battery room (see Figure 4-2A and B).

4.3.3 Microprocessor Control

The microprocessor, under normal circumstances, handles the operation, control, and monitoring of the P.V. system. For the battery

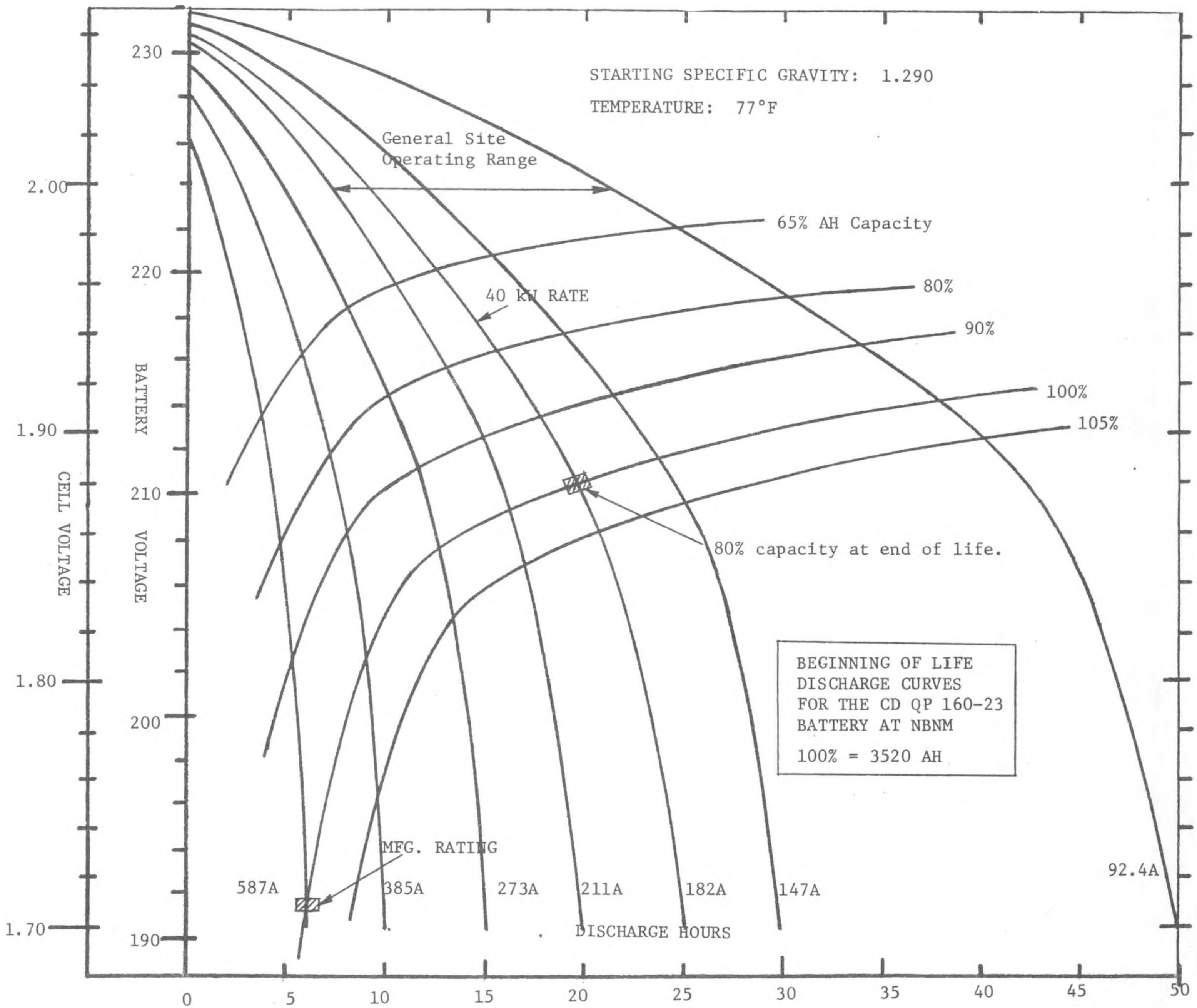

Fig. 4-1. Beginning of life discharge curves for the CD QP 160-23 battery at NBNM.

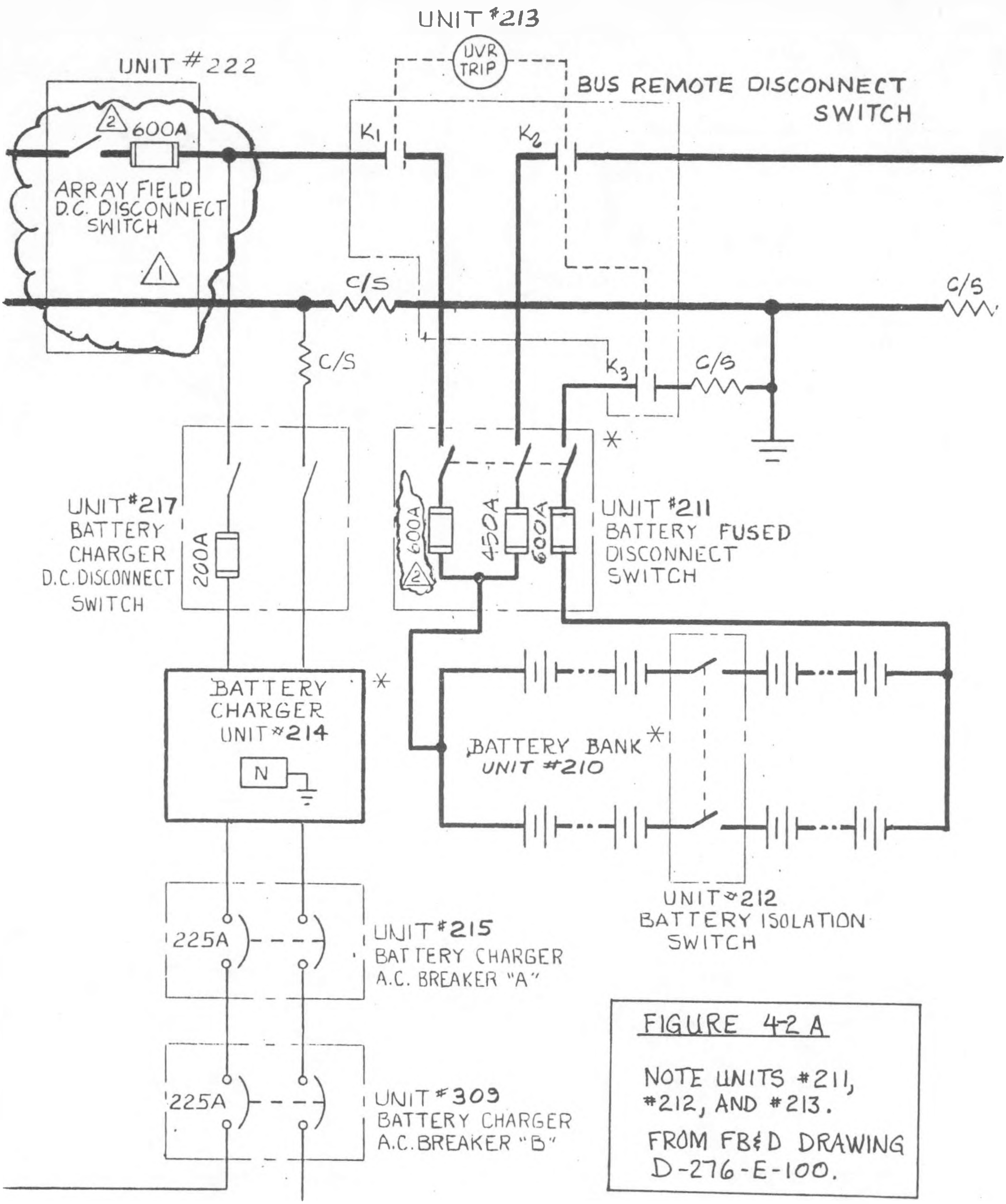

FIGURE 4-2 A

NOTE UNITS #211, #212, AND #213.

FROM FB&D DRAWING D-276-E-100.

Figure 4-2B

SPECIFIC REQUIREMENTS:

The safety fused disconnect switch (Unit #211) shall be as follows:

Enclosure ....Nema 3R - Raintight

Fusing............................Bussman FRN 600

Number of Poles...................3, all fused

Neutral...........................Not required

Ampere rating.....................600 Amperes DC

Voltage...........................250 V DC

Cabinet Dimensions................46" L x 19" W x 9" D Approx.

Switch Operating
Mechanism Construction............Heavy-duty construction with a lockable handle

Terminal Lugs.....................The terminal lugs shall accept 2 each #2/0 to 300 mcm copper conductors

Auxiliary Contacts................A single NO/NC contact for signaling which will operate in conjunction with the disconnect mechanism - type "A", rated at 1/2 amp, 120 V AC

The safety isolation switch (Unit #212) shall be as follows:

All same as above except -

Number of Poles...................2, both non-fused subsystem, the microprocessor keeps track of battery state-of-charge (SOC), voltage, current, and temperature.

The battery SOC is basically calculated by monitoring and recording the total number of ampere-hours removed from and returned to the battery. As the battery approaches 100% SOC, a voltage limit of 280 V keeps the battery from over-charging. When the battery reaches 280 V, it is held there until discharge commences. The SOC meter, at this point, has the potential of being reset to 100%. Inaccuracies in the meter's calculations are due to the fact that more ampere-hours must be returned to the battery than were removed because of the current used for gassing. An efficiency factor has been incorporated into the SOC calculation which is adjustable to take into account any changes due to battery treatment and life. As the battery sits at 280 V, the charging current will decay, indicating a nearly fully charged battery (~97%). If the SOC meter reaches 100% at this time, it will remain at 100%, giving the actual battery's capacity time to catch up as further charge is delivered.

20% SOC is the lowest allowable SOC and it is at this point that the back-up diesel generator is brought onto line. The controller has been set so that the diesel will remain on line until the battery has been charged to 80% SOC.

The trigger for the diesel turn-on is based upon the ampere-hour meter reaching 20% SOC or the battery voltage reaching a pre-determined end voltage, whichever is obtained first. An emergency back-up has been incorporated such that if the microprocessor controller fails, the site load will be automatically disconnected from the battery so that it will not be over-discharged. This back-up is a voltage-only cut-out which disconnects the main and then the UPS inverter from the battery and is set two volts lower than the end voltage that initiates diesel turn-on.

It is possible that these lower 20% SOC and cut-out voltage limits might be raised if the system operation performance indicates greater efficiency at higher average states of battery charge. If this is the case, then the proper adjustments will be made by Lincoln Laboratory.

4.3.4 Temperature Correction

The cell temperature must be taken into account for battery end voltage and the back-up voltage cut-out. Depending upon the electrolyte temperature, these end voltages will be adjusted by LL personnel in order to keep the diesel from cutting in too early or too late. For example, a rise/fall of cell temperature of 3°F from a 77°F reference will roughly give a 1% apparent increase/decrease of the nominal ampere-hour capacity (to a fixed end voltage). Table 4.1 shows what the diesel turn-on voltage and the main inverter cut-out voltage should be as a function of cell temperature. (Calculations were based upon Table 1 of the IEEE STD450-1975.)

Temperature Range (°F)	Diesel Turn-on Voltage (V)	Main Inverter Cut-Out Voltage (V)
92° and above	218	216
84° - 91°	217	215
74° - 83°	216	214
65° - 73°	215	213
58° - 64°	214	212
51° - 57°	213	211
below 50°	212	210

TABLE 4-1 BATTERY VOLTAGE AS A FUNCTION OF CELL TEMPERATURE

Note: This table assumes a minimum discharge rate of 90 A to reach the full AH rating of the battery. Voltage drops across battery leads and connectors are not included.

4.4 Acceptance Tests

4.4.1 Battery Test

The standard C & D battery acceptance test was performed on 14 August 1979 at the C & D Conshohoken plant in Pennsylvania. It consisted of a full-capacity discharge at the manufacturer's rating, i.e., the 6-hour rate (constant 293 A/cell) to 1.70 V/cell. In this case, we had agreed that the cells must have reached a capacity of at least 85%, therefore, by the time 1496 AH/cell (0.85 x 1760 AH) had been removed, the cell voltage should not have dropped below 1.70 volts. N.B. During the first six to eight percent of a battery's life, the battery chemistry gradually approaches its peak capacity condition. It takes approximately 10 to 20 cycles before the battery can give 100% of its rated capacity.

Open-circuit voltage, cell specific gravity, and cell temperature were taken on a pilot cell before the test began. (The cells had previously been equalized.) 60 randomly selected cells were connected in series and each cell's voltage was taken approximately every hour. It was shown that each cell had reached 85% capacity and, in fact, all but one of the 60 cells had reached 90% capacity. (Unfortunately, there was no way in which we could trace any particular cell to its final configuration in the battery modules, hence the present position of this one lower cell is unknown.)

4.4.2 Battery Accessories

The acceptance tests on the special devices on the tops of each cell were made, on a separate occasion, at Lincoln Laboratory, Lexington, Massachusetts. Many problems were found with all three devices, the hydrogen recombiner, the air-lift, and the level indicator.(1) The main problem resulted from the fact that while all three could operate satisfactorily alone in their original designs, they had never before been operated together as a working unit. Modifications had been made in their designs which had caused additional problems. Further redesign and modifications will be made at the NBNM site (printed as of March, 1980).

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(1) Landsman, E. E.; "Batteries for NBNM: The Air-Lift System;" MIT/LL memo; 8 January 1980.

The first modification will be to add separate orifices to each air-lift pump so that each cell will be assured of receiving an equal amount of air flow. This will eliminate the need for the single orifice supplying eight individual cells which is presently causing many problems. A test will then be performed on the air-lift system to assure its proper operation and that of the hydrogen recombiners. It is expected that the variations between the individual back pressures of the recombiners will not affect the operation of the air pumps in individual cases.

Redesign of the electrolyte level indicators is necessary to insure their proper operation. Recommendations on the necessary changes to be performed have been offered by MIT Lincoln Laboratory and it is the responsibility of C & D Batteries to effect any changes and make the replacements. The two changes that have been recommended are to (1) remove the tube around the styrofoam float and (2) seal the top of the level indicator. Water would then be added through the recombiner opening which is where the specific gravity readings are taken.

4.5 In-House Testing (17 October to 21 December 1979)

The battery tests included charge and discharge runs at various constant rates, equalizing charges, and battery transient tests (to determine the effects upon voltage of large jumps in current). Cell voltage, specific gravity, and temperature measurements were made throughout all the tests. Tests were also made on the hydrogen recombiner and air-lift system operation.(2)

Near the end of its tests, the battery was given a full-capacity performance test at the rate at which the batteries will be examined at the NBNM site during future performance tests. Because it will be practically impossible to give the batteries a constant current discharge at the site, a capacity test had to be established at Lincoln Laboratory which would provide a feasible test method at the site. The 42-kW rate was chosen as a usable rate and Figure 4.3 shows the discharge and charge runs, both done at this rate.

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(2) Brench, B. L.; "NBNM Battery Subsystem Tests"; LL internal memo; 15 January 1980.

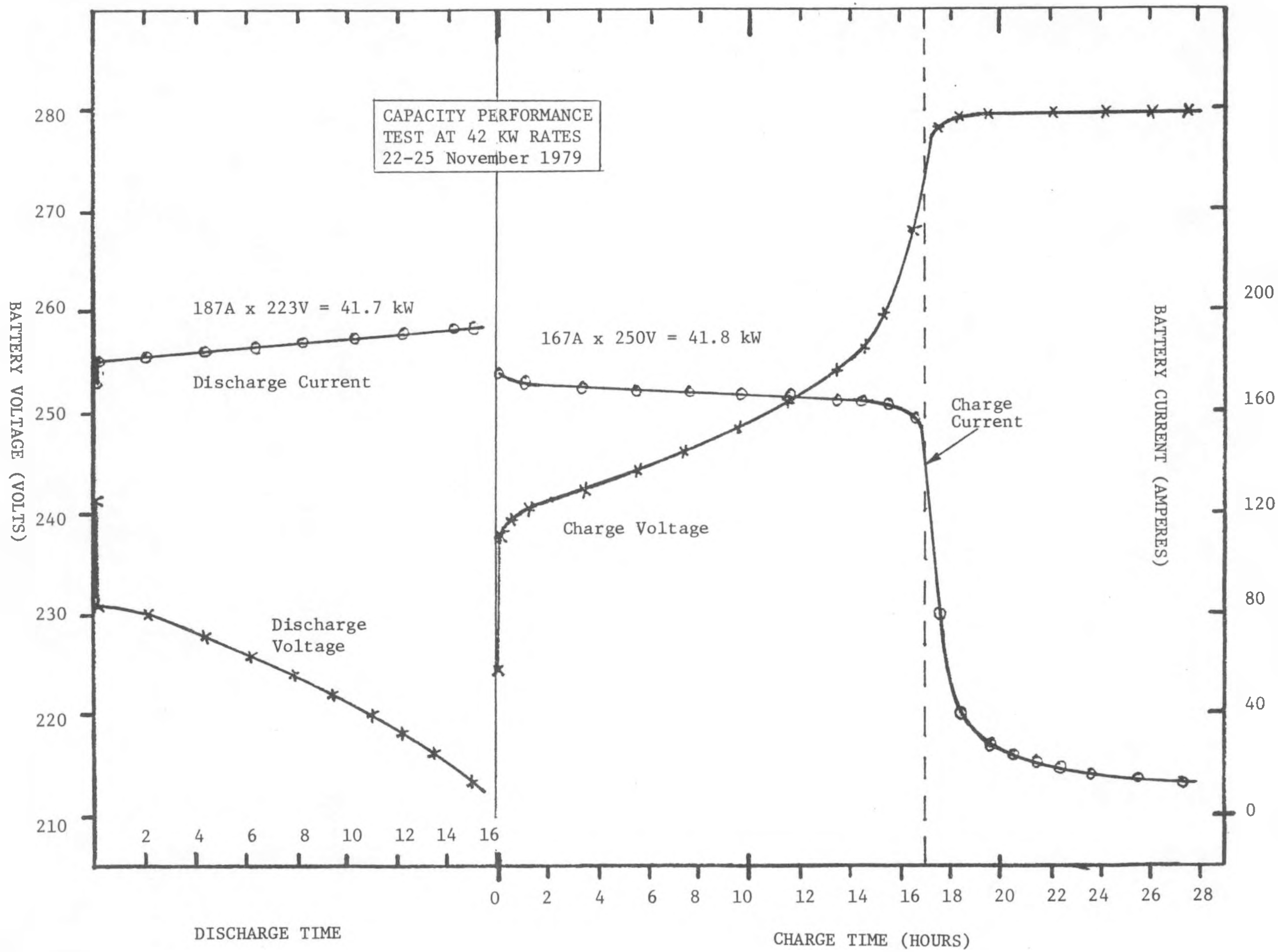

Fig. 4-3. Capacity performance test at 42-kw rates.

4.6 Battery Maintenance

Proper maintenance will prolong the life of the battery and will aid in assuring that it is capable of supplying its design power requirements. A good battery maintenance program will serve as a valuable aid in determining the need for battery replacement. PV battery maintenance shall be performed only by trained personnel knowledgeable of the battery and the safety precautions involved.

4.6.1 Equalization

4.6.1.1 Introduction

The batteries will have to be equalized periodically in order to bring all cell voltage and specific gravity readings to common values. An equalizing charge is an extended charge usually performed at a constant voltage of 2.70 to 2.75 V/cell for 3 or 4 hours (depending upon the depth of discharge) or until the cell voltage or specific gravity readings stop changing.

In this application, equalization is especially important due to the relatively low 280 V (2.50 V/cell) upper voltage of the operating voltage window. The equalizing charge will take longer due to this relatively low voltage or approximately 15 to 20 hours at 280 V.

Equalization is also important at the beginning of the battery's life in order to bring it up to 100% capacity. Cell voltage, temperature, and specific gravity readings should be made in order to keep a check on the proper operation of the individual cells. (Refer to form in section 4.9.3.)

4.6.1.2 Procedure

The battery equalization procedure follows in Table 4-2.

4.6.1.3 Commentary

For the first two months of battery operation, the equalizing charge should be performed every 2 weeks (as described on page 4 of the C & D battery manual). Specific gravity and voltage measurements should be taken on each of the 224 cells in order to determine proper performance and to try and foresee any future problems. An average cell temperature may be taken.

TABLE 4-2

NBNM Equalization Procedure

a. If the microprocessor wishes to perform an equalize charge but the operator has decided that the time is not yet right, type on the control panel's keyboard: "7 0 1 ADD ENTER." This tells the microprocessor that an equalization was completed that day and the start of the next computer equalization is delayed for two weeks.

b. If it is desirable to start an equalization on a certain day, type on the control panel's keyboard on that day: "7 0 0 ADD ENTER." This will start the equalize charge at 1700 hours (5:00 p.m.) that same day.

c. An equalizing charge can also be performed manually by starting up the generator and battery charger. Type on the control panel's keyboard: "8 X X ADD ENTER 9 Y Y ADD ENTER." The "XX" stands for the starting time (by the 24-hour clock) of the generator with the charger starting approximately 5 minutes later. The "YY" stands for the length of time in hours that the generator and charger will run. For example, "8 1 5 ADD ENTER 9 2 0 ADD ENTER" will start the generator and charger at 1500 hours (3:00 p.m.) and they will both run for 20 hours.

d. Check that the battery current and voltage will be recorded throughout the equalize charge by the data logger, otherwise readings should be recorded manually.

e. In the last hour of the equalizing period, the voltage of each cell should be recorded; the electrolyte level should be noted and recorded only if it is above the upper black ring on the level indicator or half an inch or more below the upper black ring. (Any low level cells will need watering after the specific gravities have been read and recorded.) Care must be taken as the batteries will be on line at a high voltage.

f. At the end of the equalizing charge (wait until the equalization light on the control panel goes out if performed by the microprocessor, or until the diesel has shut down and cooled off if performed manually) the diesel must again be started and the PV system shut down as per the "Procedure for Starting Diesel Generator and Securing PV Power System." (Refer to copy in Chapter 6 of the operations manual.) Do not follow steps 11 and 12 (Rev. 2) under "Securing PV System" and note especially steps 9 and 10. It will not be necessary to pull the grey battery connectors apart.

g. Each cell's specific gravity should be recorded, and cell temperatures should be recorded on pilot cells at the ends, in the middle, and on both sides of the room. If any readings are different from the rest, recheck those cells. Make certain that the float in the hydrometer is floating and that the bottom of the meniscus is read. When reading the gravity, it is possible to interpolate between the lines, for example, "1272" rather than "1270."

h. When all measurements have been made, start up the PV system and shut down the generator as per the "Procedure for PV System Turn On and Diesel-to-PV Transfer." If step "c" in this Equalization procedure was used, step "a" will also have to be completed at this time in order to keep the microprocessor from starting an equalizing charge within two weeks. Checks should also be made of the following items:

- Check all the thumbwheel selected constants on the initializer for proper values.
- Set the SOC to 99% via the keyboard if it is not already 99%.
- Check DRC switches for proper position:

DPG	ACU
Site Transfer	OFF
Battery Charger	ACU
Main Inverter	ACU
UPS Inverter	ACU

- Check that the control panel is in "AUTO."
- Check that all shutdowns have been reset.
- Check that all alarms have been reset.

i. Upon completion, return the completed form number 4.9.3.3 with the data sheets to MIT Lincoln Laboratory.* A check will be made of the cell voltage and gravity readings for any large variations. Nominal values should be 2.50 volts/cell and 1.290 g/cc. If the voltage variation is greater than 0.100 V/cell or the gravity variation is greater than 0.020 g/cc, then there could be a problem with the equalizing period, the air-lift system, or the odd cell(s). Further checks and tests would have to be made in order to determine the cause of the problem and whether or not adjustments are necessary in the maintenance procedures.

j. Rinse, with water, all equipment used, i.e., hydrometers, gloves, face shield, (not voltmeter), etc. Hang or store lab coats, soiled side facing in, and dispose of those that are badly soiled or torn. Any clothing that is suspected of having been in contact with the electrolyte should be washed as soon as possible (or rinsed in water) to prevent as much as possible any holes (or large holes) from appearing.

*or to designated technical support personnel.

For the continuing months, it is possible that the battery measurements need only be performed once every month if the average battery SOC remains high and there are frequent and long charging periods. The specific gravity, cell voltage and temperature measurements need only be taken on 3 modules (1 module = 8 cells) each time on a rotation basis (24 cell readings each month) such that in 10 months, every cell would have been read at least once. Each year these measurements should be recorded for each of the 224 cells. Again, the measurements must be checked for any large variations. The winter months could require extra equalizing runs. (See current practice for measurement schedule.)

4.6.2 Life Performance Test

4.6.2.1 Introduction

Once each year, a standard test consisting of a full-capacity discharge (using the dummy heater loads) and recharge should be performed to keep a check on battery capacity, life, and efficiency. The test will, at first, be conducted by Lincoln Laboratory as a standard procedure has not yet been finalized. The test should consist of an equalize charge, a 100% discharge at a constant power rate and a full charge at another constant rate. The 100% discharge is finished when a pre-determined end voltage is reached (the voltage is dependent upon the actual discharge rate). If the battery reaches its end voltage before the rated time, then the battery is not operating at its full capacity. The full charge is considered finished one hour after the battery has reached the upper voltage limit of 280 V. (Refer to form in section 4.9.3.)

4.6.2.2 Procedure

a. Battery current and terminal voltage should be recorded throughout the performance test (discharge and charge) by the data logger and/or manually.
b. The battery must be fully charged and equalized, as specified in section 4.6.1, before the start of the test.
c. The battery must be discharged at a specified rate of, say, 40 kW, until the battery terminal voltage equals a pre-determined end voltage of, say, 210 V (depending upon the actual rate).

(Note: The point at which the total battery voltage is taken is extremely important due to the total resistance between the battery connectors and leads. For example, when the voltage read at the inverter breaker, or meter, is 213 V at a discharge current of 180 A (40-kW rate), the voltage read across the actual battery terminals would be about 215 V).

d. All cell voltages should be periodically recorded along with spot checks of the cell specific gravities (of, say, every eighth cell). The readings should be taken at the beginning and completion of the discharge and at hourly intervals. If an individual cell is approaching a reversal of its polarity (plus 1 volt or less) but the battery terminal voltage has not yet reached its lower test limit, the test should be stopped. Throughout the test, the battery should also be observed for intercell connector heating. If any problem is found, MIT LL and/or C & D Batteries should be notified.

e. The time taken to discharge the battery to its end voltage shall be recorded. The battery capacity may be determined as follows:

$$\text{Percent capacity at } 25°\text{C } (77°\text{F}) = \frac{T_a}{T_s K_1} \times 100$$

Where: T_a = Actual duration of test to minimum specified terminal voltage.

T_s = Rated time to final voltage (211 V at the battery terminals at 180-A average discharge rate).

K_1 = Capacity correction factor relating to cell temper ature at start of test. (Refer to Table 4.2.)

When the battery capacity has dropped to 80% of its rated value (0.80 x 3520 Ah) then the battery is considered to have reached its end of life.

f. After discharge, the battery must be fully charged either from the solar array or at a specified rate of, say 20 kW, using one battery charger operating in parallel with site loads until the battery has reached the upper voltage limit of 280 V and has been kept there for one hour.

g. The time taken to fully charge the battery shall be recorded. The battery efficiency may be determined as follows:

$$\text{Round-Trip Coulombic Efficiency} = \frac{\text{Charge Removed}}{\text{Charge Restored}}$$

Where: charge removed = product of the average discharge rate in amperes and the time taken in hours to reach the end voltage.

charge restored = product of the average charge rate in amperes and the time taken in hours to fully charge the battery. If the solar array is used, an integration from charging current values taken at 1/2-hour intervals will need to be done instead.

4.6.3 Miscellaneous Maintenance

4.6.3.1 Battery Inspection

Physical inspections of the battery should be made and recorded on a regular basis. Checks should be made of the general cleanliness of the battery and the battery area, the cells for cracks or electrolyte leakage, the ambient temperature and ventilation equipment and the battery terminals and connectors for evidence of corrosion. If the measured resistance value of any intercell connection or terminal connection is more than 20 percent above the average at the time of installation, a thorough cleaning should be undertaken of the battery top to eliminate unwanted dirt and corrosion. The total battery intercell and terminal resistance measured at Lincoln Laboratory was 6.60 mΩ. Refer also to checklists in section 4.9.3.

4.6.3.2 Spare Battery

Periodic checks should be made of cell voltage, specific gravity, electrolyte temperature and level to assure proper operation of the float charger. Battery cleanliness should also be checked as with the main battery system.

4.6.3.3 Electrolyte (Fig. 4-4)

The electrolyte levels in each cell can be determined visually, without having to look into the cells, by reading the level indicators inserted into each cell top. The correct high level is that observed when the inner float tube's yellow indicator ring is 3/8 inch below the upper "O" ring on the stationary part of the level indicator. Or, if the yellow ring is between 1/2 to 3/4 of the distance from the bottom to the top black markers, this too is acceptable.

The levels should only be checked when the cells are fully charged, i.e., towards the end of an equalizing charge. Do not wait until the charge is terminated, as the levels will drop slightly as entrapped gas is vented from the cells.

If the levels are low, purified water (deionized or distilled) should be added via the hydrogen recombiner access hole in the cell top to bring them to their correct high level. If the electrolyte is allowed to drop below the low level, or more precisely, below the moss shield in the upper half of the cell, the plates will be exposed to air which will dry them out and damage them. On the other hand, do not overfill the cells. If this occurs, the electrolyte will be forced out of the cell during the next full charge or equalization and result in an electrolyte spill. Two things can then happen:

1) The electrolyte will be forced out through the recombiner, and if allowed to drip back in, the palladium in the catalyst will damage the cell; and
2) With the electrolyte spillage, some of the acid will be lost resulting in a flushed cell (i.e., a lower top specific gravity). Depending upon the frequency and severity of the flushes, the cell can be overdischarged during normal operation, damaging the cell.

The water should be added when the level indicator reads at the bottom black marker and while the cells are on charge as described in the second paragraph. Never use tap water as it contains impurities which could be harmful to the cell. Upon completion, the air lift should be run to thoroughly mix the acid and water.

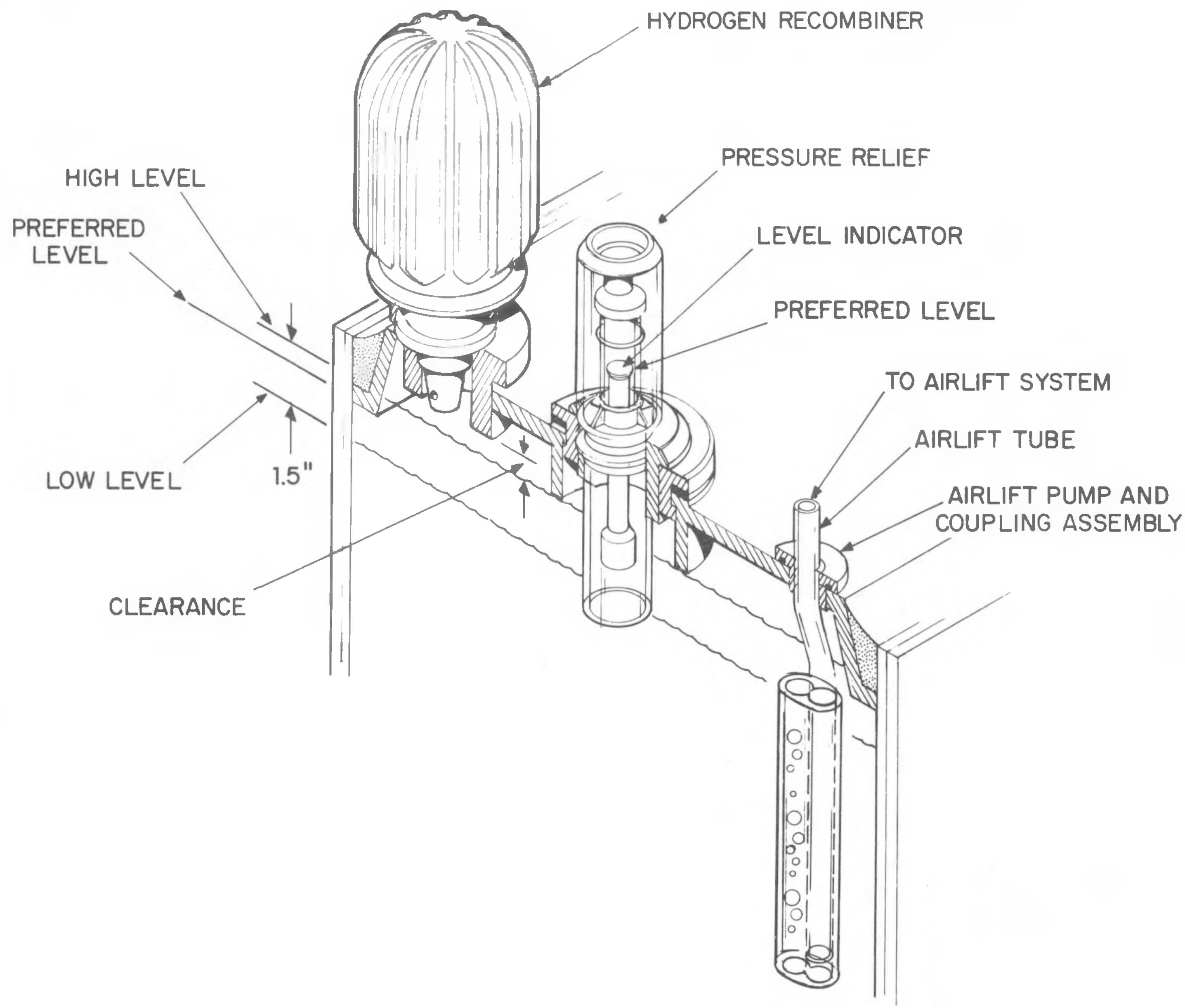

Figure 4-4. Section View of Battery.

4.6.3.4 Battery Watering (Fig. 4-4)

Low electrolyte levels can result in the tops of the plates drying out, causing damage to the batteries. Once the plates have dried out, they cannot be reactivated and the capacity of the battery is reduced in direct proportion to the area of the plate surface that has become dry.

Battery watering is always done after the batteries have been equalized and the float-type level indicator shows the electrolyte level to be at the lower "O" ring on the level indicator. The liquid level varies considerably in these cells from full charge to discharge so it is important to only add water when the cells are fully charged at the end of an equalization. If water is added at any other time, the cells may overflow the next time an equalization is done. The correct high level is that level observed when the float's yellow indicator ring is in position 3/8" below the "O" ring on the level indicator when the cells are on charge at 280 terminal volts at the end of an equalizing charge. After the charge has been terminated, the level indicator will drop as entrapped gas is vented from the cell. This is normal. The level will continue to drop as the cells discharge, and rise as they charge, but the level indicator will only indicate a correct high level condition at the end of an equalizing charge as described above.

Check very low indicators to make sure they are not stuck. Loosen and reinsert in place. If after adding water, the indicator still reads low, wash the level indicator in a baking soda bath using one pound of baking soda dissolved in one gallon of water. Rinse carefully but thoroughly with a low pressure water supply and set aside to dry. If the problem still exists, replace indicator with a new one.

The following procedures should be adhered to when watering the battery:

1. Only distilled or deionized water can be used.
2. Remove the black plastic cap on the float level indicator or use the hydrogen recombiner access hole in the cell cover as the filler hole.

3. Add sufficient water to each low cell to bring the indicator's float to the correct high level mark. To prevent overfilling, this may be taken as halfway on the level indicator. Important: do not overfill*.
4. Start the air-lift system to thoroughly mix the acid and the water.
5. If any water spills on the battery during watering it should be dried up. This prevents stray currents from flowing from cell to cell.
6. On the following day (late afternoon) the battery should be checked again for cleanliness and leakages.

4.6.3.5 Hydrogen Recombiner (Fig. 4-4)

The hydrogen catalytic recombiner inserted in the top of each cell recombines the hydrogen and oxygen given off at the end of a charge and conducts it back into the cell. Water loss is therefore almost eliminated, battery maintenance intervals for topping up with purified water are extended, and the possibility of hydrogen accumulation and gas explosions are almost eliminated.

The recombiners should be checked once every month to ascertain that they are working properly. This may be done by touching the tops of the recombiners near the end of charge on a sunny day (or during an equalizing charge). They should be warm and droplets of water should be visible on the inside of the plastic casing. Checks should also be made for any cracks or damage. If any are broken, they should be removed promptly, but carefully. There is some black powder inside the recombiner which, if spilled into a cell, will pollute the electrolyte and destroy the cell's lifetime. In a whole recombiner, the black powder is sealed and not loose.

4.6.3.6 Air-Lift System

The air-lift system (Fig. 4-5) has been installed to agitate the electrolyte at the end of charge to prevent electrolyte stratification. During discharge,

*If this accident occurs and some of the electrolyte must be removed (this can be done using a syringe), record the cell number. The electrolyte may be kept in a clean empty water container until that same cell becomes low again. Do not add to another cell as the electrolyte contains sulfuric acid.

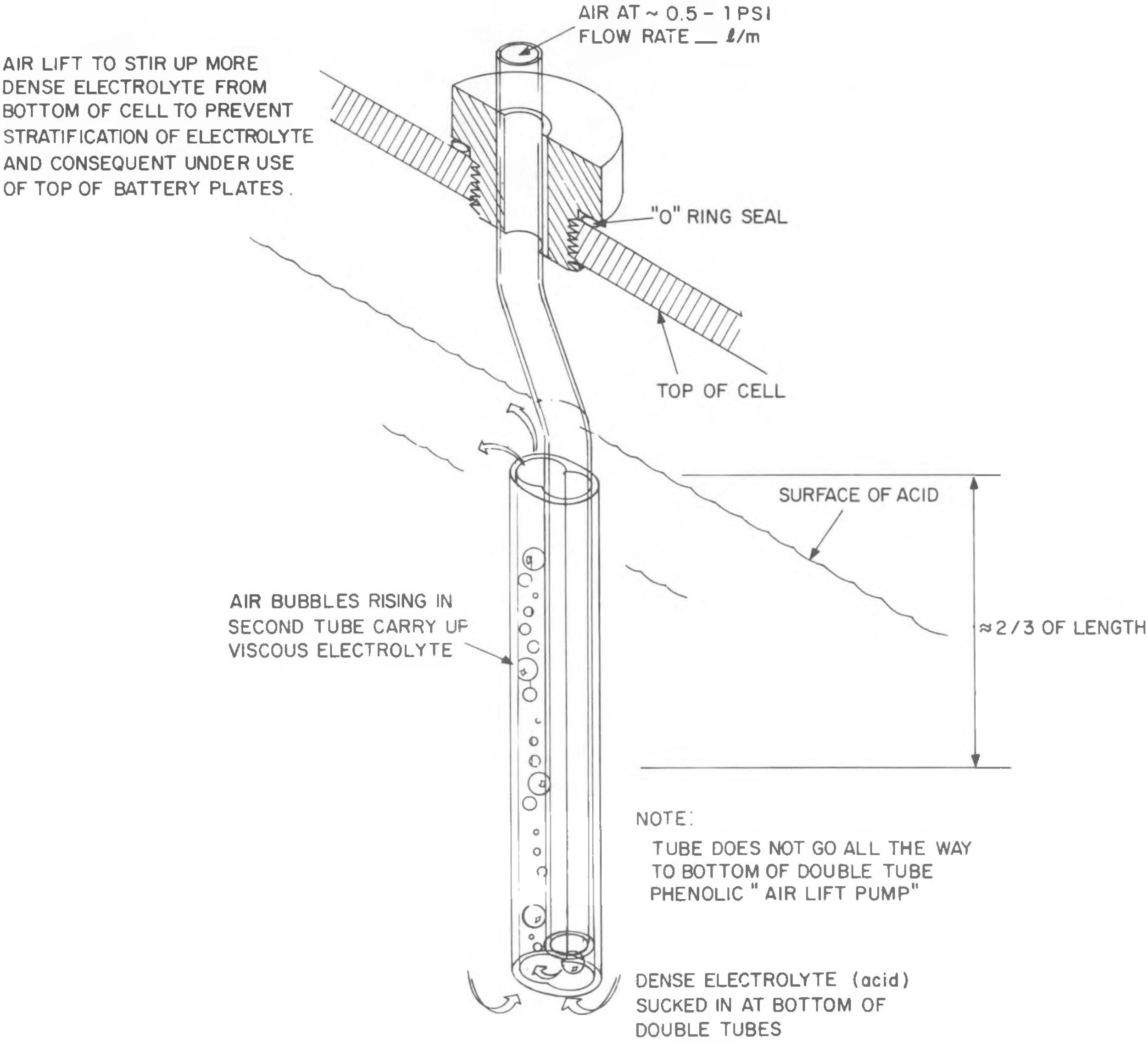

Figure 4-5. Detail of Air-Lift Pump and Theory of Operation.

the electrolyte is naturally mixed through the continual rising of the less dense electrolyte as it is formed. During recharge, the electrolyte is converted to a greater density and sinks to the bottom of the cell. There it remains until an equalization or a forced agitation is induced to mix all of the electrolyte. If the electrolyte is not mixed, the bottom of the plates will become overworked—they will sustain a greater depth of discharge than the top of the plates where the electrolyte density is higher—resulting in premature softening of the active material and subsequent loss of capacity at the bottom of the plates. Because of the relatively low upper voltage limit of 280 (2.50 V/cell), there would be insufficient gassing to mix the electrolyte without the air-lift system.

The air-lift system consists of a low-pressure air supply of 5 psig with a flow rate of 850 ml/min/cell, a plastic distribution manifold and an air-lift pump assembly for each cell. An orifice is installed in each cell's flexible air-supply tube to fix the amount of air each cell receives. The air is pumped through the inner clear plastic tubing and down approximately 2/3 the length of the cell. (Refer to Fig. 4-5.) The outer black tubing is longer, creating the "air-lift pump." The dense electrolyte is sucked in at the bottom of the outer tube and is carried up to the top of the tube with the rising air bubbles.

Over a period of time, the air-lift pump may become clogged with a calcium salt insoluble in the electrolyte. If this occurs, the precipitate may be dislodged by removing the clear plastic air supply tube and inserting a fine wire into it. The tube should then be well washed with cold water to rinse out any remaining precipitate and then inserted back into the black outer tube in the cell. If the tube cannot be cleaned, it should be replaced. Periodic maintenance checks should also be made on the air compressor and motor for cleanliness and proper operation. Any leaks in the plastic distribution manifold or the pipes with the air tank assembly should be repaired immediately, otherwise the air-lift pumps will not sustain enough bubbling time to thoroughly mix the electrolyte. The automatic timer should be set to operate the pumps three times each day for 15 to 20 minutes each period, starting at 12 noon, again at 2 p.m. and finally at 4 p.m.

4.6.3.7 Eyewash Stations

The two eyewashes and the shower should be periodically checked to assure proper operation.

4.6.3.8 Hydrogen Detectors

Periodic checks should be made of the two hydrogen sensors and their alarms. The hydrogen detectors are sensitive instruments and calibration checks should be made every two months. (Refer to the Mine Safety Appliances manual.)

4.7 Battery Safety

4.7.1 Protective Equipment

The following protective equipment should be available to personnel who will be working around and with the batteries:

1. Goggles
2. Acid-resistant gloves
3. Protective aprons, with sleeves
4. Shoe covers
5. Eye wash facility (and shower)
6. Bicarbonate of soda or equivalent neutralizing agent for acid spillage. (One pound to be available in the Battery room, the rest may be stored in the Storage room.)
7. Insulated tools which will be used around or on the batteries.
8. Non-metallic, or insulated flashlight
9. Rubber safety mat

4.7.2 Protective Procedures

The following precautions should be made in the battery room and when working around the batteries: (Refer to the checklists in Section 4.9.3.)

1. Absolutely no smoking or open flames.
2. The "Buddy System" must be adhered to at all times when working in the battery room.
3. Ensure that the battery room ventilation is operable.

4. Ensure unobstructed aisles from the battery room.
5. Periodic inspection should be made of the "protective equipment."
6. "No Smoking" and "Danger—High Voltage" signs shall be displayed inside and "No Unauthorized Personnel" shall be posted at both entrances to the battery room.
7. If work is to be performed over an exposed cell, a protective, insulating surface should be used to stand on by the worker, e.g., dry wood or a thick rubber sheet.
8. NEVER walk on top of the batteries or use them as a work top.
9. When taking gravity readings, do not allow the electrolyte to be spilled on top of the battery. Also, prevent any dirt or particles from falling into a cell. Keep battery tops clean.
10. Rinse off hydrometers and gloves with water when finished using them.
11. In case of fire, use the CO_2 fire extinguisher and not water, since water can conduct current and cause shocks and shorted cells.
12. In case of any accident, know the locations of the battery disconnect switches.
13. A curtain should be hung between the shower and the nearby batteries to prevent those batteries from becoming wet if the shower is used and thereby increasing the danger of shocks.
14. When cleaning a battery module, the following procedure should be used. For dirt and other particle matter, a blast of low-pressure compressed air can be used (or see note below), first making certain that all cell top vents are closed to prevent dirt from falling inside and contaminating the cells. Should the cell tops become wet with water or electrolyte, use a solution of baking soda and water (one pound per gallon) to neutralize the cell top. Wipe clean with paper towels or a clean rag. (Note: A water-moistened clean wiper may also be used to remove dirt particles as opposed to the compressed air blast.)

15. Burns caused by acid or electrolyte should be treated as follows: (NAVSHIPS Manual 9623.907)

   a. First attention should be given to possible presence of acid in the eye. If present, the eyes should be washed out immediately with large amounts of water, repeating this operation several times to make certain that all traces of acid have been removed. Wash out thoroughly under the eye lids. This can be accomplished on the lower lid by pressure downward below the eye. The upper lid should be elevated with repeated flushing of water under this lid. For quick treatment, a water supply should always be in the proximity of the battery.

   b. Clothing that may have been splattered with acid should be promptly removed. Skin areas touched by acid should be promptly washed with copious amounts of water. Following thorough washing, sodium bicarbonate pastes or solutions should be applied.

   c. Send for proper medical attention without delay.

4.8 Manufacturer's Instruction Manuals

The following three handbooks may be referred to for maintenance of the Battery Subsystem:

- C & D Manual
- Curtis Instruments Battery State-of-Charge Meter Manual
- The operations manual concerning "Turn-on, Turn-off Procedures for the PV System"

4.8.1 C & D Battery Manual*

The C & D Battery Manual which is attached, includes the following material:

- Description
- Cleaning
- Air-Lift Pumps
- Hydrogen Recombiners
- Charging
- Watering

4.8.2 Curtis Instruments Battery State-of-Charge Meter Manual*

The Curtis State-of-Charge Manual which is attached, includes the following material:

- Parts List
- Calibration and Controls
- Description and Block Diagrams
- Electrical Specifications
- Programming and Test Specifications

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*Site copies only

4.9 Schematics/Drawings

4.9.1 Photographs

The major components of the Battery Subsystem are shown in the illustrations following.

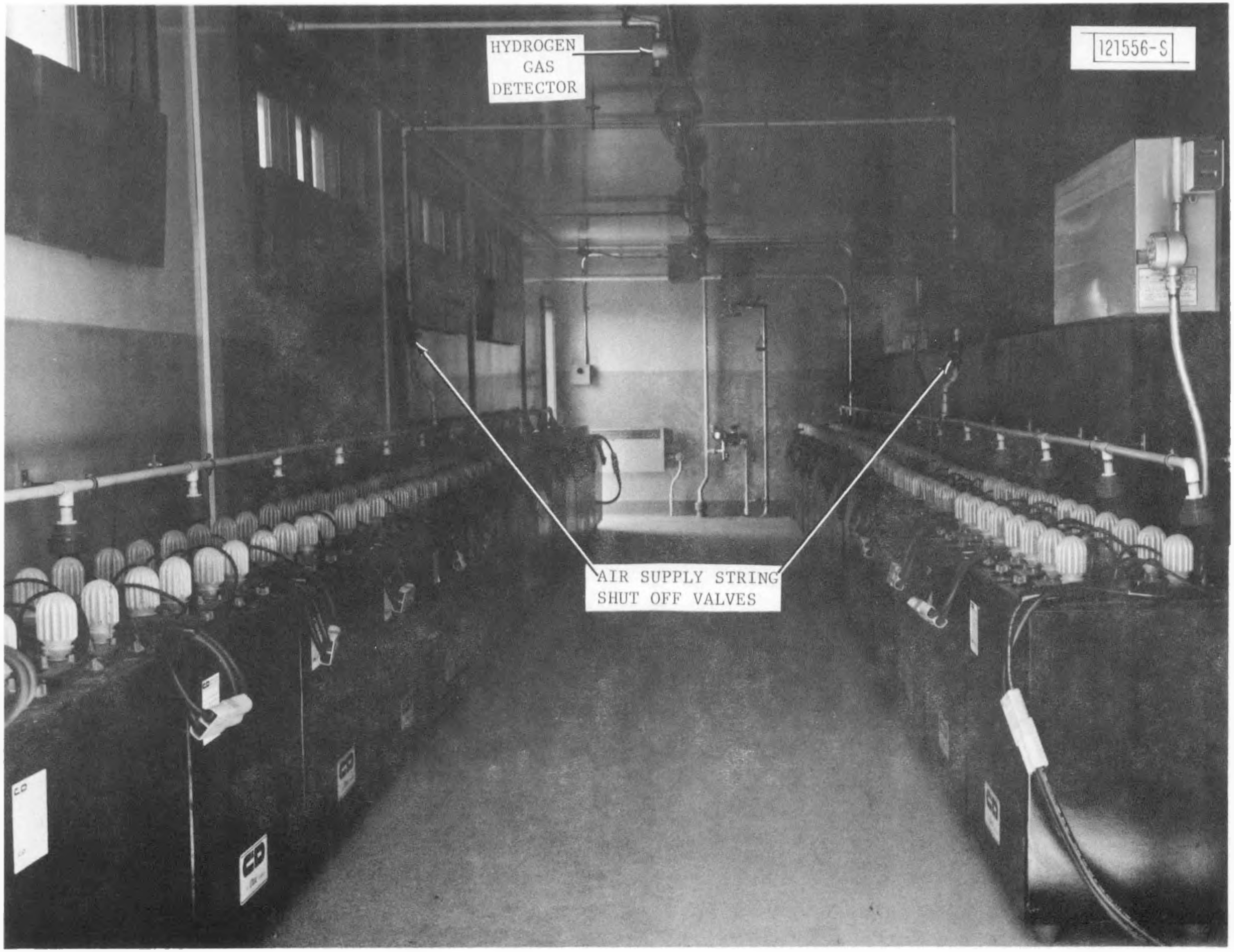

Fig. CP4-1. Battery room.

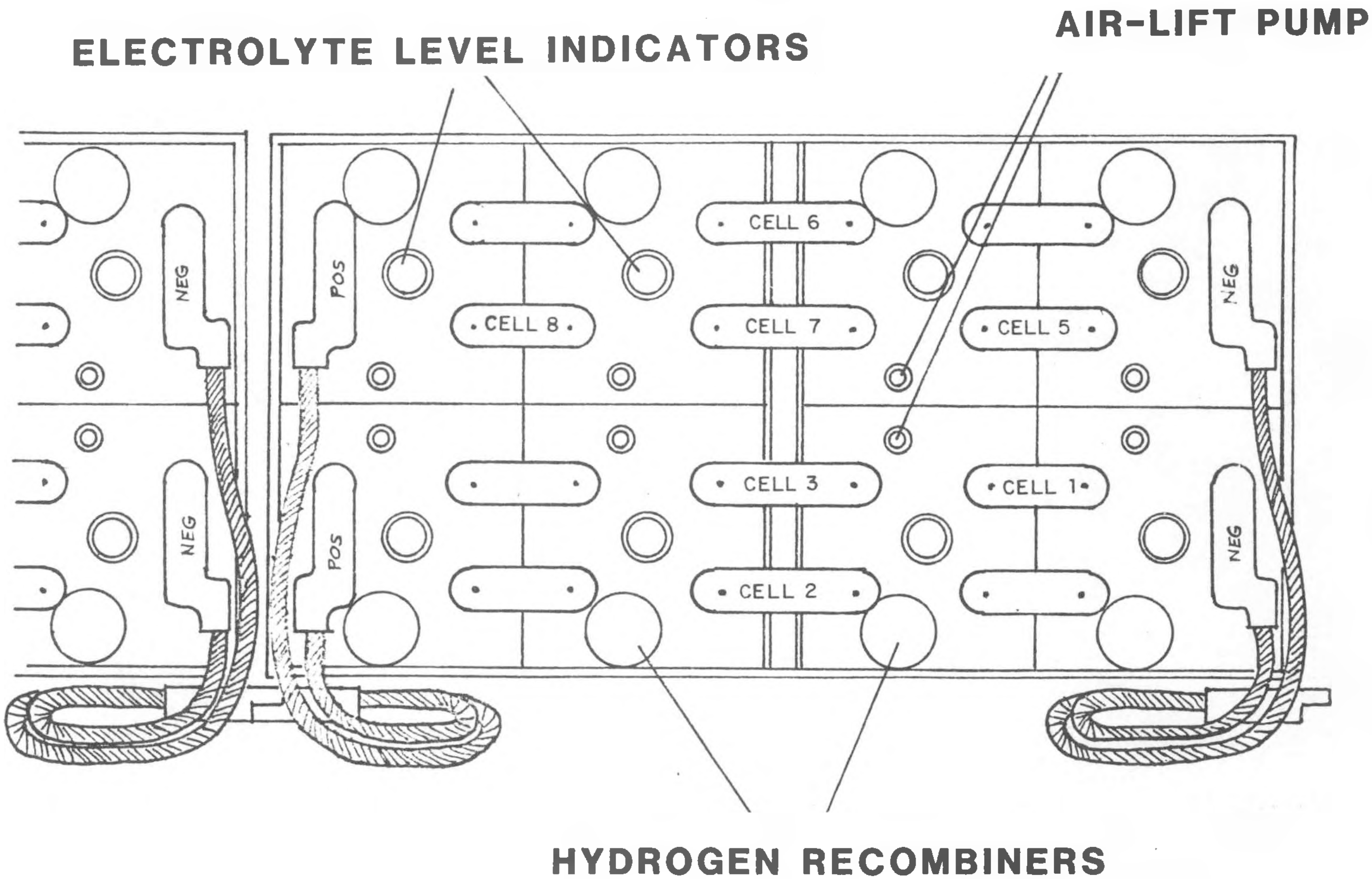

Figure CP4-2. NBNM Battery Module (Sketch)

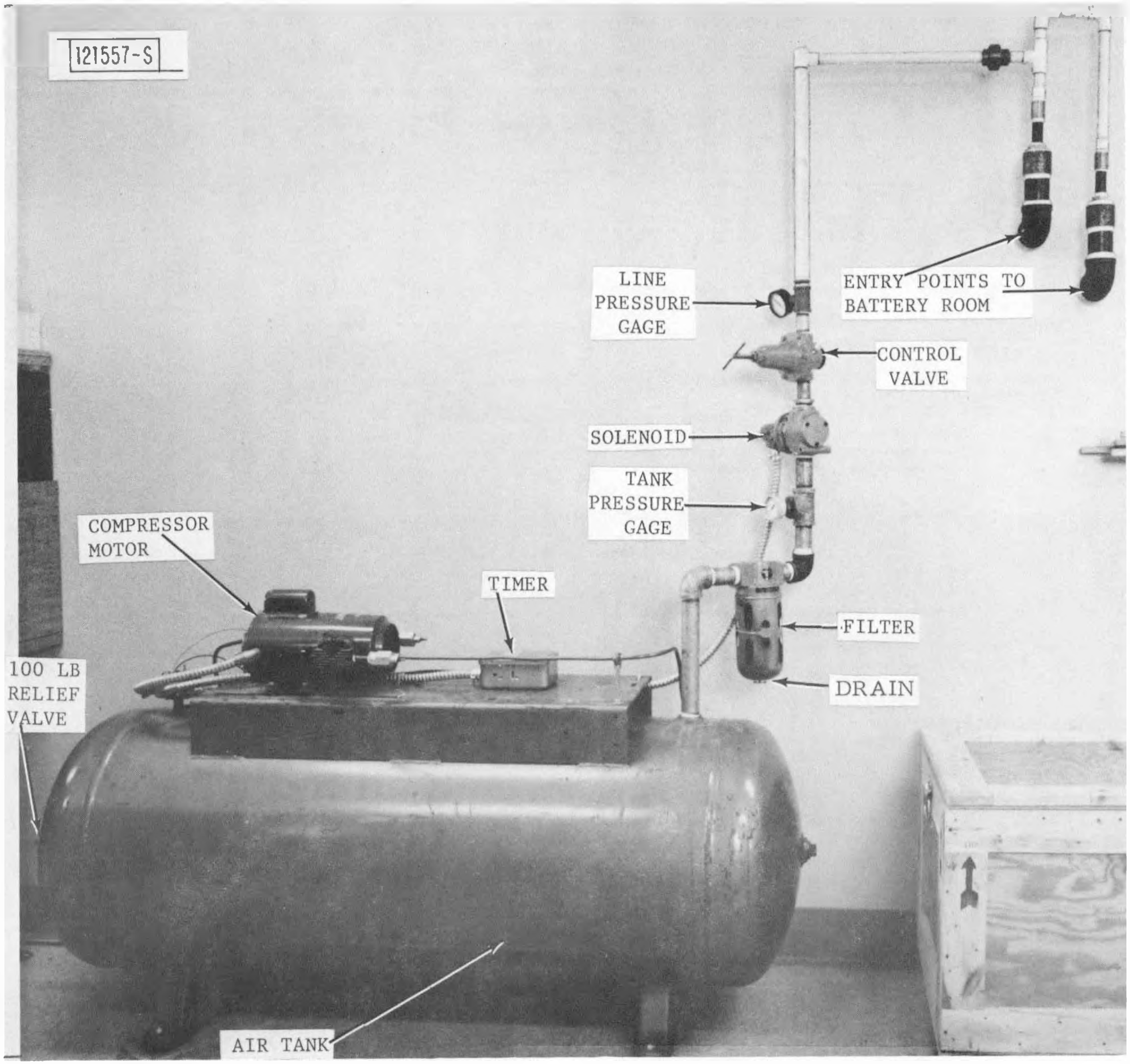

Fig. CP4-3. Air supply system.

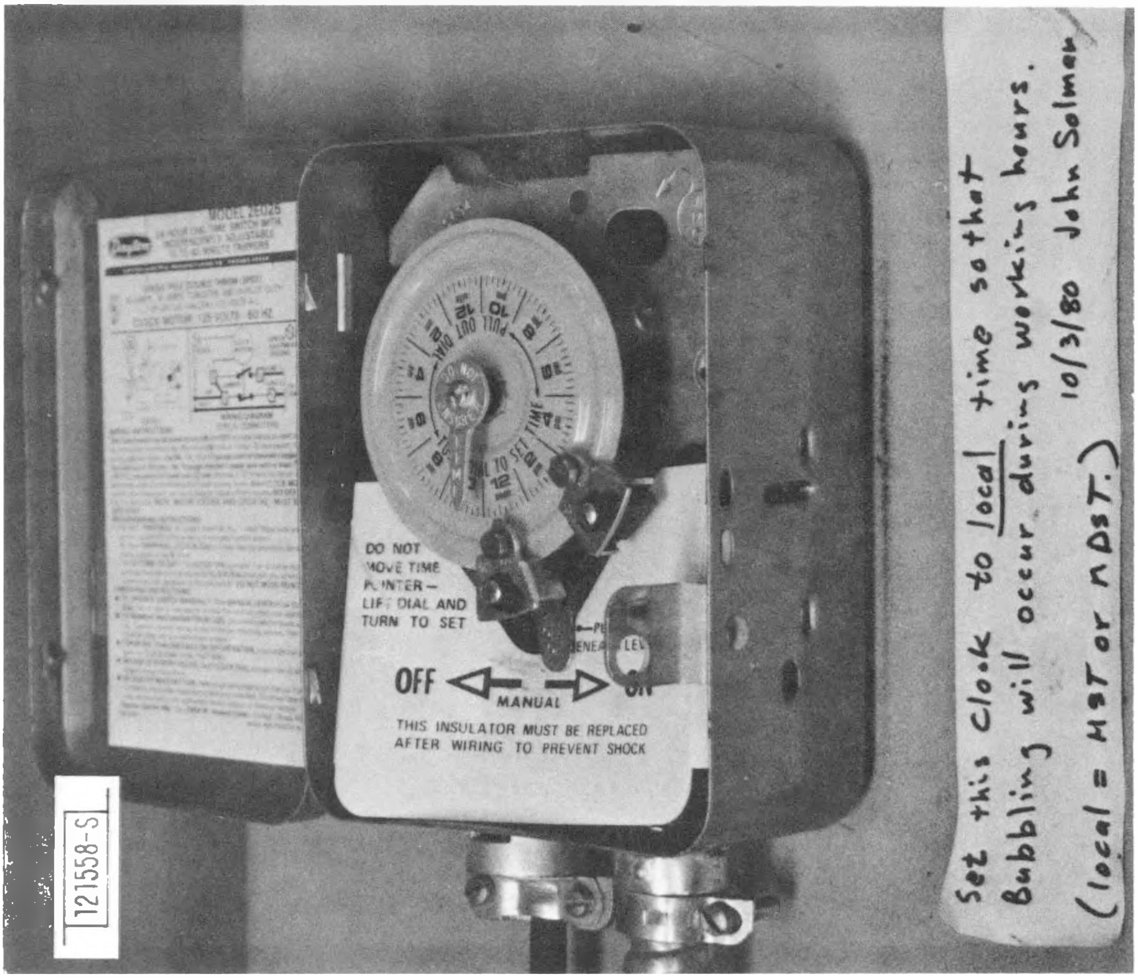

Fig. CP4-4. Mechanical timer air-lift system, Equipment room.

Fig. CP4-5. Battery disconnect switches.

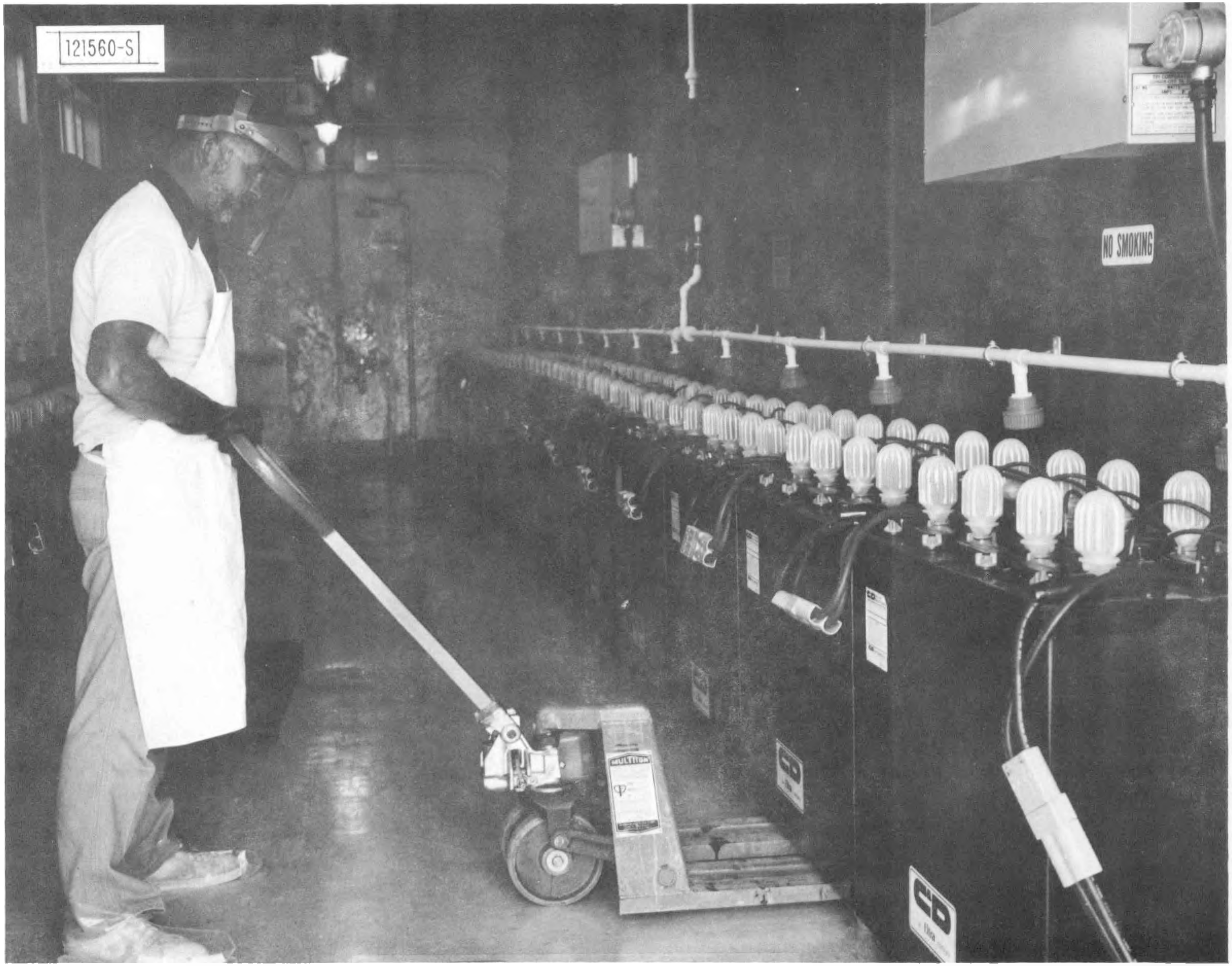

Fig. CP4-6. Battery lifting device.

4.9.2 Drawings*

The drawings included here for the Battery Subsystem are as follows:

1. Battery Room - modified C & D Drawing No. M-7256-1
2. Battery Module - C & D Drawing No. N-1679-2
3. Air-Lift System (NOT FINAL)

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*Site copies only

4.9.3 Maintenance Checklists

The maintenance checklists included here for the Battery Subsystem are as follows:

- Battery Room Monthly Checklist
- Spare Battery Monthly Checklist
- Equalization Records
- Performance Test Records

BATTERY ROOM MONTHLY CHECKLIST

DATE: ______________________ TIME: __________ SIG: ____________

CLEANLINESS	1	2	3	4	5
	(just cleaned)		(dusty)		(grimy)
1. Batteries					
2. Battery Area					
3. Air-Lift Machinery					
4. Eyewash Stations					

OPERATION	1	2	3	4	5
	(fine)		(occasional problems)		(trouble)
1. Vent Fans					
2. Air-Lift Equipment					
3. Eyewash Stations					
4. Shower					
5. Hydrogen Detector (sensors)					
6. Hydrogen Detector (alarms)					
7. Windows (easy open?)					

Please make a note of the following items:

1. Battery room temperature: ____________
2. Cracks in battery cells or casing? ____________
3. Battery electrolyte leakage? ____________
4. Battery terminal or connection corrosion? (See also 14.) ____________
5. Hydrogen recombiners - cracks or breakage? ____________
6. Protective clothing - full supply? ____________

7. Protective clothing - any damage; needs replacement? ____________________

____

8. Insulating equipment - missing or damage? (Flashlight, rubber sheet, shower curtain) ____

____

9. Baking soda supply? (If damp, needs replacing) ________________________

____

10. Battery water supply? ____

____

11. Atmosphere (air) - stuffy? clean? needs airing out? ____________________

____

12. Date of last cleaning: ____

13. Operational CO_2 fire extinguishers available? ______________________

14. Intercell resistance measurements:

2 x 56 small interconnects (0.045 mΩ) = ______________________________

2 x 28 large interconnects (0.059 mΩ) = ______________________________

27 rear (long) wires (0.396 mΩ) = ______________________________

27 front (short) wires (0.279 mΩ) = ______________________________

Further comments and notes:

SPARE BATTERY MONTHLY CHECKLIST

DATE: ______________________ TIME: ______________ SIG: ___________

CELL NO.	1	2	3	4	5	6	7	8
CELL VOLTAGE								
SPECIFIC GRAVITY								
ELECTROLYTE TEMP.								
ELECTROLYTE LEVEL								

Please note date of last thorough cleaning and inspection of the following items, and record comments.

1. Cleanliness? ____

____

2. Cracks in cells or casing? ________________________________

____

3. Electrolyte leakage? ______________________________________

____

4. Terminal or connection corrosion? __________________________

____

5. Hydrogen recombiners - cracks or breakage? _________________

____

EQUALIZATION RECORDS

DATE: ______________________ PERSON RECORDING: ____________________

PERSON READING: ____________________

START TIME OF EQUALIZE: ____________ TERMINAL VOLTAGE (207) __________

FINISH TIME OF EQUALIZE: ____________ FINISH CURRENT (207) __________

START UP

1. Generally, one will have to type in "700 ADD ENTER" to command the microprocessor to start the equalize charge that day.
2. See section 4.6.1 for detailed explanation.

MEASUREMENTS (attach data to this form)

1. During the last hour of the equalize charge, record -
   a. cell voltages (on line)
   b. electrolyte levels (only if low level)
2. At the end of charge, restart the generator and secure the PV system using the latest Procedures.
3. After disconnecting the battery, record -
   a. cell specific gravities
   b. cell temperatures (pilot cells only)

COMPLETION

1. Start up the PV system and shut down the generator using the latest Procedures.
2. Check all appropriate switches and controls.
3. Send this form along with the data sheets to MIT Lincoln Laboratory.
4. Clean battery equipment and lock up Battery room.

PERFORMANCE TEST RECORDS

DATE: ____________________ SIGNATURE: ______________________________________

1. Record average specific gravity, cell voltage (on charge), and cell temperature at end of equalizing charge before test discharge. (Use pilot cells.) Attach records to this form.

2. Determine (calculate) the average discharge current and time taken to reach the end voltage:
current = __________________ Amps ; discharge time = ____________ hrs.

3. Calculate the energy removed from the battery from the parameters in step 2.
________ Amps x ________ hrs. = __________________ AH removed.

4. Determine (calculate) the average charge current and time taken to reach full charge:
current = ______________ amps; charge time = ____________ hrs.

5. Calculate the battery round-trip efficiencies:

$$\eta_{voltage} = \frac{\text{Average discharge voltage}}{\text{Average charge voltage}}$$

$$\eta_{AH} = \frac{\text{AH removed}}{\text{Average charge current x charge time}}$$

$$\eta_{energy} = \eta_{AH} \times \eta_{voltage}$$

DATE ______________ TIME ______________ NAMES ______________

S.G.* - Hydrometer(s) used: ______________ TEMP. CORR. FACT.: ______________

CELL* VOLTAGE - Meter used: ______________

STATE OF BATTERY (SOC): ______________

*CIRCLE CORRECT READINGS

MODULE		CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8
1	9C00624								
2	599								
3	604								
4	611								
5	615								
6	613								
7	609								
8	605								
9	618								
10	616								
11	621								
12	620								
13	614								
14	626								
15	601								
16	622								
17	607								
18	600								
19	608								
20	617								
21	606								
22	603								
23	625								
24	619								
25	623								
26	610								
27	602								
28	612								

5.0 DIESEL GENERATOR CONTROL SYSTEM

The diesel engine generator control can be separated into three main functions:

(1) Engine safety shutdown circuits which prevent or terminate engine operation if engine cranks too long and fails to start, oil pressure failure, engine coolant overheat, engine over-speed, or coolant level low.

(2) Starting/cranking sequence.

(3) Oil pressure monitoring time delayed enable.

5.1 Detailed Description (Figures 5-1 through 5-3)

The 24-volt battery is trickle charged by the battery charger. The charger is powered by site power so the battery is always charged, even when the generator is not running. In MANUAL (2) position (S1, sheet 1), 24 volts is applied to MCR pin 7. MCR will be energized if all the following relays are not energized:

(1) OCF, overcrank failure

(2) OPF, oil pressure failure

(3) WTF, water temperature failure

(4) OSF, overspeed failure

(5) WLF, water level failure

The "red" bus has 24 volts applied through D1 which applies power through MCR 1/3 (sheet 2) to the white/red bus. The engine gauges are now powered as well as the electronic throttle control and fuel solenoid. Power is routed through CR 1/4 and ACR 1/4 to the engine auxiliary crank solenoid. This starts the engine cranking. Power through D8 illuminates DS8 and energizes MOCT. MOCT ground return is supplied through D9 and MCR 6/8. If the engine does not start within 10 seconds, MOCT latches via 5/7. This grounds OCF 2 via D11. OCF 6/8 completes a latch function and MCR is deenergized, stopping all action. DS2 remains illuminated as a telltale indication. Switch S1 must be cycled to OFF then ON again to try again.

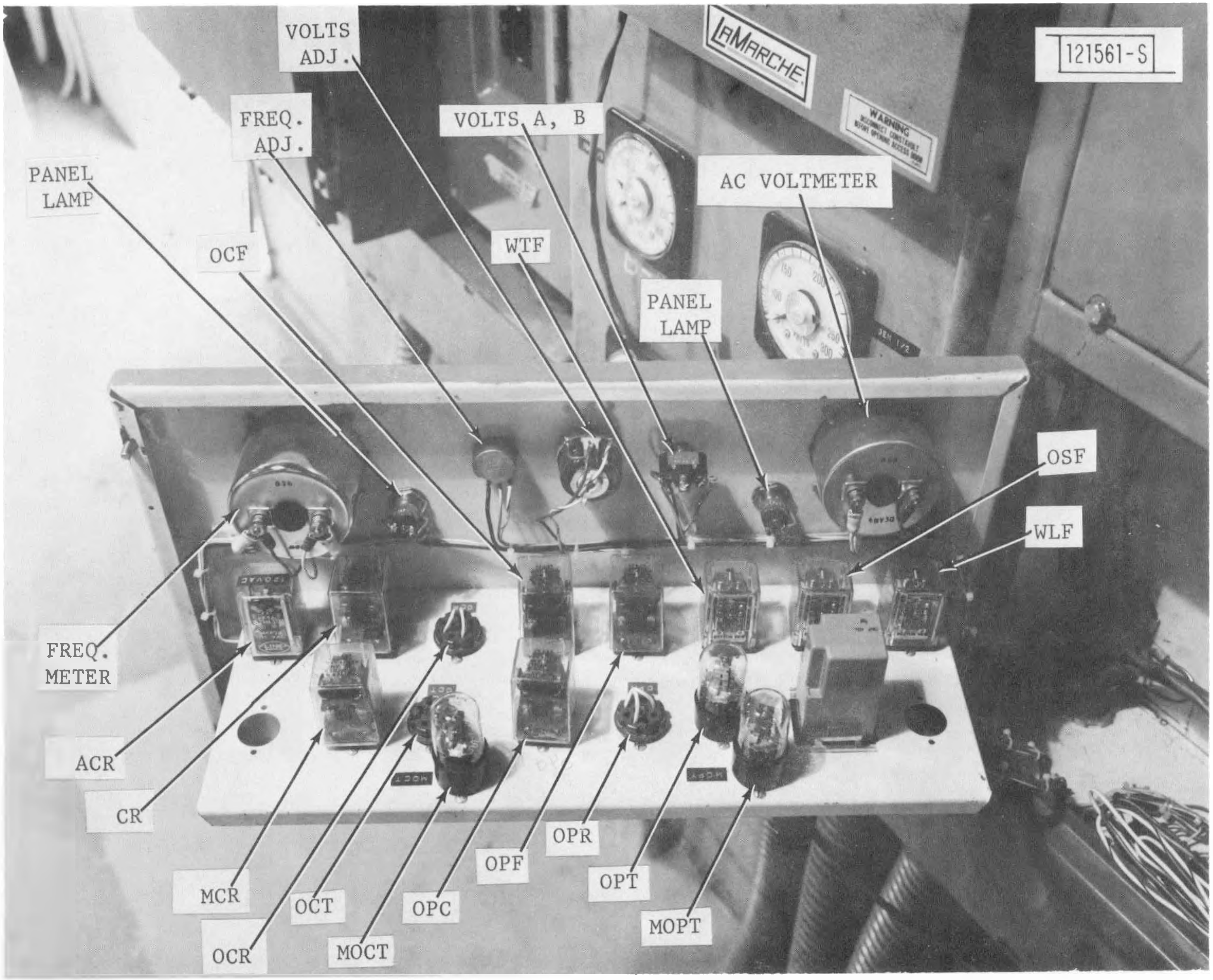


Fig. 5-1. DPG control panel—controls and relays.

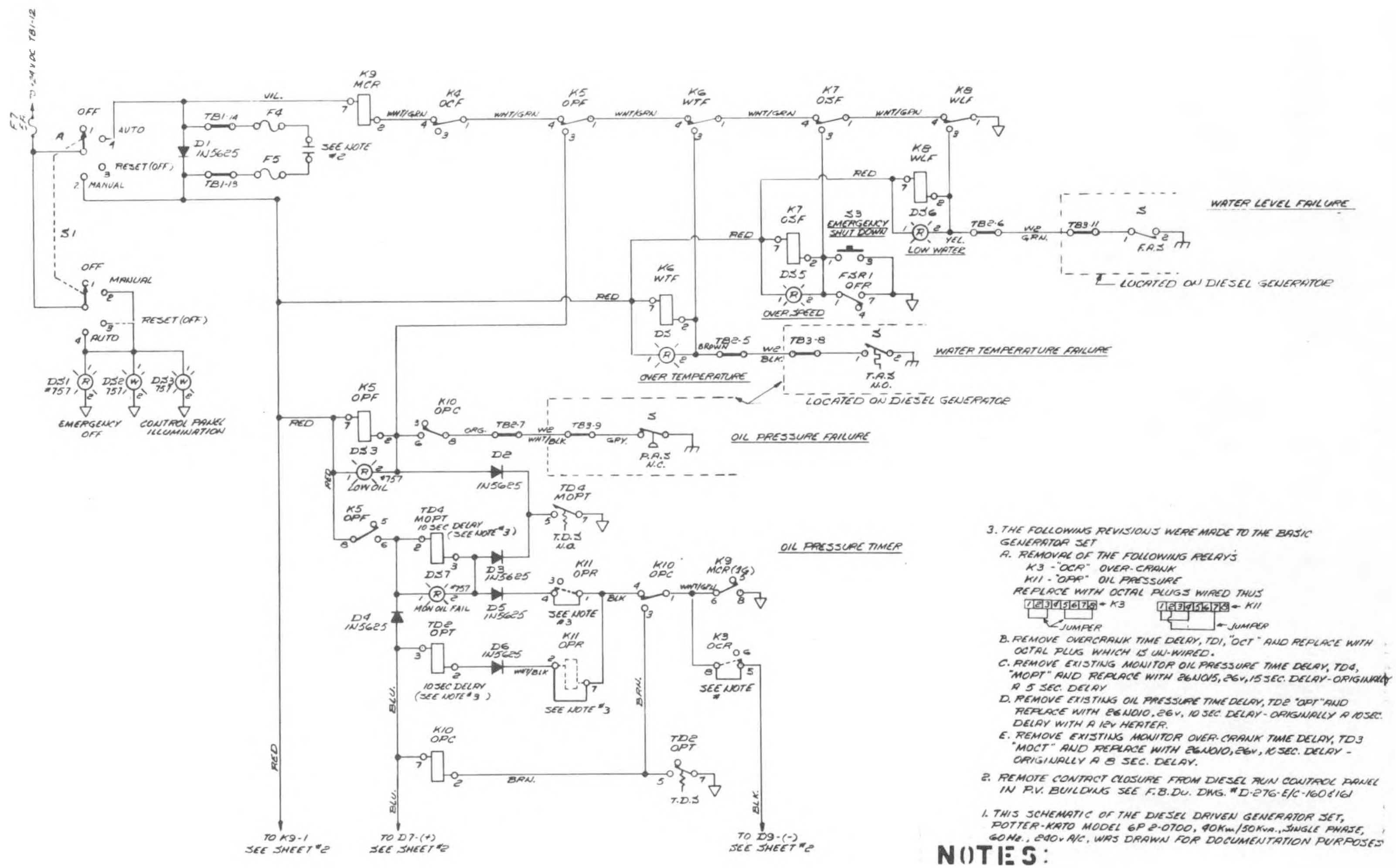


Figure 5-2. Diesel Generator Schematic, Part 1.

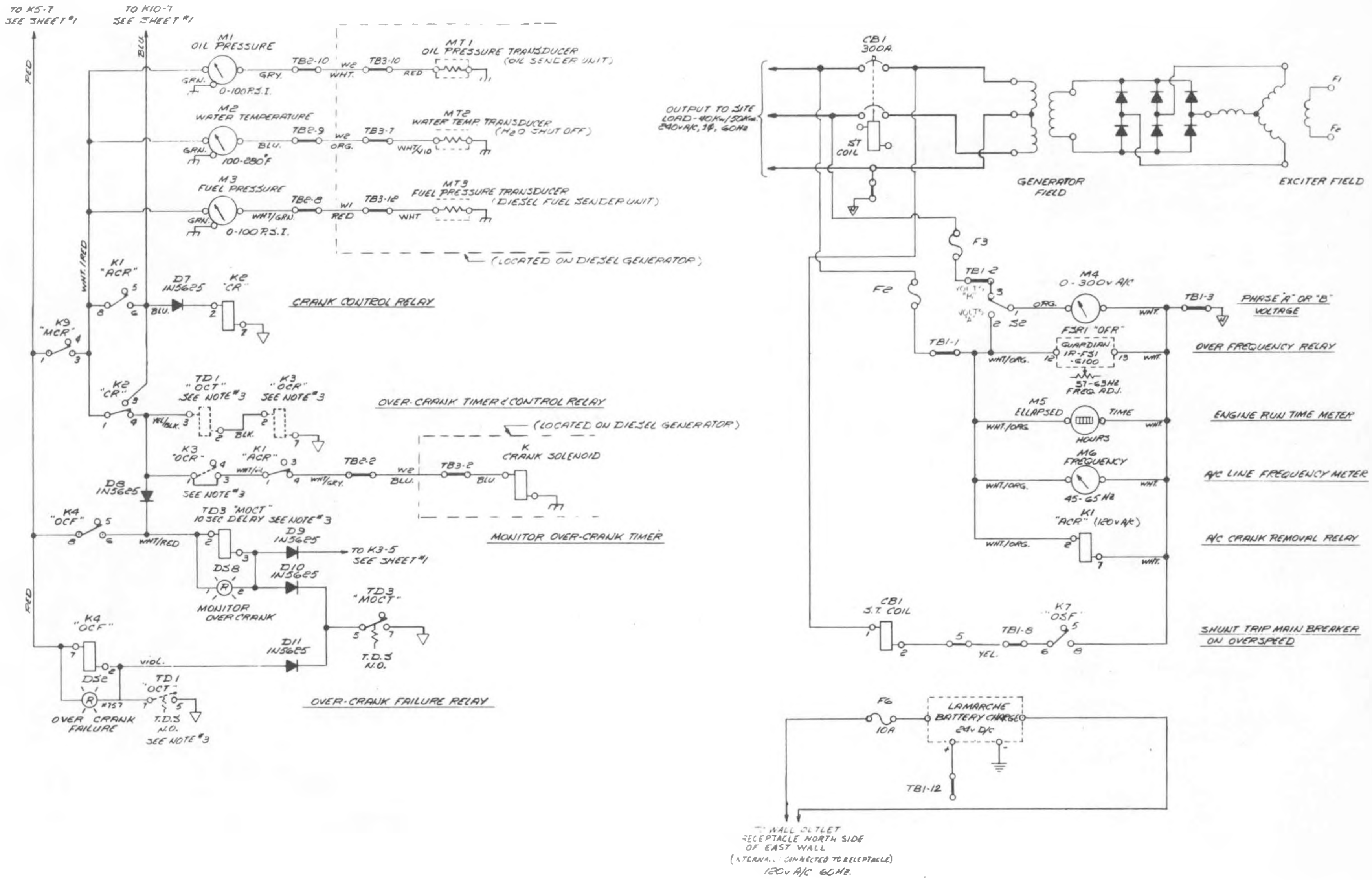


Figure 5-3. Diesel Generator Schematic, Part 2.

If the engine starts, ACR senses that there is generator output voltage and powers the "blue" bus via ACR 6/8. This activates CR via D7 which latches via CR 1/3. CR 1/4 opens and power is thus removed from the crank solenoid and MOCT. The CR latch action is required in case a transient undervoltage caused possibly by a motor start momentarily drops out ACR (or generator field is turned off) causing the running engine to momentarily crank. OPT (sheet 1) and DS7 now have power via "blue" bus and it times to 10 seconds before energizing OPC which latches via OPC 1/3 and removes power from the timers and DS7. OPC 6/8 enables the oil-pressure failure-sense circuitry. The time delay is required to allow buildup of oil pressure, otherwise OPF would immediately stop the engine. If OPT or OPC fail, MOPT times out in 15 seconds, latches via MOPT 5/7 and stops the action via OPF with both DS3 (monitor oil pressure) and DS7 (low oil) left as telltale indications.

Low water level energizes WLF, stops the engine, latches via WLF 1/3 and leaves DS6 (low water) illuminated for the telltale indication. Water overtemperature energizes WTF which stops the engine, latches via WTF 1/3. DS (overtemperature) remains illuminated for the telltale indication. Overspeed or emergency shutdown button energizes OSF which stops the engine, and latches via OSF 1/3. DS5 (overspeed) remains illuminated as a telltale indication and CB1 is tripped.

S1 AUTO position only powers the "red" bus. External contacts across D1 then remotely control MCR and the engine. RT is used for remote trouble indication. As long as none of the failure relays is actuated and S1 is in MANUAL or AUTO position RT remains energized. Any failure deenergizes RT whether or not the engine is running.

5.2 Service Tips

If the engine will not crank, check DS (overtemperature lamp) or DS6 (water level failure lamp). These are the only two items which can inhibit a crank sequence. If this is not the trouble, DS8 the CRANKING lamp will indicate if MCR has been energized. If not, visually and aurally (relay click) check for MCR motion inside the plastic case as S1 is cycled ON-OFF. If DS8 illuminates, check for voltage at TB2-2. If it is there, the trouble is at the engine.

If the engine cranks, starts and then is automatically shut off, check DS7 (low oil) and DS3 (monitor oil pressure). If both remain illuminated, the OPT has failed; check timing which should be 15 seconds. If only DS3 is illuminated, the engine has lost oil pressure; time to shutdown should be 10 seconds from when cranking lamp extinguishes.

F2 and F3 are located behind the frequency meter on the partition which separates the top and bottom sections of enclosure. If F2 is opened for any reason, the elapsed time meter, frequency meter, phase B voltage and ACR will not receive power. If ACR does not receive power, the engine starter motor will not stop after the engine starts. This has occurred once resulting in burnout of the crank solenoid. The overcrank timer should have prevented this occurrence but did not because of design deficiencies which have been corrected. If F2 is blown, the engine will start and run but MOCT will stop the engine in 10 seconds. Note that the crank solenoid is not the solenoid mounted on starter motor. It is a Ford-type starter relay (but 24-V coil) located in the generator-mounted junction box (the throttle control electronics is also located here). Failure of this crank solenoid saved the starter motor from complete destruction.

5.3 Functional Test of Failure Switches and Lamps

With the engine running, a temporary jumper across F.A.S., T.A.S. or P.A.S. should stop the engine and illuminate the appropriate indicator, thus checking those lamps. Pressing the emergency stop should stop the engine-illuminate DS5 (overspeed lamp). Low oil and overcrank failure lamps are checked each time the engine is started.

TABLE 5-1

Diesel-Driven Generator Set DPG Control Panel
List of Relays and Functions

NOTE: All relays and timers are 24- or 26-volt coils.

Relay	Function
ACR	Ac crank removal relay. Energized when there is voltage output from the generator. Used to stop the engine from cranking and energize CR.
CR	Crank removal relay. Latches when energized by ACR. Guarantees that engine cranking stops and MOCT is deenergized. Starts OPT timing.
OCF	Overcrank failure relay. Latches when energized by MOCT and stops engine cranking until reset.
OPF	Oil pressure failure relay. Turns off engine and latches when energized by pressure actuated switch (P.A.S.) after being enabled by OPC.
WTF	Water temperature failure relay. Stops engine and latches when energized by temperature actuated switch (T.A.S.).
OSF	Overspeed failure relay. Stops engine and latches when energized by OFR or emergency shutdown button.
WLF	Water level failure relay. Stops engine and latches when energized by float-actuated switch (F.A.S.).
MCR	Master control relay. Initiates engine start sequence when energized. Stops engine when deenergized.
OPC	Oil pressure control relay. Enables oil pressure failure function when energized by OPT.
OPT	Oil pressure timer. Times 10 seconds after cranking stops to enable oil pressure failure circuits.
MOCT	Monitor overcrank timer. Stops engine cranking if engine has not started within 10 seconds.
MOPT	Monitor oil pressure timer. Shuts down engine if OPT has not enabled the oil pressure failure circuitry within 15 seconds.

TABLE 5-1 (Continued)

Relay	Function
OFR	Overfrequency relay. Closes a contact to stop engine if speed is excessive.
RT	Remote trouble relay If deenergized, to indicate a failure to the computer in the PV building whenever any failure relay is actuated. (Not yet connected to PV building.)
OCR	See Lincoln Laboratory Drawing D75717, Note 3 for MIT Lincoln Laboratory supplied replacement jumper plug
OPR	See Lincoln Laboratory Drawing D75717, Note 3 for MIT Lincoln Laboratory supplied replacement jumper plug
OCT	See Lincoln Laboratory Drawing D75717, Note 3 for MIT Lincoln Laboratory supplied replacement jumper plug (purposely left unwired)

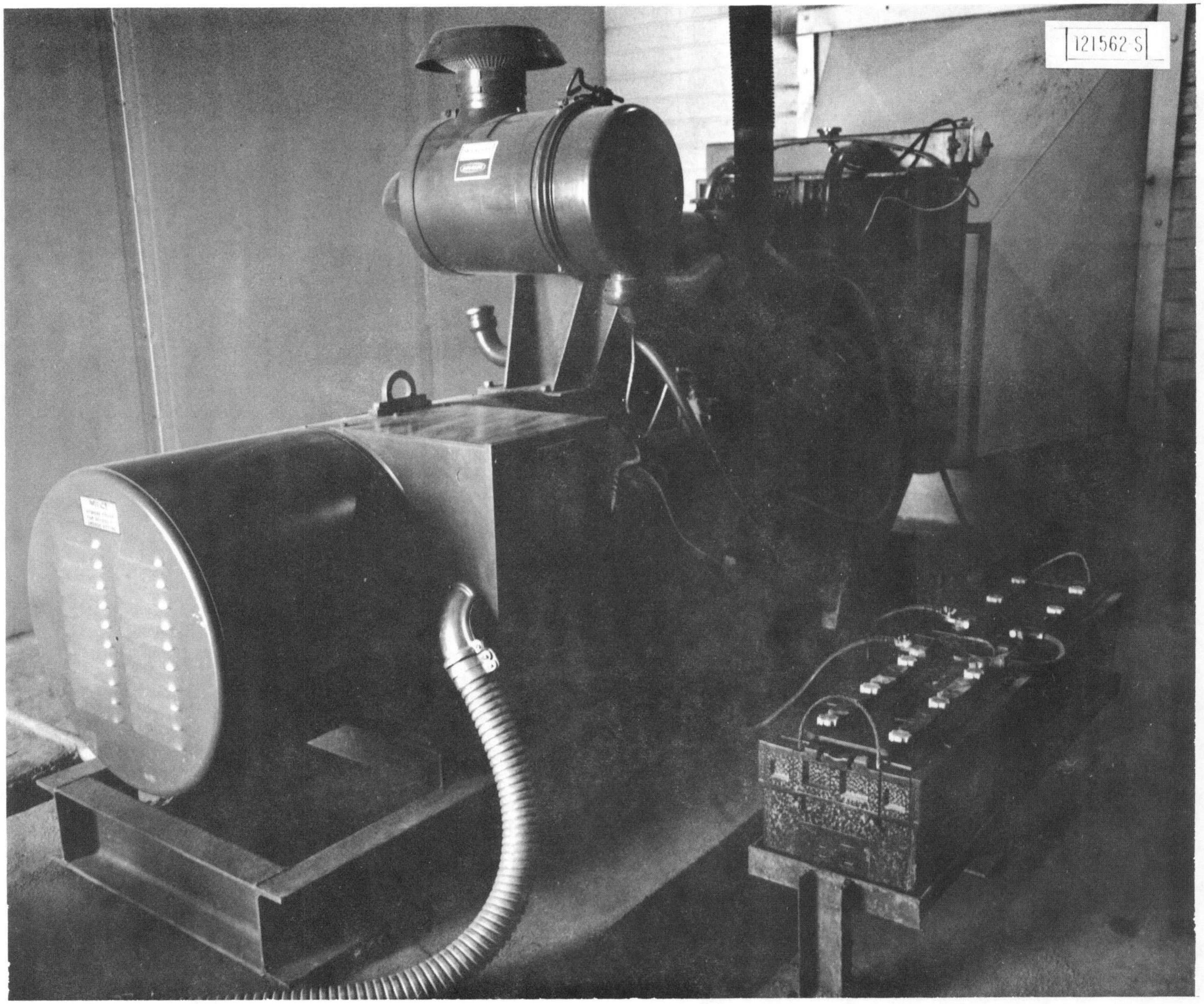


Fig. CP5-1. Diesel generator unit 301.

6.0 SITE TRANSFER SWITCH

6.1 General

The site transfer switch provides a means of distributing power to the site loads from one of the two power sources: PV power as provided by the main inverter and backup power as provided by the diesel-powered generator (DPG).

The site transfer switch was designed to provide the following capabilities:

a. It prevents the two power sources being applied to the site loads simultaneously.
b. It enables local and remote operation from both the generator bulding and the PV building, respectively.
c. It can disconnect the site loads from either or both power sources.

6.2 Description

The site transfer switch comprises a double-throw transfer switch and control circuit power stepdown transformers (240:120 Vac) mounted in a NEMA Type 12 enclosure as shown on Figs. 6-1 through 6-4. Figure 6-5 depicts the control circuit diagram. Site copies of this book are furnished with drawing D-75718.

The automatic double-throw transfer switch is composed of two reversing starter contactors (NEMA size 5-K1A & K1B) mounted adjacent to each other as shown on Fig. 6-5. A mechanical interlocking mechanism joins both contactors to prohibit both contactors from operating simultaneously, thus preventing closing of the circuit between the site load and both power sources. Each contactor is actuated by its own operating coil, which operates at 120 Vac, 60 Hz, and each includes two normally open/closed auxiliary contact pairs (K1A & K1B), which are used for the electrical interlocking function, prohibiting the simultaneous electrical operation of the contactor's operating coils (Fig. 6-5). The function of the other contact pairs (K1A2 & K1B2) is to provide a means of indicating the operational position of the transfer switch. For example, if the site loads are operating from the PV power source, the indicator lamp DS1, INVERTER, will become illuminated.

Control transformers T1 or T2 provide the individual contactor's coil power and the power required by the control circuits, depending on the power source. These transformers are standard control circuit stepdown transformers, rated at 350-volt-amp (3325 volt-amp inrush capacity) which steps down the 240-Vac supply voltage to 120 Vac for use in the control circuit. Type MDX3 fuses provide overcurrent protection for the control circuits.

6.3 Operation

The site transfer switch may be operated in one of three ways (Figs. 6-1 through 6-5) by key switch S1:

a. PV BLDG. - Remote control operation of the site transfer switch from the PV building.
b. OFF - Maintenance operation from the generator building.
c. GEN. BLDG. - Local operation of the site transfer switch from the generator building.

NOTE

Normally, key switch S1 is kept in the GEN. BLDG. position.

Figure 6-1. Site transfer switch with control unit
Units 306 and 306A.

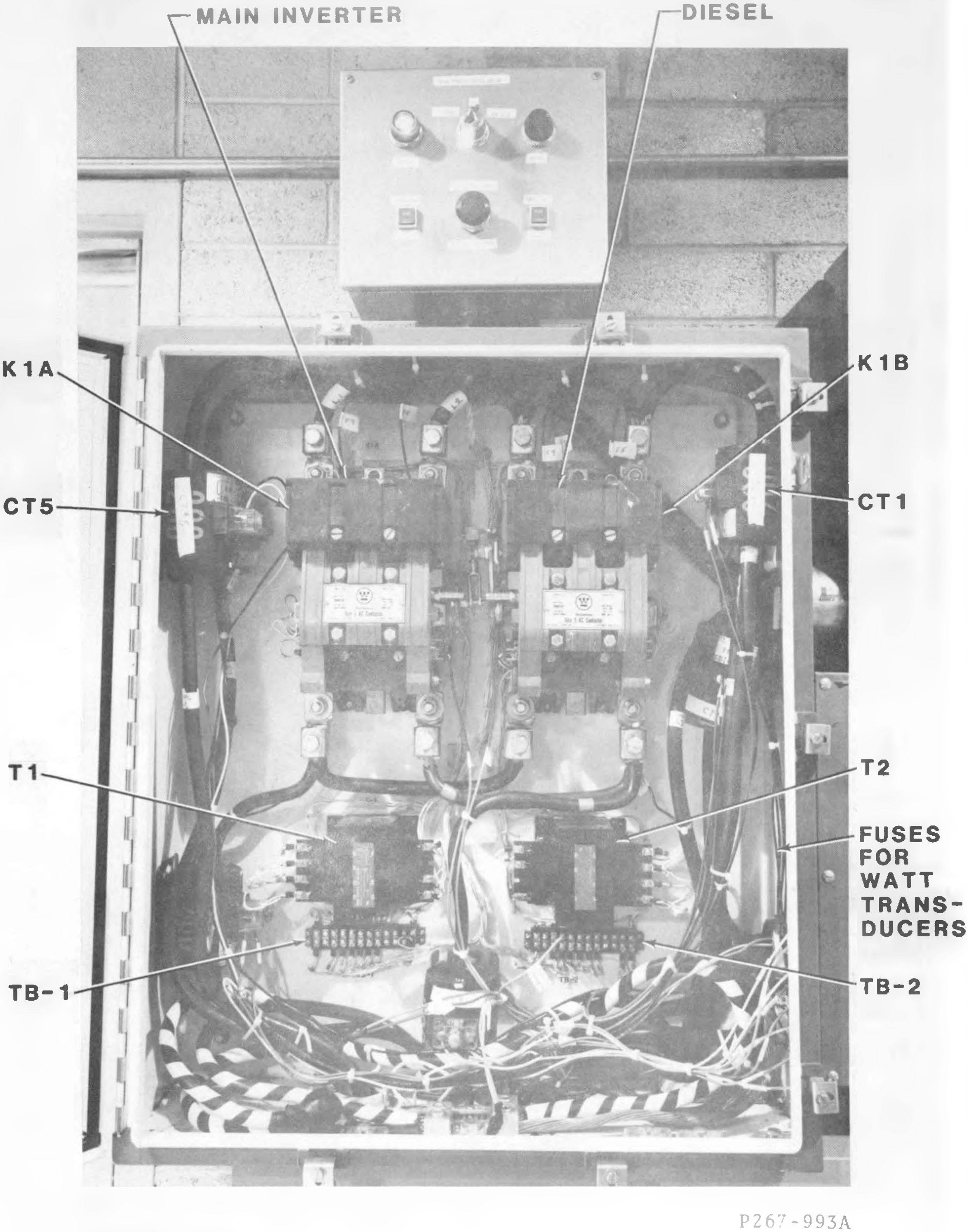


Figure 6-2. Site transfer switch, inside view.

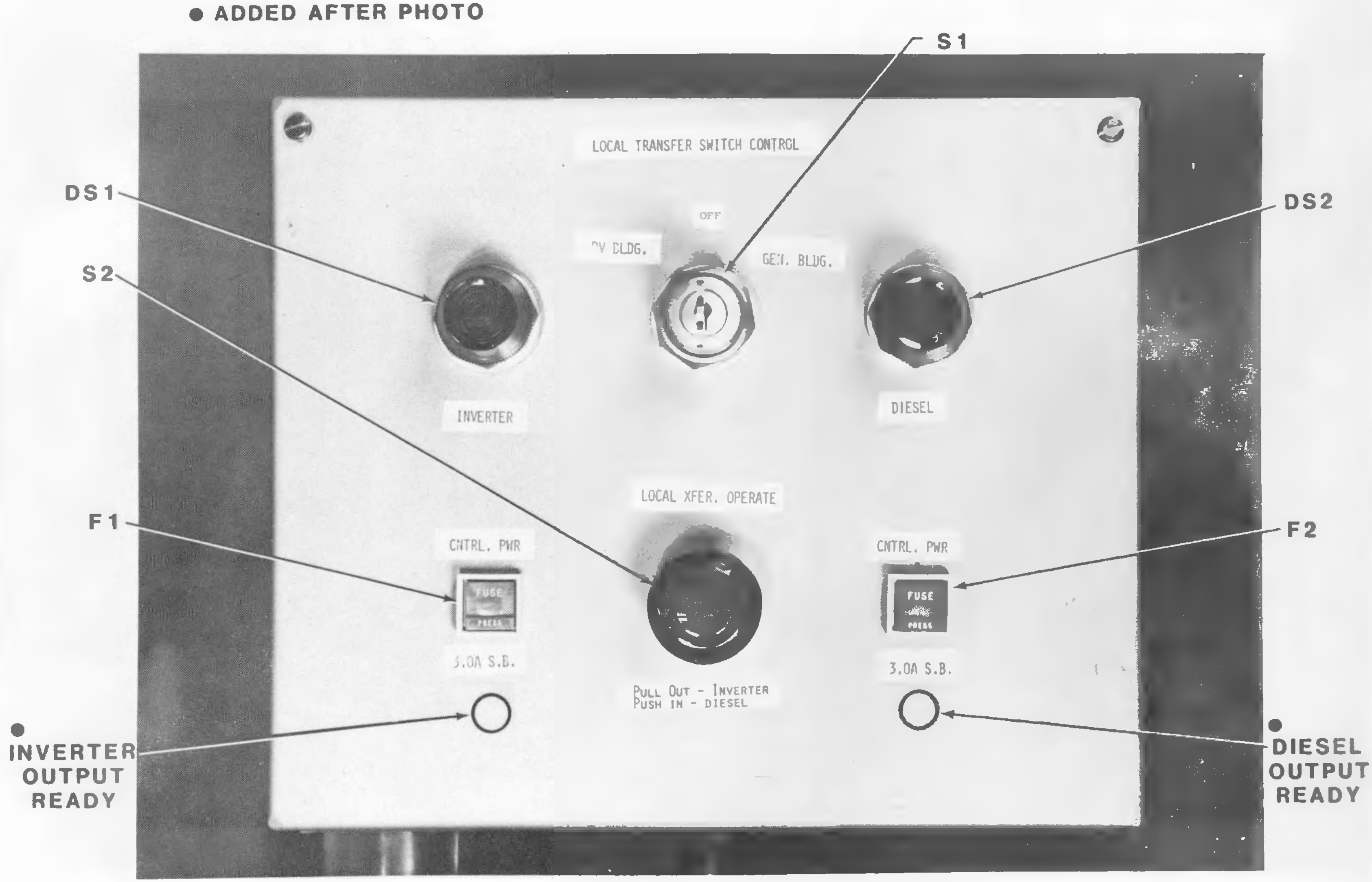


Figure 6-3. Site transfer switch contorl unit.

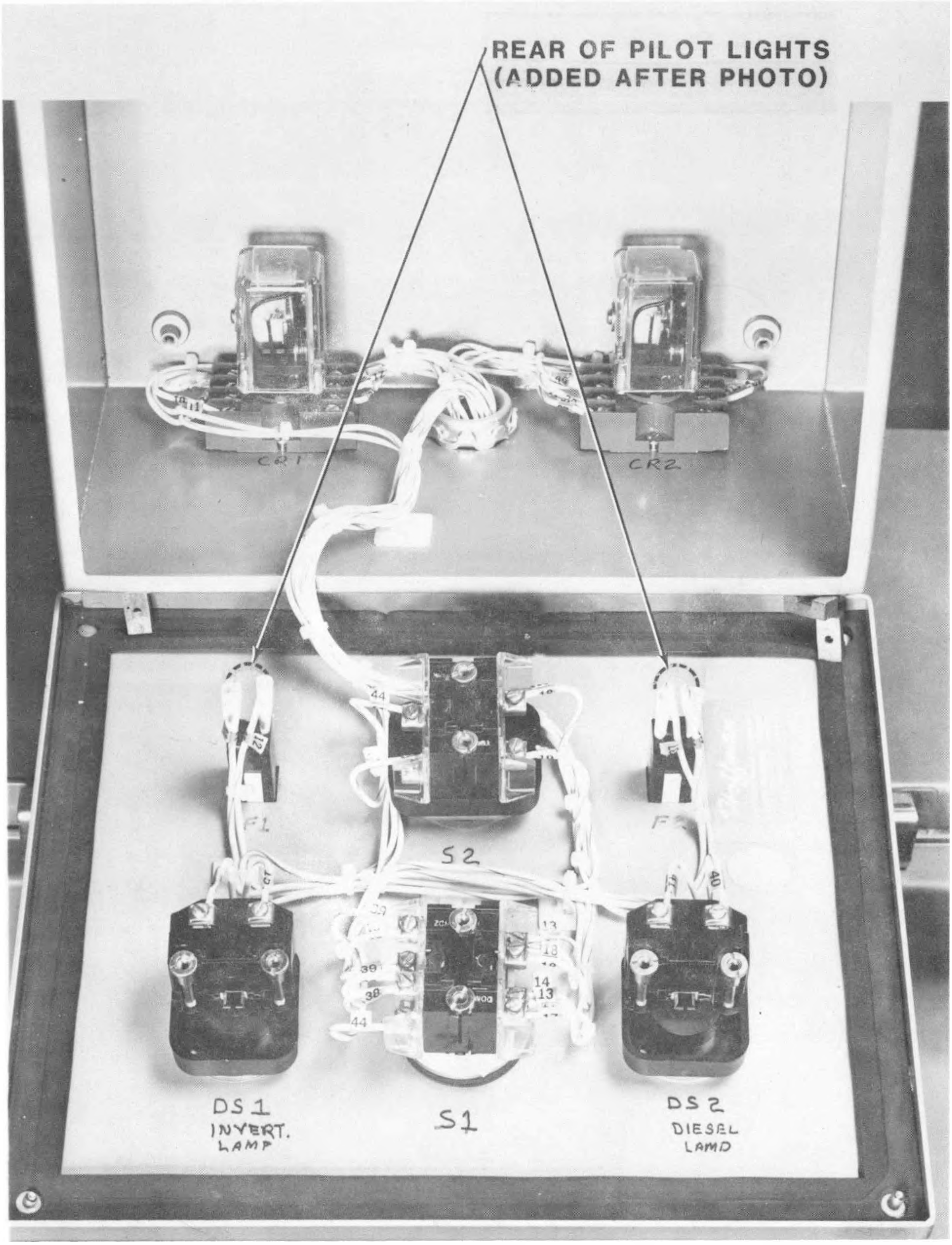


Figure 6-4. Site transfer switch control unit, inside view.

C74-1729

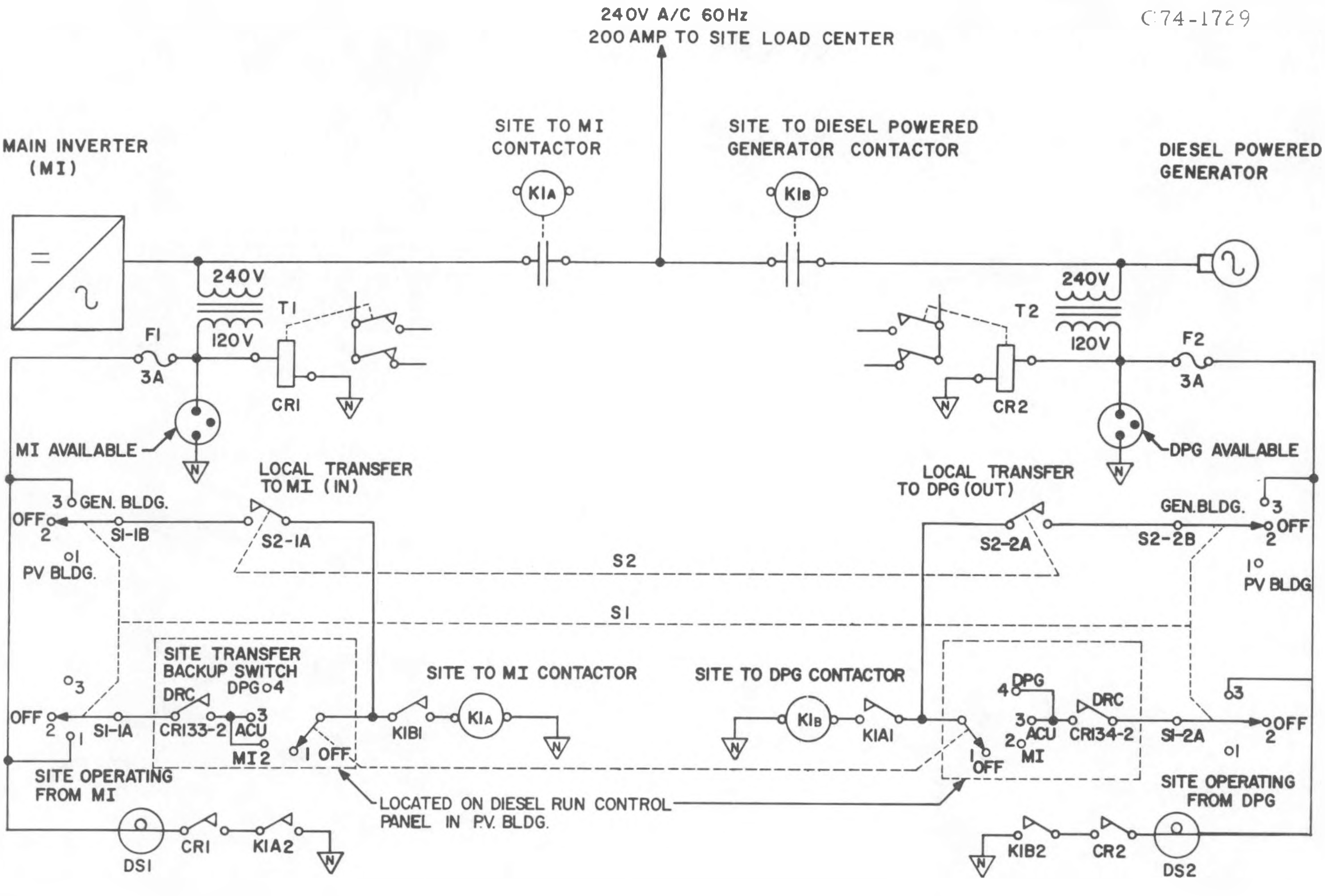


Figure 6-5. Site transfer switch control circuit diagram.

In the PV BLDG. position, the operational control of the site transfer switch is managed by the operating system in the PV building. In the OFF position, the site transfer switch provides electrical isolation between the site loads and either of the two power sources for any electrical maintenance required on the site loads side of the site transfer switch. In GEN. BLDG. position, the operation of the site transfer switch is made by the operator in the generator building.

If the load transfer is to be made with the site transfer switch on the GEN. BLDG. position, the operator must first select which power source is to be used. This is accomplished by means of the LOCAL XFER. OPERATE switch S2 (Figs. 6-1 & 6-3) which is pulled out for inverter operation and pushed in for DPG operation.

CAUTION

> The site transfer switch should not be used to transfer loads from the DPG to PV without first switching off all motor loads that might be running by using the switches in the site load center. A few seconds (5-10) should be allowed for the motors to stop before transferring the site. This procedure is a normal part of the startup procedure for the PV system; in this way the main inverter is protected against damage from high current surges resulting from the back EMF of a running motor not being in synchronism with the new applied voltage.

6.4 Operational Cycling

Prior to transferring the site from DPG to PV, a cycle-down sequence of the site loads should be initiated by placing the circuit breakers located in the main distribution panelboard on the west wall of the generator building to their OFF positions.

After transfer to the PV power source has been completed and the site transfer switch lock is engaged (Fig. 6-5), a cycle-up sequence should be initiated. This is the reverse of the cycle-down sequence, except for the sequence of placing the circuit breakers to their ON positions; the circuit breakers associated with the pump motors in the maintenance shop and the voltage step-up transformers supplying the visitor center should not be placed on their ON positions until after all other circuit breakers have been placed on their ON positions.

Then place the circuit breaker associated with the pump motors in the maintenance shop to its ON position. Wait about a half minute and place the circuit breaker associated with the voltage step-up transformer to its ON position.

The reason for this delay is to accommodate the high inrush currents required by these loads and to allow enough time for the PV inverter to absorb any current surges caused by the electric pump motors or the step-up transformers. These power surges cause the inverter to current-limit momentarily, lowering the output voltage to below the threshold (80% of normal) required to maintain the site transfer switch holding coil in place.

To transfer the site from PV to DPG power, the site transfer switch lock must be released, as noted in Para. 6.5 below.

6.5 Site Transfer Switch Lock

A year after the site became operational the site transfer switch began to occasionally "chatter" (rapid opening and closing of the contacts) when the PV inverter became current limited.

Analysis of this phenomenon showed that if the current surge is large enough to cause the ac output voltage to drop below 200 Vac, the main inverter contactor k1A opens. Without the load on contactor K1A, the inverter output returns to normal, reclosing contactor K1A. If the overload condition is still present, contactor K1A will open and then close repeatedly, causing the "chatter" to persist.

This contact "chatter" can cause large current surges that can damage the main inverter. To prevent this, a mechanical locking device has been devised and installed in the site transfer switch. Follow the procedures indicated below after completing the operational cycling procedures in Par. 6.4.

6.5.1 Site Transfer: DPG to PV

a. Pull out green knob on Unit 306A to put site transfer switch in position.
b. Open door of the site transfer switch (Unit 306) and push in site transfer switch lock knob and turn 90 degrees to the right to engage lock for PV contactor.
c. Close door to press locking device against PV contactor. Latch door shut.

6.5.2 Site Transfer: PV to DPG

a. Open door of site transfer switch and release site transfer switch lock by turning knob 90 degrees to the left. The knob should then protrude approximately one inch.

b. Close door of site transfer switch.
c. Push in green knob on Unit 306A to transfer the site from PV to DPG.

CAUTION

The site cannot be transferred from PV to DPG without releasing the site transfer switch lock. Follow the procedures provided above, or, in an emergency, open the site transfer switch door (Unit 306) to disengage the site transfer switch lock.

6.5.3 Testing Site Transfer Switch Lock

The function of the site transfer switch lock should be tested periodically (with the site on PV) by shutting off all loads except the generator building lights and pushing in the control power fuse (F1) on unit 306A (as if to remove it). If the lock is working properly, a thump will be heard as the PV contactor in Unit 306 releases, but the lights will not blink. If the lights blink, the lock must be readjusted.

The contact "chatter" problem could be alleviated in the future by employing a manual transfer switch without contactors, or providing a backup power supply to prevent current surges and the resultant contact "chatter".

7.0 IN-RUSH CURRENT CONTROL UNIT

7.1 General

The in-rush current control unit provides a series resistance of 2.2 ohms (R1) into the primary side (240 VAC) of the step-up transformer that supplies the visitor's center feeder. This resistor is used to increase the rate of decay of the in-rush current supplied by the site inverter, reducing the current burden of the inverter, which is current-limited to approximately 200 amps. When this transformer is energized, there is an initial in-rush of current that may be on the order of ten times the rated current of the transformer for about one-half second. Refer to Figs. 7-1 and 7-2.

7.2 Unit Description

When ac voltage is applied through CB6 and CB9 (located in panel board P, Unit 304), control relay K4 energizes the coil of power contactor K1B, which connects the 2.2-ohm resistor in series with the 240-volt primary of the 25-kVA step-up transformer feeding the visitor's center circuit. Two auxiliary contacts are associated with this contactor: one latches the power contactor's coil ON; the other initiates a zero-to-one second timer (K2). At the end of the predetermined time delay (0.5 seconds) the time-delayed relay contacts close, energizing power contactor K1A; its power poles are wired in parallel with the 2.2-ohm resistor to shunt current around the resistor. Two auxiliary contacts are also associated with this contactor: one latches the power contactor's coil ON; the other, a "late breaking" contact prevents an "open-circuit" transition when power contactors K1B and K1A are turned ON and OFF.

An overtemperature sensing circuit senses when resistor R1 is too hot. This sensor, mounted on a bracket adjacent to the resistor, will sense a high temperature of 160°F, which would occur if shunting contactor K1A failed to energize. At 160°F, the overtemperature switch will close, latching control relay K3 ON thereby de-energizing both power contactors (shutting down the visitor's center feeder circuit) and turning ON the overtemperature indicator light.

The in-rush control unit may be reset using the reset switch S2 provided the temperature sensor has reached its lower limit reset temperature of 140°F. Refer to Section 10.0 for related information.

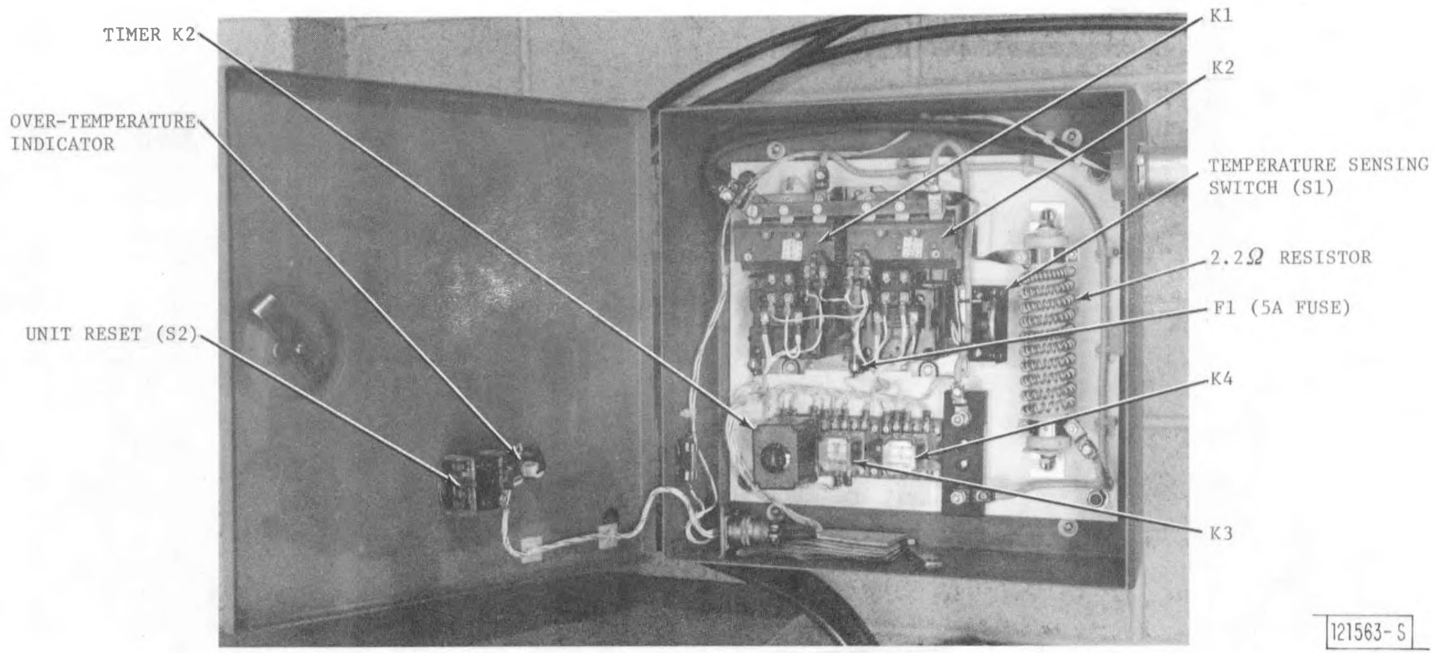


Fig. 7-1. Transformer in-rush control box (Unit 311).

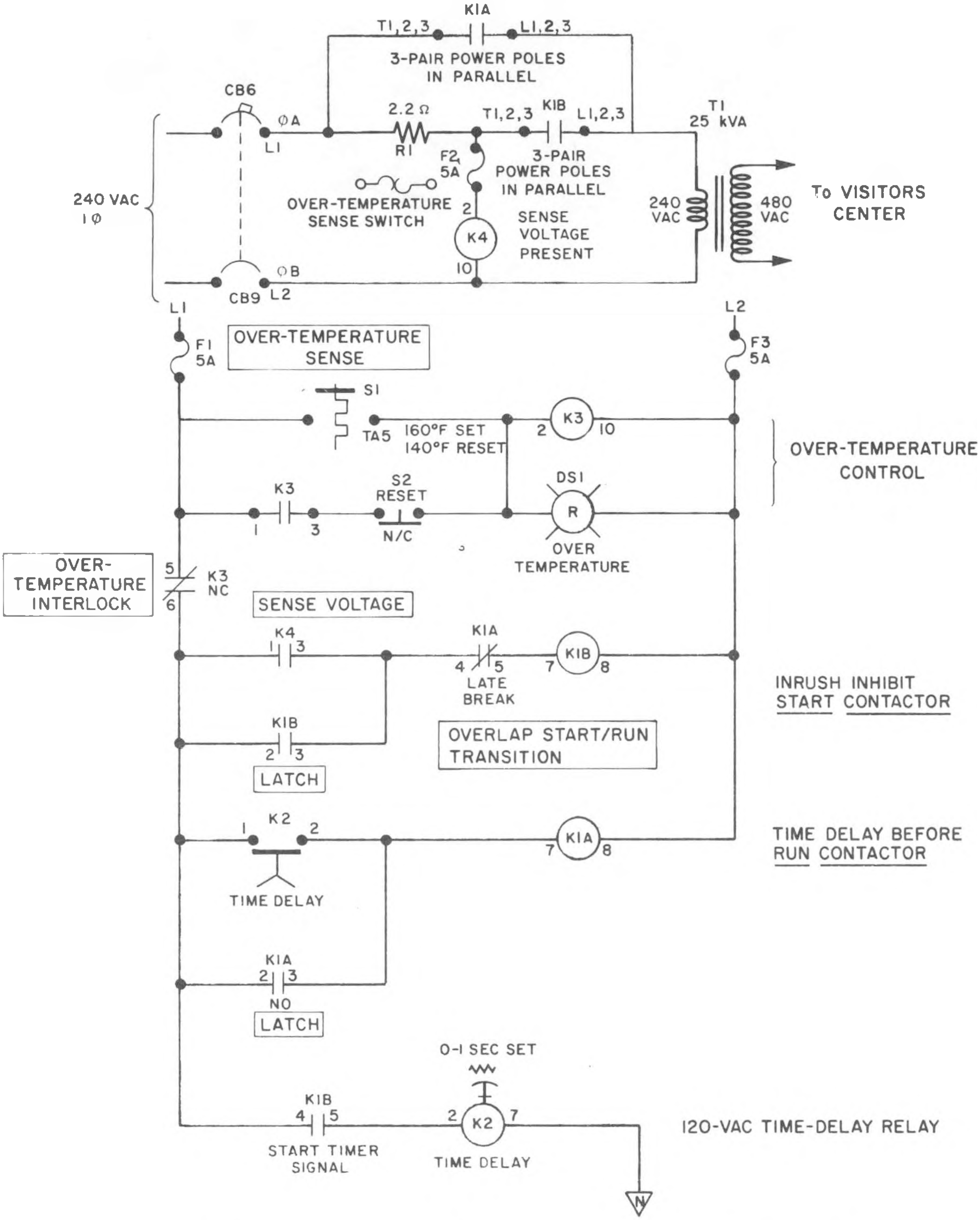


Figure 7-2. In-rush current control unit, schematic

8.0 SEARS ELECTRIC FURNACE

The Sears electric furnace is used as a resistive load to discharge batteries or to provide a load for inverter testing.

The furnace elements have been rewired to permit front panel toggle switch control of the heating elements, as shown in Fig. 8-1. The toggle switches control thermal relays that switch power to the furnace resistance elements. There is a 20- to 30-second delay from the time an element is selected ON or OFF until that element is actually switched.

On-site copies of this manual contain a copy of the Sears instruction manual. All other copies contain a reproduction of the cover page.

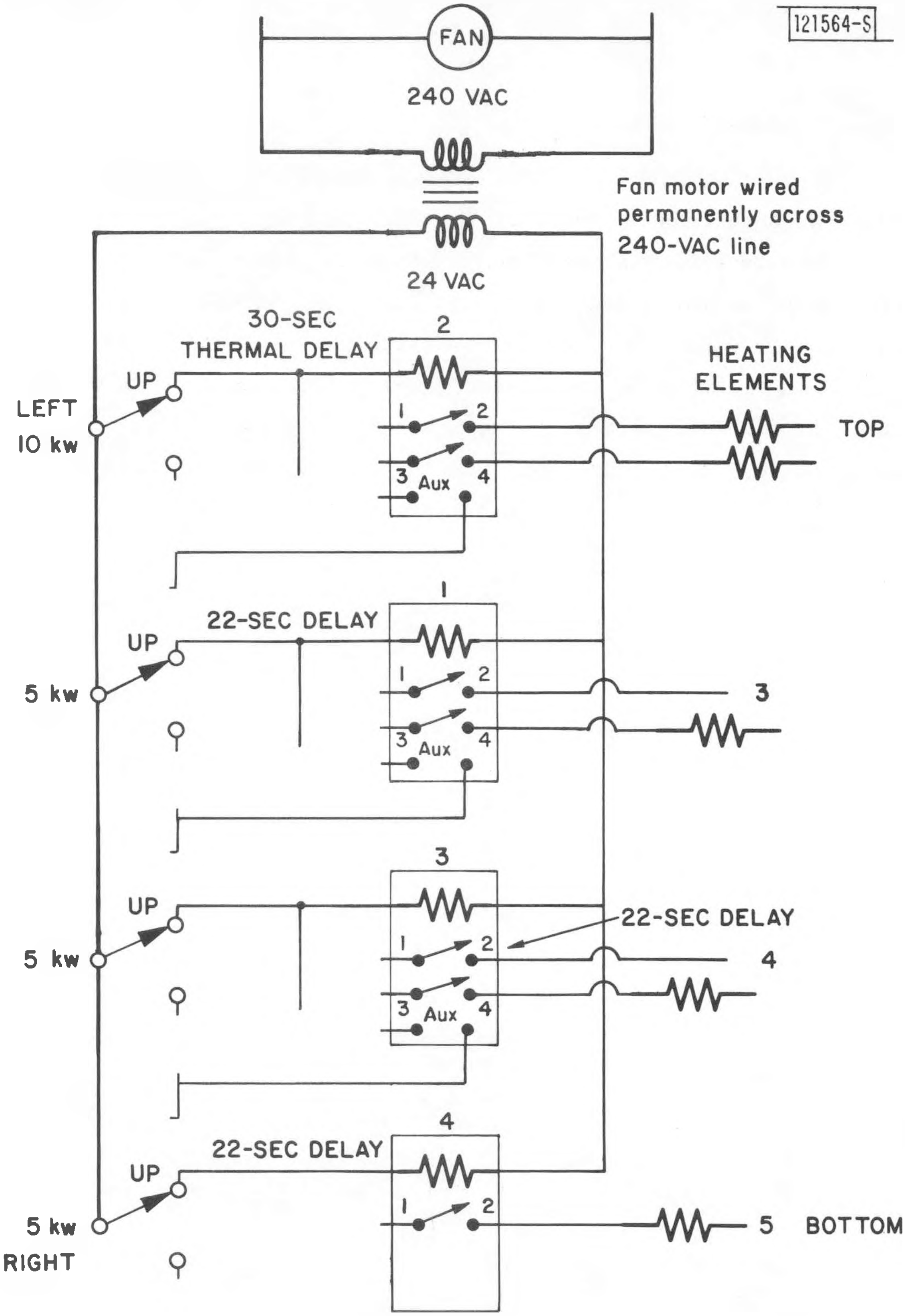


Figure 8-1. Electric furnace control modifications.

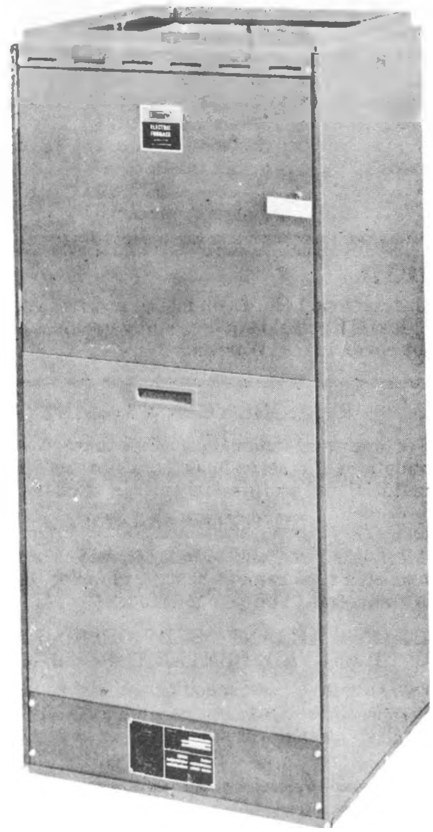
Sears

owners manual

MODEL NOS.
→ 867.587240 ←
867.587250
867.587260
867.587290

CAUTION:
Read All Instructions Carefully Before Starting The Installation.

Save This Manual For Future Reference.



ELECTRIC FURNACE

- **Installation**
- **Operation**
- **Repair Parts**

Sears,Roebuck and Co.,Chicago Il 60684 U.S.A.

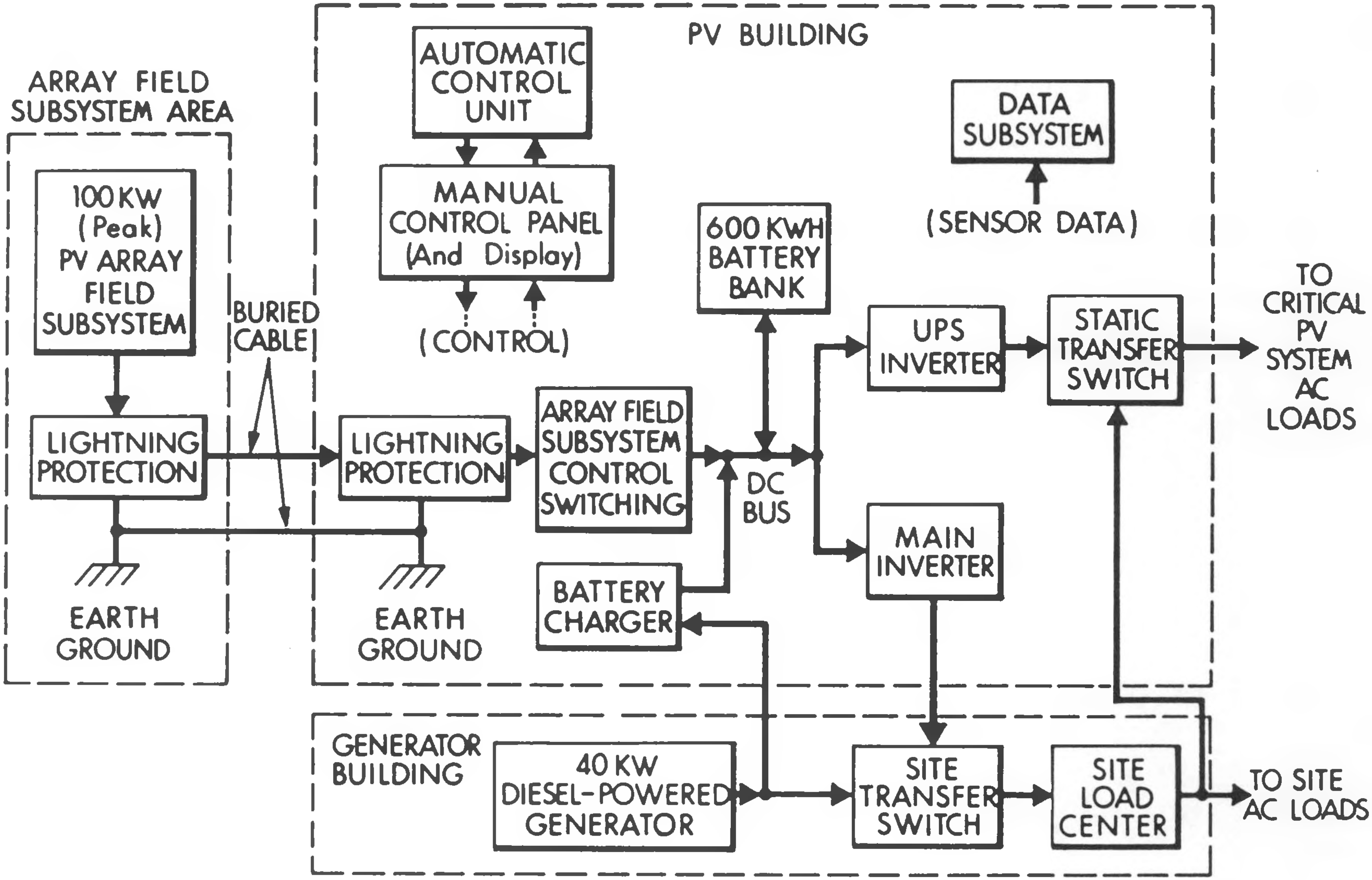


Fig. 9-1. Simplified PV power system.

9.0 SYSTEM TESTING

The NBNM PV power system was tested during its construction first at the component level, then at the subsystem level, and finally at the system level (refer to Fig. 9-1). The component tests of the inverters, battery chargers and battery are described earlier in this manual.

9.1 Power Processing Subsystem Test

The power processing components were shipped to MIT Lincoln Laboratory where they were assembled into the subsystem shown on Fig. 9-2.

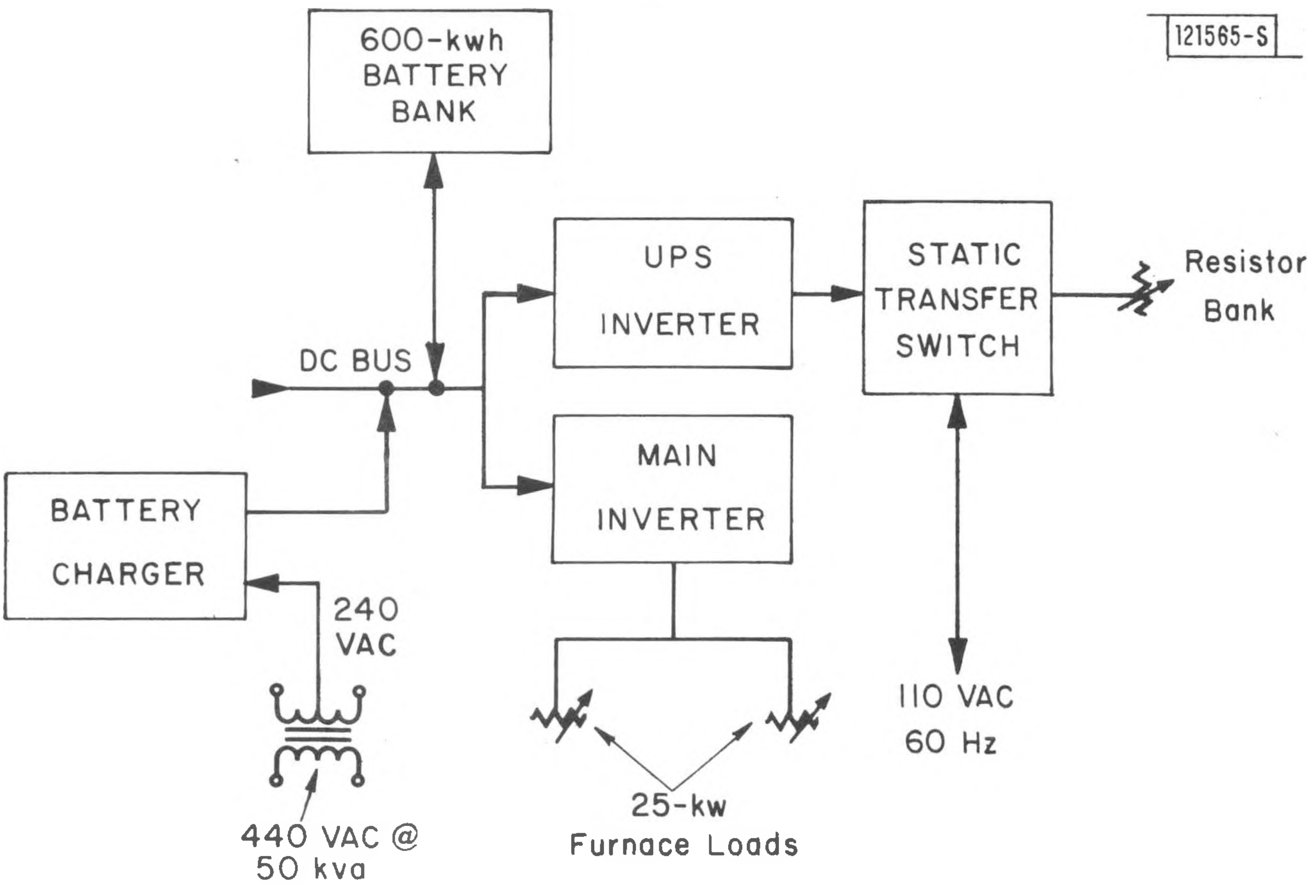


Fig. 9-2. Power processing subsystem test configuration.

The test setup for the power processing subsystem test is shown on Fig. 9-3. The two 25-kW furnace loads shown consist of several 5-kW elements which had been made switch selectable for use in this test. The main components shown are the main inverter, the dc test and metering panel, the battery chargers, the UPS inverter with its resistive load, and the battery.

The battery (together with its air-lift system) is shown in Fig. 9-4. Fuses, mounted in the battery positive and negative leads, reduce the possibility of shorting the battery. The white plastic pipes distribute air from the air compressor tank.

9.2 Control Subsystem Test

The off-site test of the control and signal conditioning subsystem was done on the premises of Ford, Bacon and Davis in Salt Lake City, Utah. Fig. 9-5 shows a simplified diagram of the equipment configuration. The equipment was arranged in the test room as shown in Fig. 9-6.

ACU operation was tested with a subscale battery (a 12-volt motorcycle battery) and an array simulator consisting of 48 current sources powered from an unregulated dc power supply. Sunlight variations were simulated by means of a Variac autotransformer, which varied the ac input to the dc power supply. The input voltage divider and current shunt for the ACU analog inputs were scaled appropriately to simulate the output voltage and current of the battery.

A separate test was done on the power control devices in the AFSC and I-V load box using three 150-volt, 10-ampere power supplies with a series resistor to provide a Thevenin approximation to one of the 48 PV array subfields.

9.3 Preliminary PV Site System Test

The test setup shown on Fig. 9-7 was carried out in February 1980. It provided an early test of the interface between the main inverters and battery chargers to the site loads and generators.

As a result of this test, two major changes were made: a transformer inrush current limiter box (Unit 311) was built and incorporated into the system (refer to Chapter 7.0); the sequential interconnection of the two battery chargers through a revised battery charger interface to the DPG.

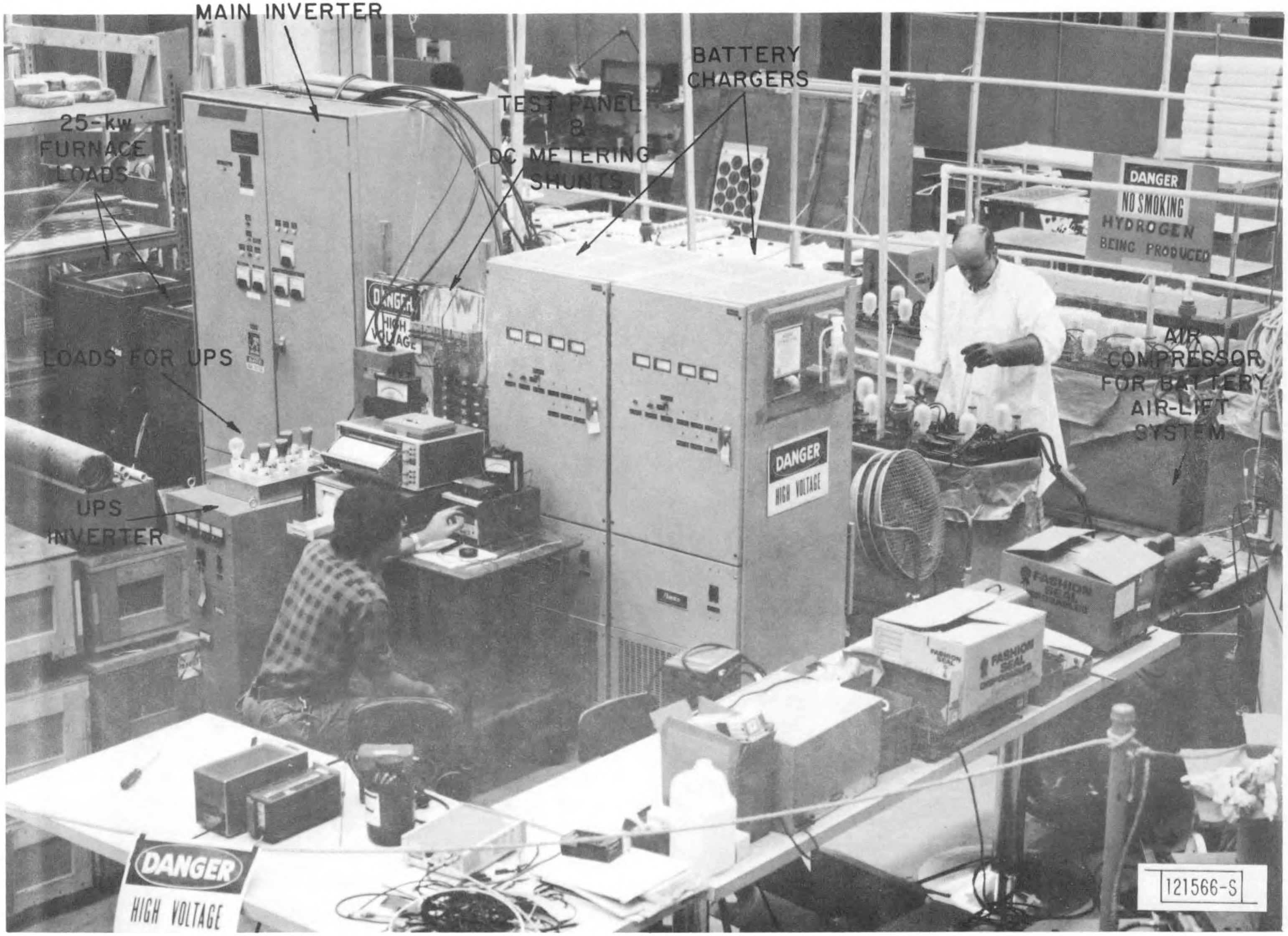


Fig. 9-3. Power processing subsystem test setup showing inverters and loads.

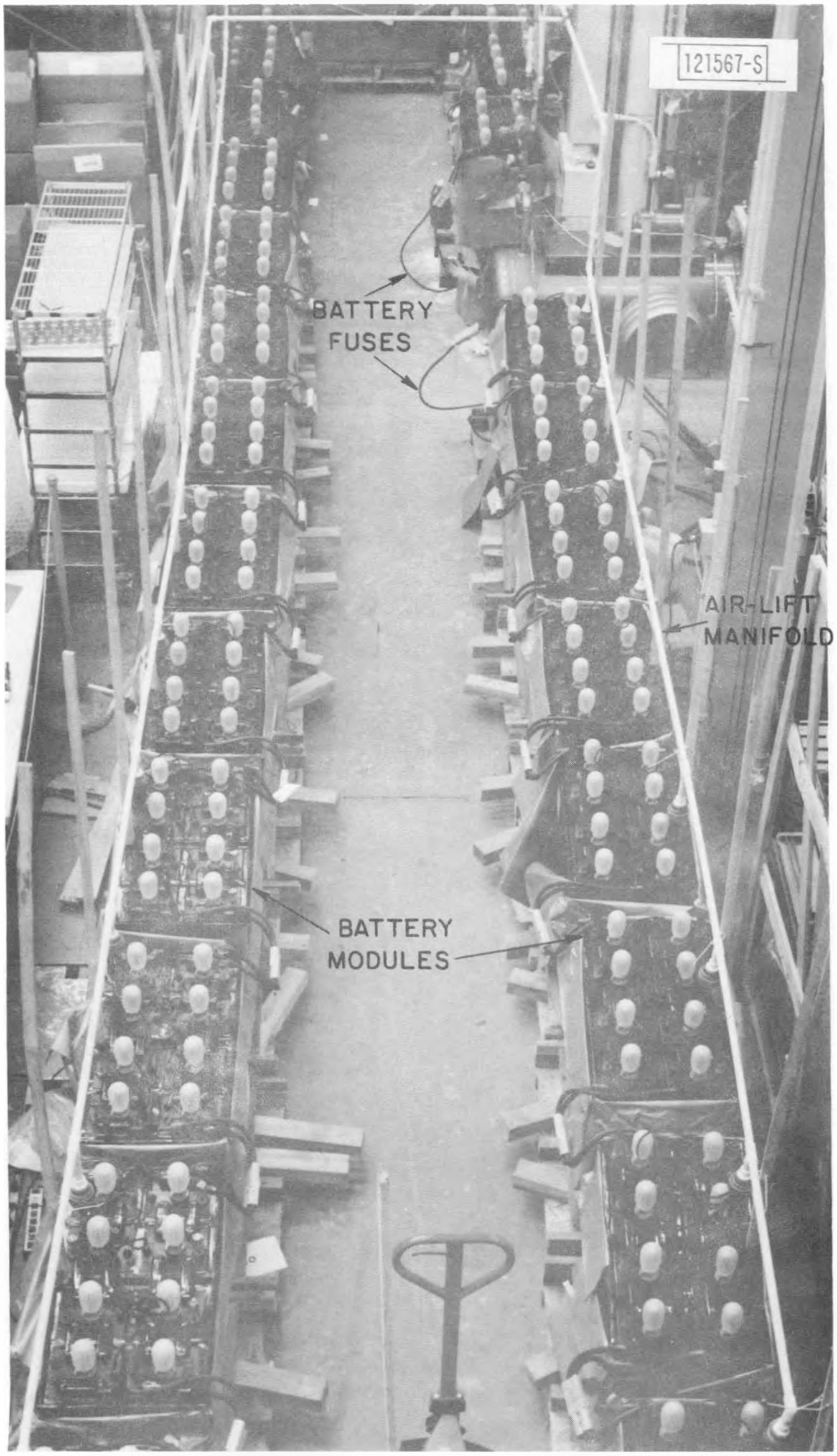


Fig. 9-4. Power processing subsystem test setup showing battery.

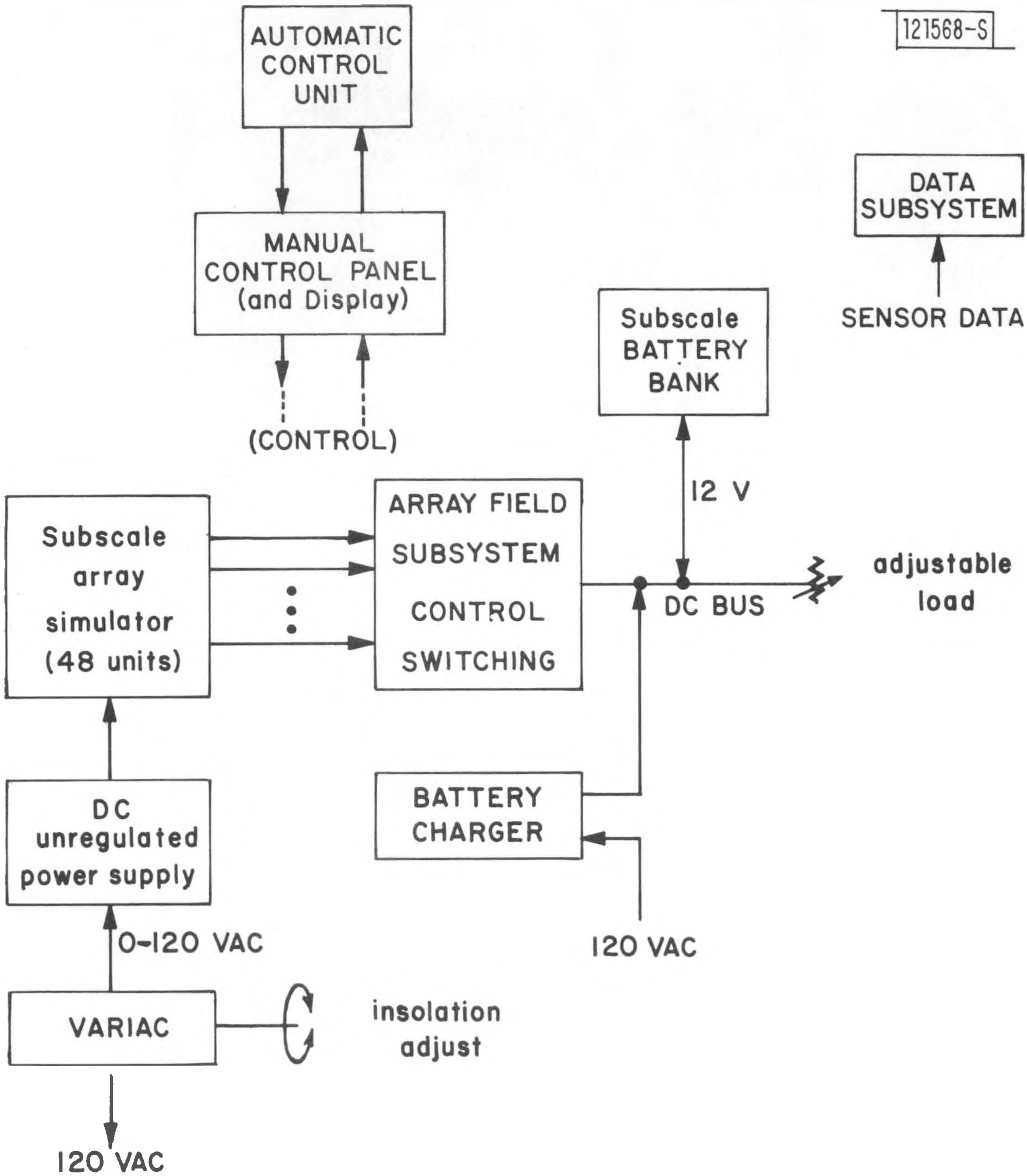


Fig. 9-5. Control subsystem test.

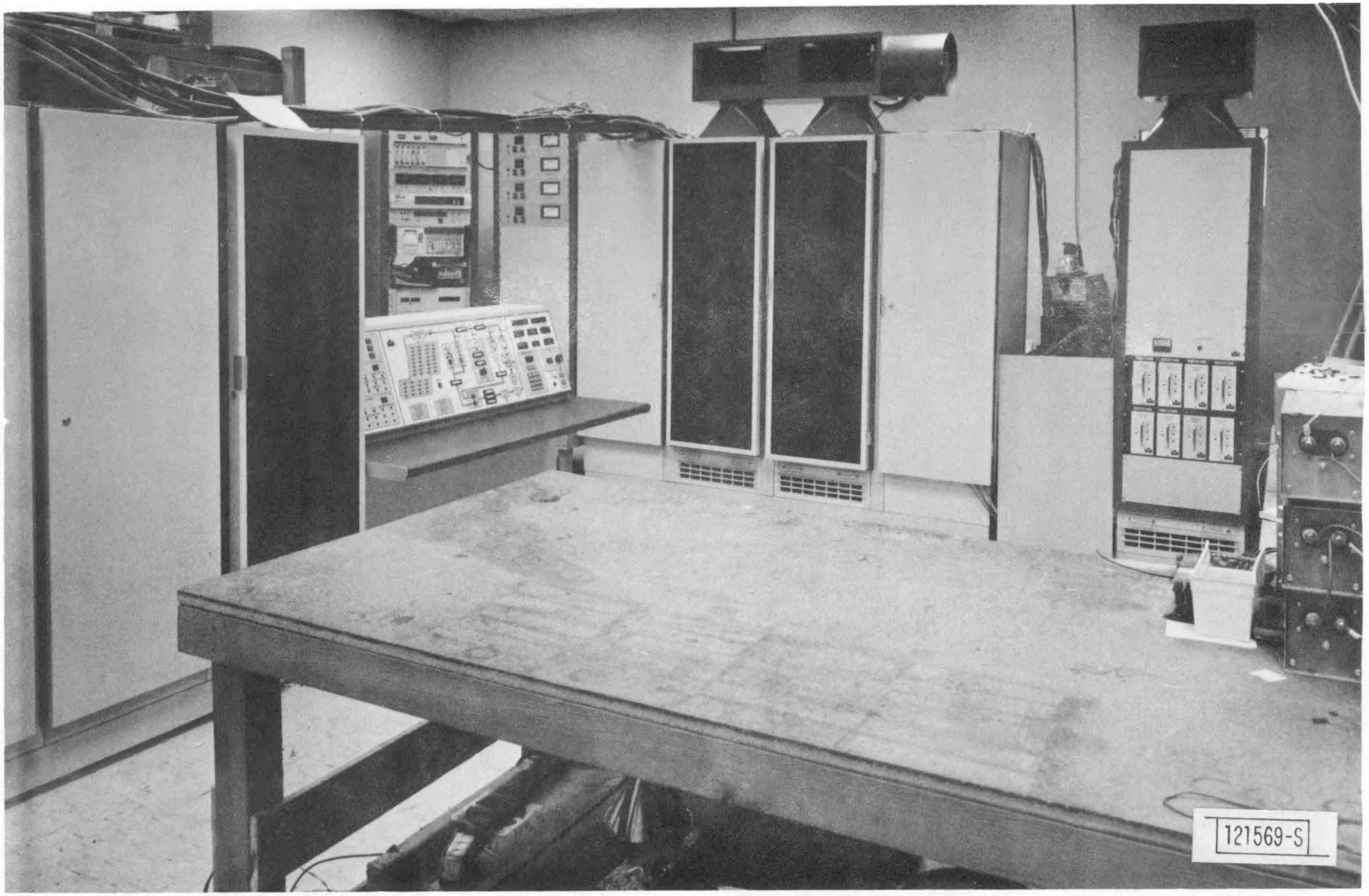


Fig. 9-6. Control subsystem off site test at Salt Lake City.

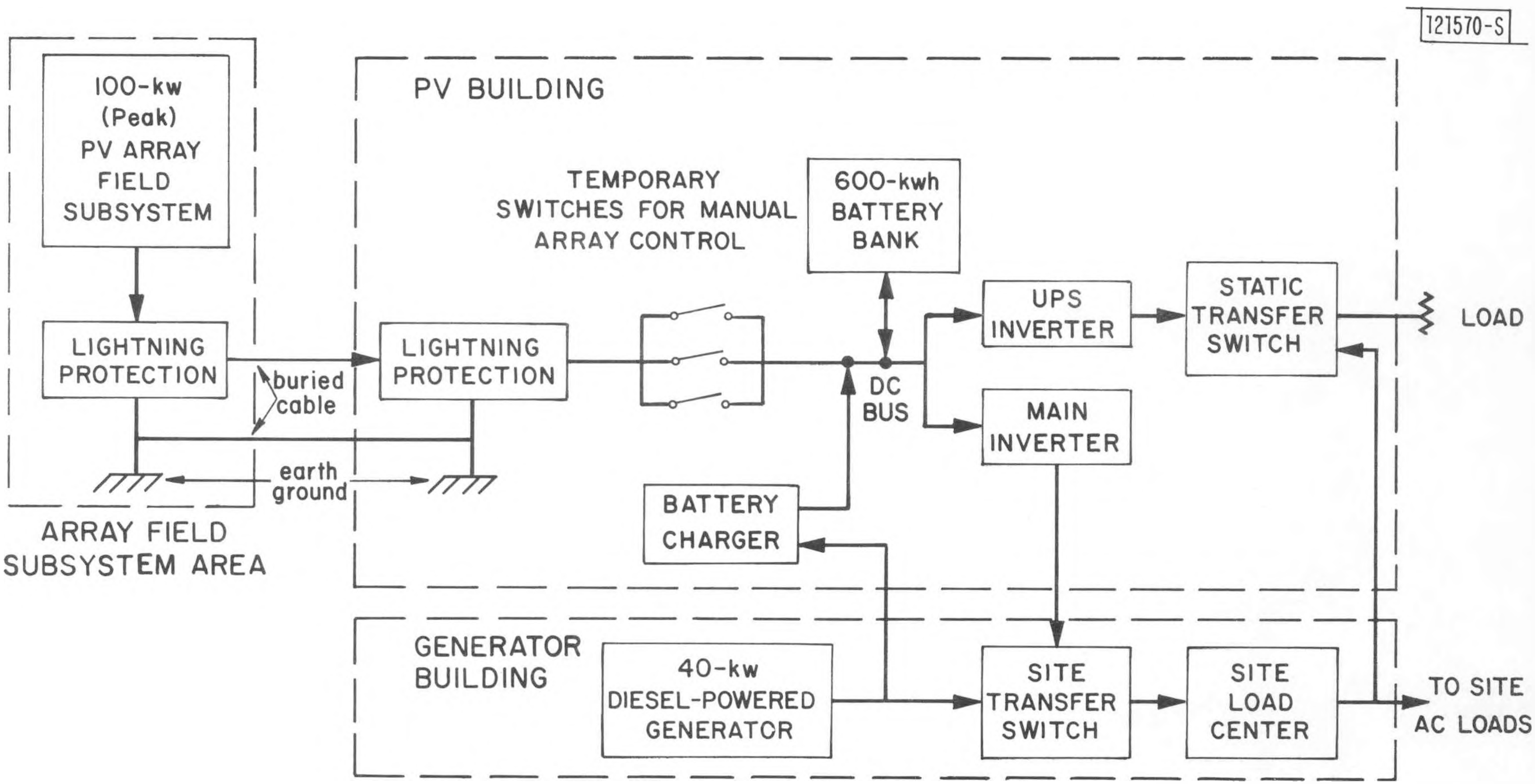


Fig. 9-7. Preliminary PV power system test at site.

10.0 MISCELLANEOUS

10.1 Under-Voltage Cutout Relays and Timers

The main inverter has the excess current capability to start any of the site motors, as long as not more than one motor is started at the same time. Simultaneous motor starting may cause the motor to stall, which effect could damage the motor, other site ac loads or the main inverter.

To remedy this, under-voltage cutout relays with restart timers were installed in January, 1982 on the 3-HP air compressor motor and the 2-HP domestic hot water pressurization pump motor, located in the maintenance building.

The under-voltage cutout relays sense whether the motor voltage is less than 200 vac. If so, it shuts off the motor and starts a timer to delay the restart for a selectable interval, either 60 seconds or 100 seconds, depending on which motor needs to be restarted.

Other motors at the site may be started without difficulty by shutting off either or both of the above-mentioned motors. Any additions to the site loads should tend to minimize motor starting current requirements.

10.2 High-Voltage AC Distribution System

In November 1981, NPS installed a new 7.2-kV high voltage transmission line to convey ac power to the visitor's center and the wells. Because the newest well is located almost a mile from the site load center, it was necessary to install the high-voltage transmission line to minimize wire losses.

The high-voltage ac distribution system includes four transformers interconnected by a high-voltage cable. A 25-kVA stepup transformer (240 VAC: 7.2 kVAC) located on a pad outside the generator building transmits the ac power over the high-voltage cable to the three stepdown transformers, which provide power at 120/240 VAC to the visitor's center and the two wells.

Installation of this system caused two problems. The first was a wiring error at the stepup transformer in which the center tap of the 240-VAC winding was inadvertently grounded, thus bypassing the transformer inrush current-limit circuit for half of the 120/240-VAC line. This problem was corrected by ungrounding the center tap of the stepup transformer so that the 2.2-ohm resistor is in series with the entire 240-vac winding of the 25-kVA transformer.

The second problem involved a resonant circuit. A 1200-Hz series resonance was derived from the high voltage line capacitance and the leakage inductance of the stepup transformer and presented to the main inverter, where a 150-amp peak-to-peak harmonic current caused the inverter to sense the wrong current limit value and to then current limit prematurely. This problem was solved in March, 1982, by installing a bank of capacitors (with a value of 125 µfd) across the 240-VAC line to detune the 1200-Hz series resonance and to reduce the value of the resultant harmonic current to an acceptable value.

CAUTION

> If the 240-VAC breaker for the capacitor bank either trips or is turned off, it should not be reset until the breaker for the visitor's center is shut off at the generator building. This action enables the transformer inrush control (Unit 311) to limit the magnitude of the capacitor charging current to below 100 amps.

A long-range solution to the second problem is the installation of a 1200-Hz trap within the main inverter enclosure to confine the harmonic current there. A suitable trap is available from the manufacturer of the inverter.