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THE PHOTOVOLTAIC HIGHER EDUCATION NATIONAL EXEMPLAR FACILITY (PHENEF) AT GEORGETOWN UNIVERSITY

Final Project Report

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FINAL PROJECT REPORT

BACKGROUND

Georgetown University in a proposal dated January 17, 1980, applied for a grant from the U.S. Department of Energy to construct a Higher Education Exemplar Photovoltaic Facility on the Georgetown University campus. An addendum to the proposal dated April 18, 1980 entitled "A Grant to Construct a National Exemplar Higher Education PV Academic Facility Revised to Meet Criteria of the Under Secretary of Department of Energy" reduced the scope of the proposed grant and incorporated DOE guidelines. In August, 1980, the U.S. Department of Energy awarded the proposed grant to Georgetown University. The grant covered the following tasks:

Task I - The Department of Energy would participate in the building of an academic facility that would facilitate the integration of flat plate photovoltaic roof modules with an optimally oriented solar architecture. The completion of the facility to be built on the Georgetown University Campus and known as the Georgetown University Intercultural Center was to be a jointly funded endeavor with the Department of Education funding $9.2M through a grant and a loan, Department of Energy funding a maximum of $ 4M and Georgetown University funding the residual costs.

Task II - Georgetown University would provide the necessary skills, services, materials, equipment and facilities to design, furnish, install and make operational the Georgetown University Intercultural Center Photovoltaic System. The specific objective of this effort would be to build an exemplar flat plate electrical grid connected photovoltaic (PV) system which would demonstrate integration of PV modules into a watertight roofing surface. The system capability, measured at the input to the inverter, would be a 300 kilowatt peak power system as measured at the normal cell operating temperature and an insolation of 100 milliwatts per square centimeter at the collector surface. DOE funding under the grant for the PV system would be limited to a system cost of $20.00 per peak watt up to maximum of six million dollars. The modules utilized in the PV system would be of a production-ready design incorporating the following features:

A. Fire rateable under UL790.

B. High area power density.

C. No exposed conductive surfaces.

D. Glass cover plate or equivalent.

E. Integral bypass diodes.

F. Integral UL rateable module-to-module connectors.

G. Internal circuit and cell interconnector redundancy.

H. Integral cross strapping between parallel circuits.

I. Will meet Jet Propulsion Block V Design & Test Standards.

DESIGN, CONSTRUCTION AND COMPLETION OF THE GU INTERCULTURAL CENTER

The GU Intercultural Center was designed with provisions for a photovoltaic roof array. The building designers included: Metcalf and Associates, Architects and Planners, Washington, DC.; Ashen and Allen, Consulting Engineers, San Francisco, CA; Syska and Hennessy, Consulting Engineers, New York, NY; MMP, Structural/Economic Consultants, Washington, DC.; and Lester Collins, Landscape Architect, Washington, DC. The building's architectural design, orientation, structure and roof were created in consonance with the physics of solar photovoltaics with a view towards maximizing electrical power output.

The building was constructed near the center of the 105 acre GU Campus as shown on the aerial photograph in Figure 1. A photograph of the ICC building taken when the PV system was being installed is shown in Figure 2. The building , 226,000 NSF, has seven levels. The lower six levels are used for educational purposes while the top level houses HVAC and electrical equipment. The roof is split up into four individual sections. The lowest section is split into three parts separated from each other by terraces. The second roof section is in a slightly higher plane than the lowest roof, while the third roof section is also in a slightly higher plane than the second roof section. The fourth roof section is at the same height as the third roof section, but is separated from it by a horizontal Irma roof. All four roof sections make an angle of 35 degrees with the horizontal, facing 1 degree 55 minutes east of south.

GU awarded a construction contract to the low bidder, The George Hyman Construction Company, Washington, DC. Construction of the building began in early 1980 and was completed in May, 1982 at a cost of $23 million..(without the PV roof array).

ACQUISITION OF THE PHOTOVOLTAIC SYSTEM

This effort consisted of three distinct phases: contractor selection, system installation, and test and acceptance of the PV system. As a first step, Georgetown University selected Science Applications International Corporation (SAIC) to provide technical assistance in the conduct of the program.

A Request for Proposal was developed and released in December, 1981. The RFP required prospective vendors to provide samples of modules for Block V testing to be performed for DOE by the Jet Propulsion Laboratory, Pasadena, CA. Four firms responded to the RFP and supplied modules for Block V testing: BDM International (BDM), Hughes Aircraft Co.(HAC), Stone and Webster Engineering (S&W) and Solarex, Inc.. In May, 1982 Georgetown University disqualified all four proposals because all modules supplied by the offerors failed the JPL Block V tests. The four offerors were asked to supply new modules for testing and revise and re-submit new proposals. Revised proposals were received in August 1982. BDM proposed using Arco Solar modules, HAC proposed using Solerex modules, S&W used Westinghouse modules, and Solarex proposed their own modules. All modules were retested. As a result of the retesting and full evaluation of proposals, GU selected Hughes Aircraft Co. as the successful offeror. and entered into a contract with Hughes effective March 8,1983.

The Hughes contract team consisted of the following firms:

Hughes Aircraft Corporation - responsible for the overall conduct of the project.

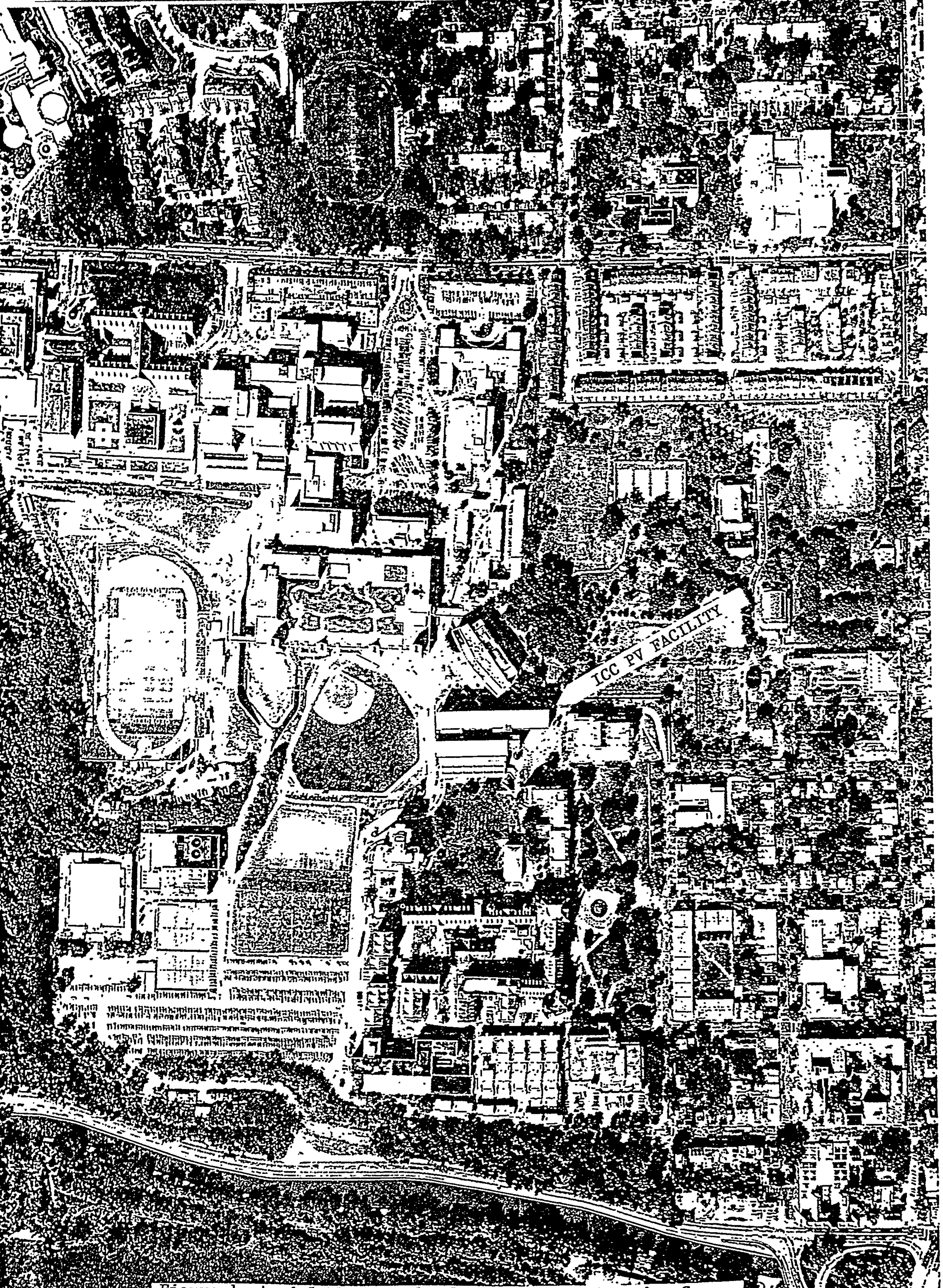


Figure 1: Aerial Photograph of Georgetown University Campus

Figure 2: Photograph of ICC Building in 1982 as PV System was being installed

Burns and Roe Pacific, Inc. - responsible for the design of the photovoltaic support structure and the waterproofing features of the roof. In addition, Burns and Roe served as on-site construction manager for HAC to coordinate the installation of the photovoltaic roof.

Custom Walls & Windows, Inc. - responsible for the installation of the PV module mounting system. The structural system used for mounting the PV modules was a modified Model 1600 sloped glazing structure manufactured by Kawneer Co. Inc.

Dynalectric Company - responsible for the installation of the PV modules, the inverter and all electrical wiring.

Solarex Corporation - responsible for the manufacture of 4464 photovoltaic modules.

Windworks, Inc. - responsible for the design and manufacture of the 300 kW Power Inverter.

Installation of the photovoltaic roof was completed and accepted in August, 1984. The power measured and delivered met the 300 kW minimum power requirement. Final cost of the installed system, including GU support costs and consultants, amounted to $5.89 million or $19.60/kW for the 300 kW array.

PHOTOVOLTAIC SYSTEM CONFIGURATION

PV Modules. The Solarex flatplate photovoltaic module has a nominal surface dimension of two feet by four feet, and is approximately 0.312 inches thick. Figure 3 is a close-up photograph of installed modules. The module comprises seventy-two (72) rectangular solar cells which measure 3.54 inches wide by 3.74 inches long. The 72 cells are arranged in six 12-cell rows with narrow interstitial spacing between cells. The solar cell circuit and diodes are arranged on a low-iron, tempered glass superstrate which is 0.187 inches thick. The back of each module circuit is potted with a thin layer of clear silicon polymer and an additional layer of pottant containing two Amp Solarlock connectors attached to the plus and minus circuit terminals. Each module is covered with a glass coverplate, .125" thick, with the embossed or stippled side out. The performance characteristics of the modules as designed were as follows:

Power	=	72 watts
Voc	=	20.2 volts at Air Mass 1.5
Isc	=	4.7 Amp @ 100 mw/cm^2
Vmax Power	=	16.5 volts @ 28 degrees C
Imax Power	=	4.36 Amp
Efficiency	=	11.6% (cell area)
Efficiency	=	10.0% (module area)

Power Conversion and Conditioning System. The power conversion, conditioning and control system inverts the variable DC output of the solar array into controlled three phase, four-wire AC electrical power (480Y/277 Y, 60 Hz) of a quality and stability suitable for injection into and paralleling with the utility electrical grid. A simplified block diagram of the power conversion and control subsystem is shown in Figure 4. Control Specifications for the 300 kW Power Converter, which was produced by Windworks, Inc., are outlined in Table 1.

Branch Circuits and Wiring. Electrically, the array is divided into ten branch circuits which are connected in parallel at the Inverter. Each branch circuit is fed through a power collection panel box, located near the appropriate section of the array, and routed through a DC contactor, located at the Inverter. The system power is generated by 124 bipolar strings. Each pole of the string is formed by 18 modules wired in series, producing a nominal voltage of 250 volts per pole or 500 volts per string. The 18

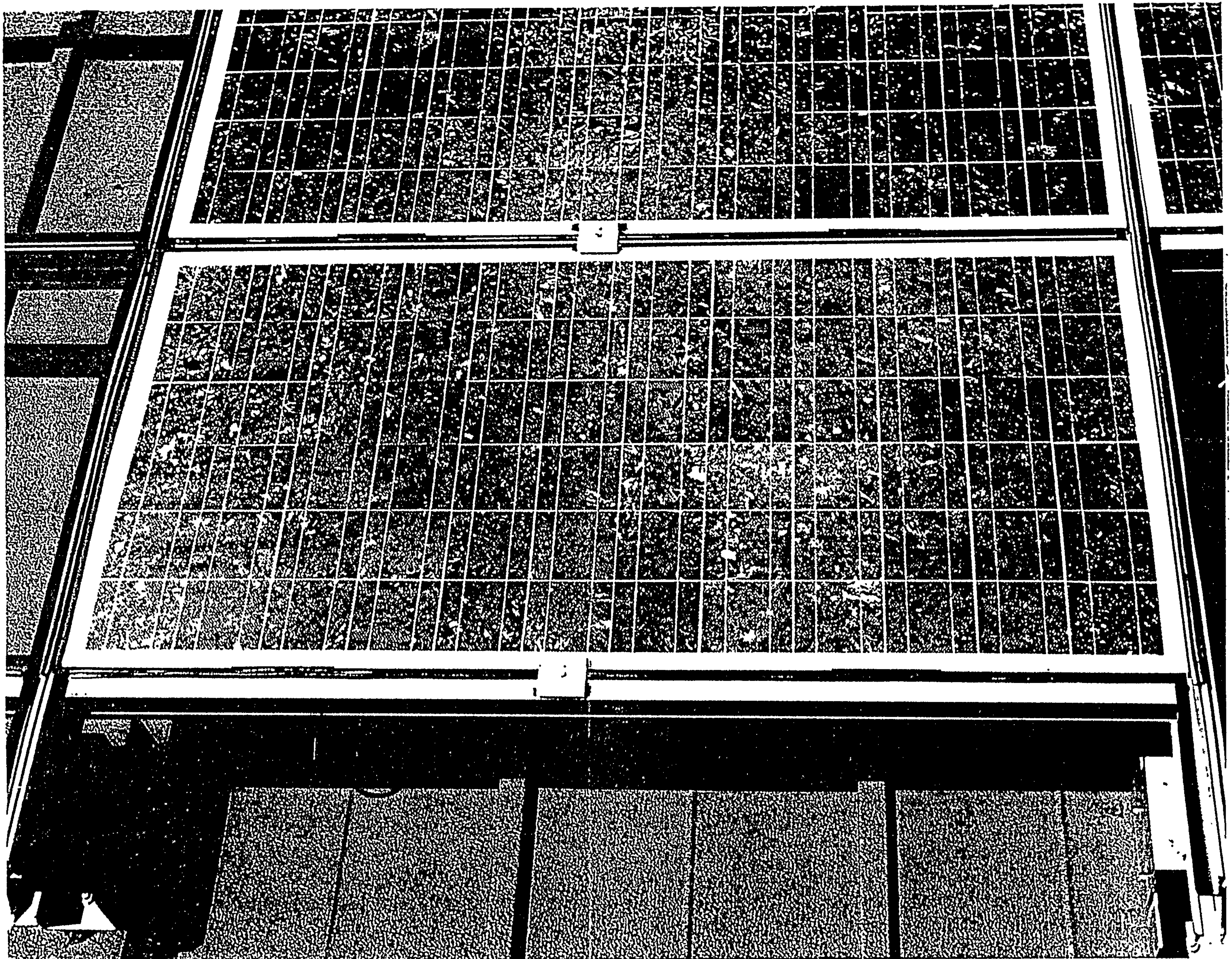


Figure 3: Close-up Photograph of Installed PV Modules

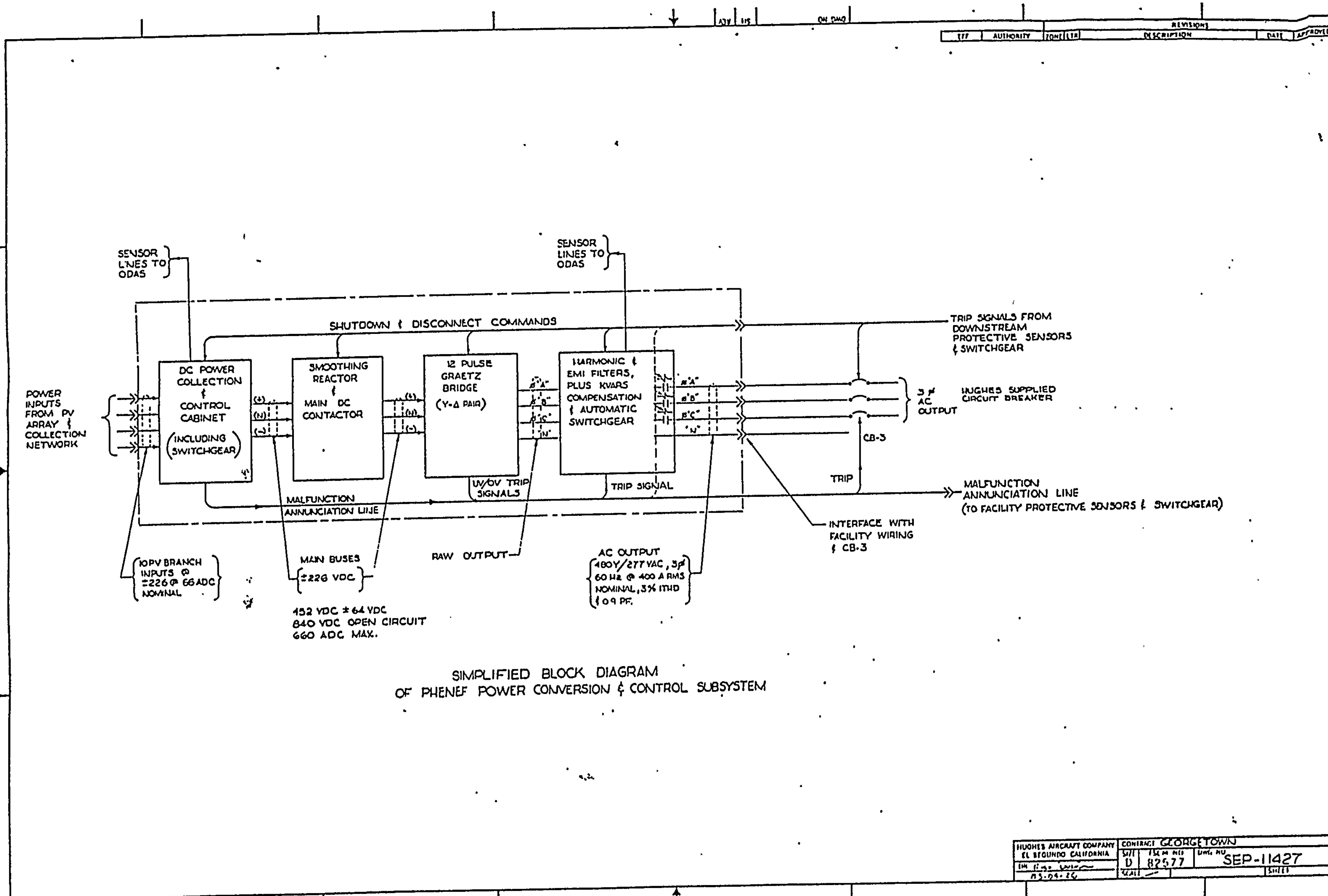

SENSOR LINES TO ODAS
SHUTDOWN & DISCONNECT COMMANDS
POWER INPUTS FROM PV ARRAY & COLLECTION NETWORK
DC POWER COLLECTION & CONTROL CABINET (INCLUDING SWITCHGEAR)
SMOOTHING REACTOR & MAIN DC CONTACTOR
12 PULSE GRAETZ BRIDGE (Y-Δ PAIR)
HARMONIC & EMI FILTERS, PLUS KVARS COMPENSATION & AUTOMATIC SWITCHGEAR
TRIP SIGNALS FROM DOWNSTREAM PROTECTIVE SENSORS & SWITCHGEAR
3 ∅ AC OUTPUT
HUGHES SUPPLIED CIRCUIT BREAKER
CB-3
TRIP
UV/OV TRIP SIGNALS
TRIP SIGNAL
MALFUNCTION ANNUNCIATION LINE
MALFUNCTION ANNUNCIATION LINE (TO FACILITY PROTECTIVE SENSORS & SWITCHGEAR)
INTERFACE WITH FACILITY WIRING & CB-3
10PV BRANCH INPUTS @ ±226 @ 66 ADC NOMINAL
MAIN BUSES ±226 VDC
452 VDC ± 64 VDC
840 VDC OPEN CIRCUIT
660 ADC MAX.
RAW OUTPUT
AC OUTPUT 480Y/277 VAC, 3∅ 60 Hz @ 400 A RMS NOMINAL, 3% ITHD & 0.9 PF.
SIMPLIFIED BLOCK DIAGRAM OF PHENEF POWER CONVERSION & CONTROL SUBSYSTEM
REVISIONS
HUGHES AIRCRAFT COMPANY EL SEGUNDO CALIFORNIA
CONTRACT GEORGETOWN
D 82577
SEP-11427

Figure 4

Table 1
Control Specifications for 300 kW PHENEF Power Converter

Manufacturer:	Windworks, Inc.
P/No:	Gemini S6-750-24V-3
Configuration:	12 pulse, line-commutated, Graetz Bridge with KVARS compensation and harmonic filters.

<u>Electrical Characteristics</u>

DC Input Voltage:	325-475 VDC
Nominal Input DC Power (at input terminals)	400 VDC and 758 ADC (nominal) at pk array output of 303 kW (nominal); ±200 VDC (nominal) bipolar
Output Voltage:	480 Y/277, 3 phase, 60 Hz 4 wire
Output Power:	275 kW nominal at full array power input (303 kW @ 28°C) 100 mW/cm^2
Voltage Regulation:	±1%
Frequency Regulation:	60 Hz±1%
Maximum Power Tracking:	To within ±1% of the array E-1 characteristic for maximum power extraction
Harmonic Distortion:	less than 5 % THD
Efficiency:	95% nominal at full load
Inverter Power Factor:	to 90% lagging, 66% to 100% of full load
Maximum Continuous AC Busbar Draw:	345 amps RMS line current
Abnormal State Off-line Trip:	Loss of utility power Downstream fault (under voltage, loss of power transfer) Automatic/manual inverter shutdown
Normal State, Off-line Trip:	Evening shutdown

modules within each string are matched to produce current within +/-0.025 amps of each other. Each pole is wired through a standard AC circuit breaker serving as a disconnect or isolation switch in the power collection panel box, where like poles are connected in parallel. The number of strings per panel box vary from 9 to 16. A photograph of a typical panel box in shown in Figure 5.

Array Support Structure. The array support structure, manufactured by Kawaneer Co., was mounted on the existing subroof by the installing distributor, Custom Wall Window Inc., using horizontal oriented, steel furring members. A typical grid anchor detail is depicted in Figure 6. Figure 7 shows the framing on the North roof section prior to installing the PV modules.

ON-SITE DATA ACQUISITION SYSTEM (ODAS)

Toward the end of construction, an on-site data acquisition system (ODAS), supplied by Sandia National Laboratories, was installed to monitor system performance during the first year of operation. The Government-furnished ODAS equipment consisted of a weather station, a Hewlett-Packard 9845T computer, and a modem for transmitting data collected data to a remote Data Reduction Center for analysis and reporting,

PHOTOVOLTAIC SYSTEM PERFORMANCE

The first full month of recorded ODAS data was November, 1984. A summary of the monthly ODAS data on system performance for the 14 month period, 11/1/84 - 12/31/85, is provided in Appendix A, along with the individual monthly data. Also included in Appendix A are monthly summaries of significant events occurring during the 14 month period. These summaries were compiled by SAIC, the technical consultant to Georgetown University. The averages and totals of monthly hours of operation, array solar energy, and PCU AC energy output are summarized in the tables. During the 14 month period, the system logged 3,385 hours of operation with an average of 242 hours per month. The average output per month was 21,351 kW-hrs and the total for the 14 month period was 298,908 kW-hours. The peak months were March and September, with 31,813 kW-hrs and 33,853 kW-hrs respectively.

Through August, 1985 the PV system was plagued by nuisance ground fault trips. To reduce the number of nuisance trips, HAC, with the concurrence of GU, raised the ground fault interrupter circuit threshold up from 25 milliamperes to 100 milliamperes. This action reduced the number of nuisance ground fault trips over the following three months.

On December 9, 1985, an incident occurred that resulted in the PV system being taken out of service for 10 months. While doing a module cleaning experiment, the GU consultant, SAIC, opened the circuit breakers for half-strings 60-1 and 60-2 in junction box 5. By mistake, SAIC turned off the branch DC contactor in the control room for junction box 3 instead of box 5. As a result, the breaker for half-string 60-2 did not clear the DC current but burned out along with several diodes. The circuit breakers were designed to be used only as cold disconnect or sectionalizing switches and then only after turning off the branch DC contactor in the control room. Because of the danger of repeating this incident or experiencing other operating scenarios that could develop and trip the breakers under load, the University considered the operation of the system to be potentially dangerous and elected to shut the system down until the issue was satisfactorily resolved. To correct the problem, the following design changes were agreed upon and installed during the Summer, 1986:

- Install upgraded panel boards providing individual diode heat sinks and non-metallic mounting support.
- Add metal oxide varisters (MOV) from neutral to ground at each panel board junction box.

- Add fuse and fuse clip in series with each source circuit cold disconnect circuit breaker.

A photograph of the upgraded panel box is shown in Figure 8 .Operation of the system resumed on October 30, 1986. The PV system has continued to operate from that date (the past 7 1/2 years) with only minor problems and no significant outages. AC output in 1991 (the final year of the grant period) totaled 273,835 KWH. GU maintenance personnel perform annual inspections and correct any deficiencies found.

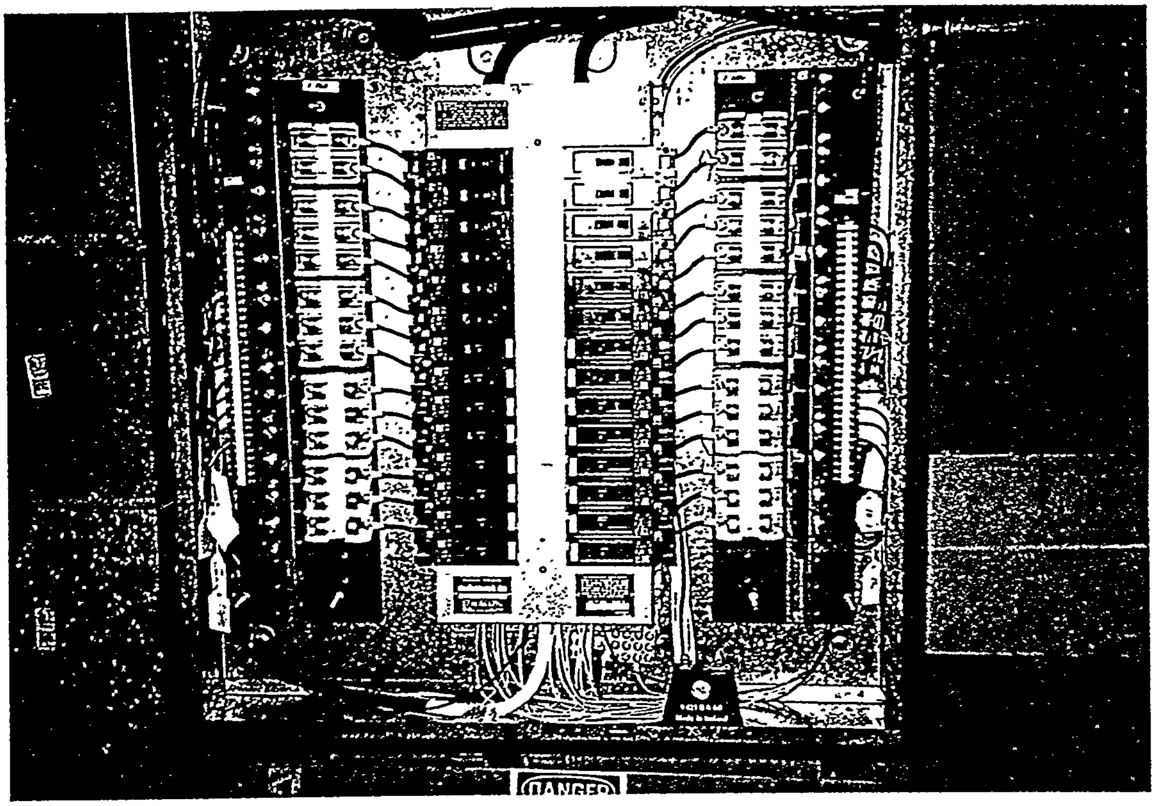


Figure 8. PV panel box after changes installed in 1986

At the direction of Sandia National Laboratories, independent testing of the PV system was performed by New Mexico Solar Energy Institute on three different occasions - April 22-24, 1985, July 13, 1988 and November 3, 1988. The testing revealed significant degradation of energy output over time. Using five spare PV modules as a reference, and assuming the modules installed were like the spare modules, the testing team concluded that the installed modules had degraded from about 66 W per modules (295 kW) to 47 W (210 kW) - a loss of 29 percent. The testing team attributed 20% of the loss to soiling of the modules but couldn't account for the other 9 percent except to point out that "this 9 percent drop in four years is larger than that seen on other arrays of similar age."

When the PV modules were originally fabricated, the University directed that the stippled side of the glass cover plate on the modules be on the outside, mainly to reduce glare. This rough non-glare finish on the glass surface does not allow the natural washing by rain to easily remove the accumulated grime. Plans were made to completely scour and wash the entire PV roof; however, after discussion with DOE representatives, it was decided that cleaning would not be cost effective. Consequently, the roof has never been thoroughly cleaned.

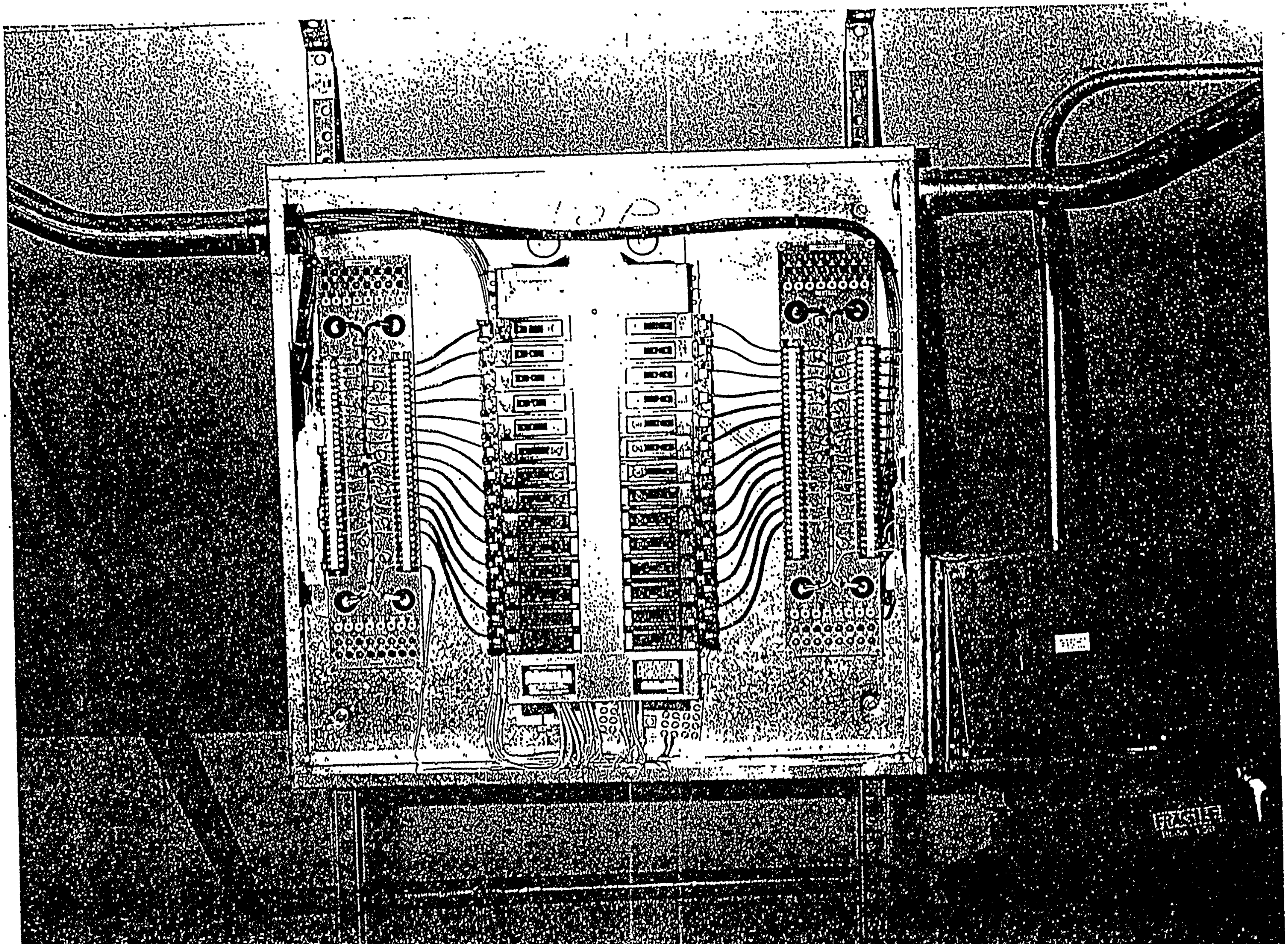


Figure 5: Typical Panel Box

TYPICAL GRID ANCHOR DETAIL

HUGHES
HUGHES AIRCRAFT COMPANY

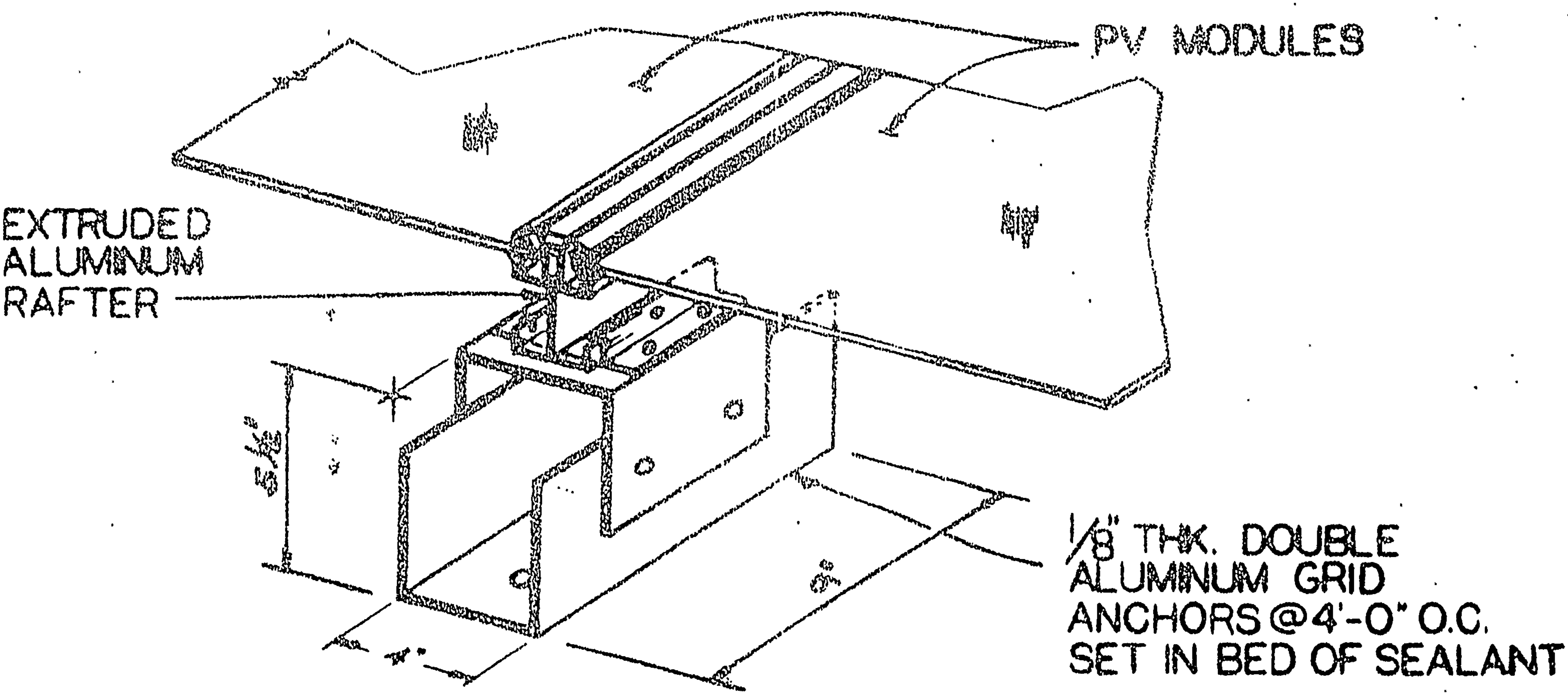


Figure 6

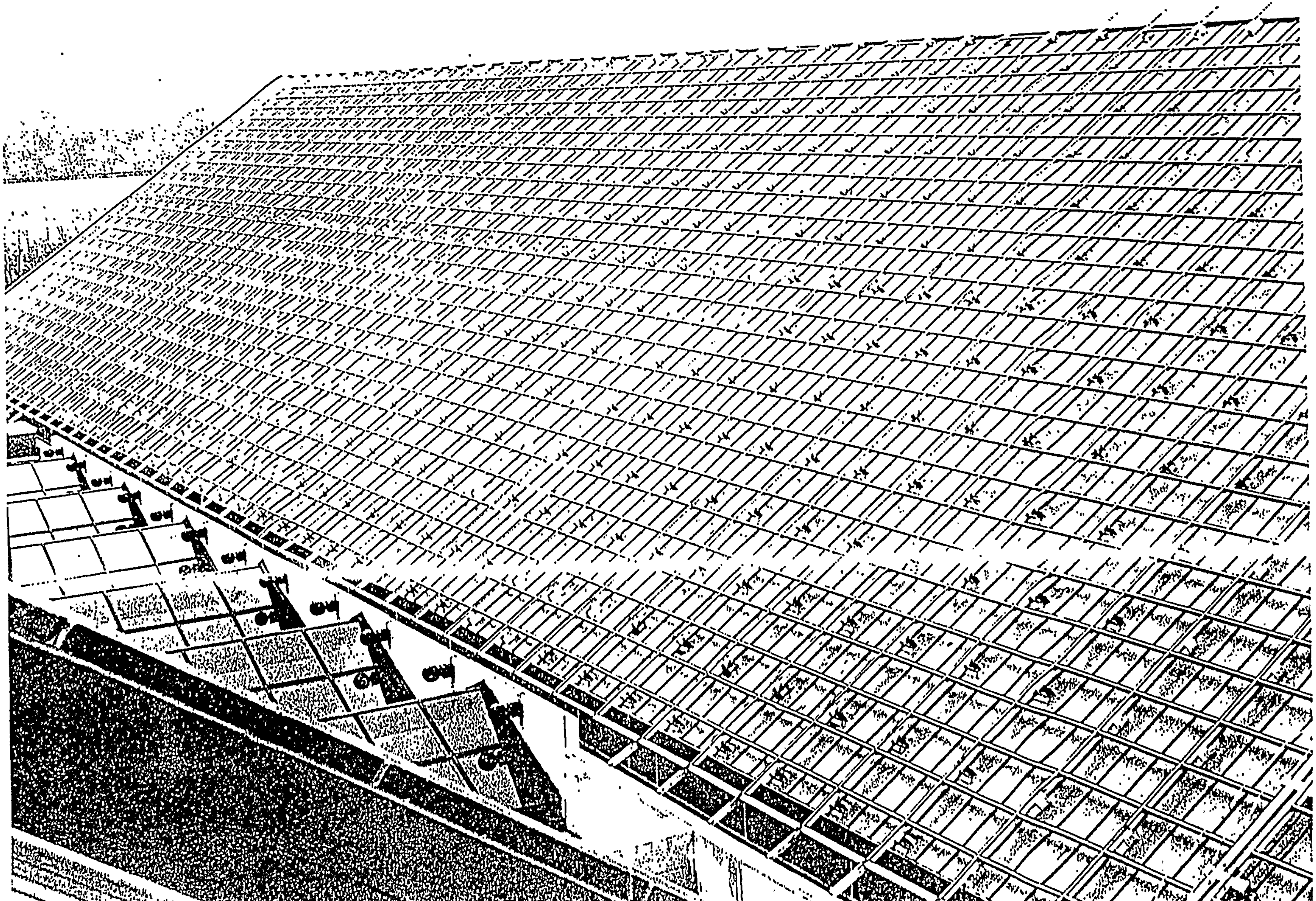


Figure 7: PV Module Framing

Because the PV modules were mounted over an existing closed roof with restricted ventilation between, the modules operate at elevated temperatures which reduces energy output. No cost effective plan has been developed to alleviate the temperature problem.

SUMMARY AND CONCLUSIONS:

The primary objective of building a 300 kW flat plate electrical grid connected photovoltaic (PV) system which would demonstrate integration of PV modules into a watertight roofing surface was achieved at Georgetown University. This system was and still represents the largest roof-top installation of a flat-plate photovoltaic system. Over time, the output from the system has gradually deqraded, primarily from the soiling of the roof surface. Periodic cleaning of the roof surface to maintain energy output levels is not considered to be a cost effective alternative. Mounting the PV modules over an existing closed roof with restricted ventilation affected energy output. On-line system reliability remained high after the system improvements were installed in 1986.

Appendix A

Monthly Perfomance Summaries for the Period 11/1/84 - 12/31/85

Summary of Total System Performance for the Period November 1, 1984 through December 31, 1985

The total system performance summary charts represent a summary of the recorded ODAS data presented in the monthly reports. This is all the recorded data to date. They display the averages and totals of monthly hours of operation, array solar energy, and PCU AC energy output.

The first chart shows the total hours of system operation. The average number of hours operation per month was 242 and the total number of hours for the 14 month period since the ODAS started recording data was 3,385. August 1985 had the highest number of hours of operation with 345 hours logged. December 1985 had the least number of hours (82) due to the system shut down on December 12.

The second summary chart displays the total solar energy incident on the array plane for each month. The average solar energy was 379,041 kW-hrs per month. The highest numbers recorded corresponded to the months that had the longer days, April through September, with April having the highest value of 508,794 kW-hrs. That was a particularly clear and dry month. (Less than one-quarter inch of rain recorded.) The total solar energy available to the solar photovoltaics was 5,306,567 kW-hrs for the 14 month period.

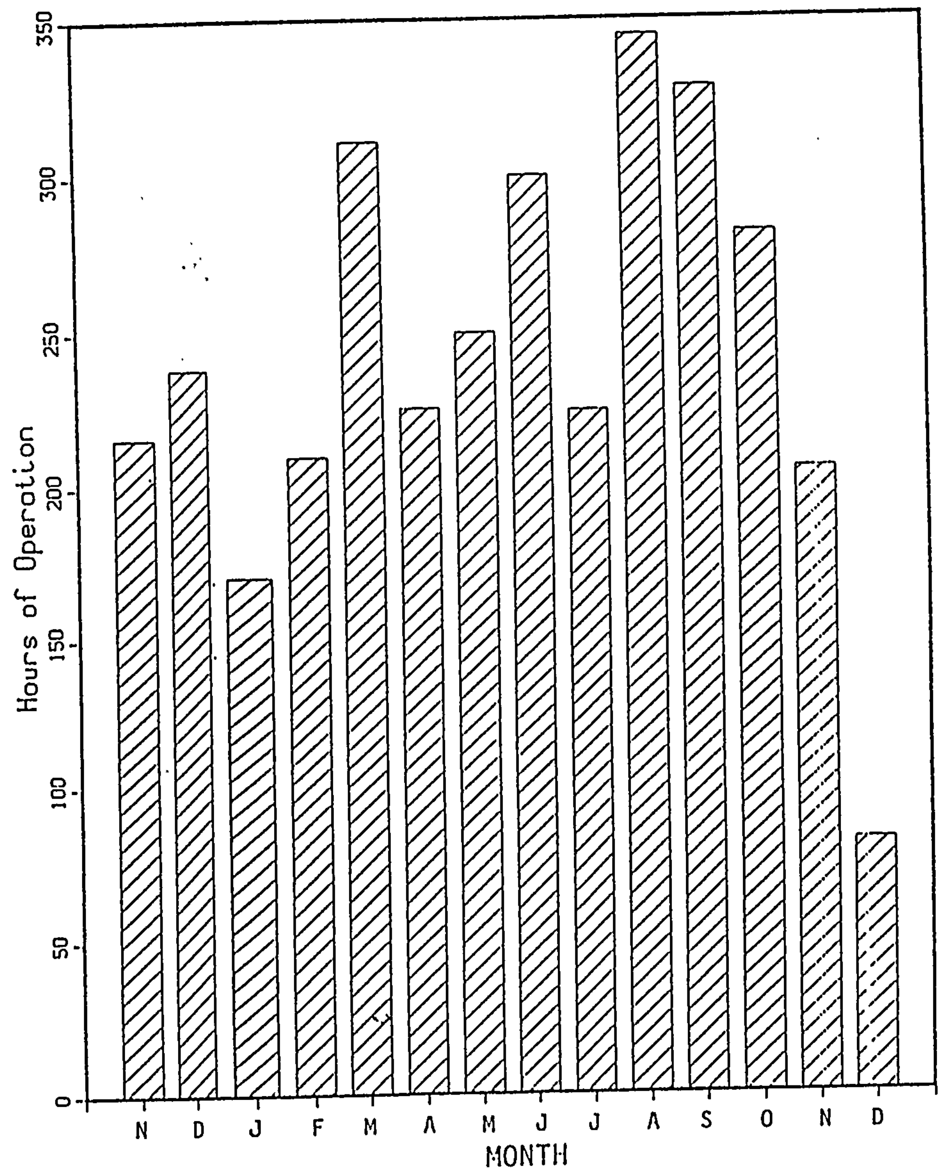
The final summary chart displays the PCU output AC energy for each month. The average output per month was 21,351 kW-hrs and the total for the 14 month period was 298,908 kW-hrs. At a rate of 10 cents per kW-hr, that corresponds to approximately $30,000 worth of electricity. The peak months were March and September, with 31,813 kW-hrs and 33,853 kW-hrs respectively. There is a characteristic double peak in the data with these two equinox months at the peaks. This occurs because there are two major influences on the PCU output performance: the solar energy available and the module cell temperature. The summer months provide the most hours of sunlight, however the higher temperatures reduce the module efficiency. The opposite is true in the winter. In the Spring and Fall, the days are long enough to provide many hours of sunlight, and the temperatures are cool enough to allow for more efficient operation, therefore the highest PCU energy conversion occurs on these sunny, cool days.

Summary Table for Monthly ODAS Data

Month		Hours of Operation	Array Solar Energy (kW-Hrs)	PCU Output Energy (kW-Hrs)
November	1984	215.67	328,063	22,091
December	1984	238.17	264,443	18,262
January	1985	170.50	306,312	15,734
February	1985	209.50	370,591	21,599
March	1985	311.00	431,843	31,813
April	1985	225.17	508,794	22,513
May	1985	249.83	475,493	20,893
June	1985	299.83	457,628	24,965
July	1985	224.17	494,547	19,303
August	1985	344.83	420,933	27,991
September	1985	328.00	490,147	33,853
October	1985	281.50	321,881	22,383
November	1985	205.00	221,725	12,382
December	1985	81.67	214,167	5,126
Averages:		241.77	379,041	21,351
Totals:		3,384.84	5,306,567	298,908

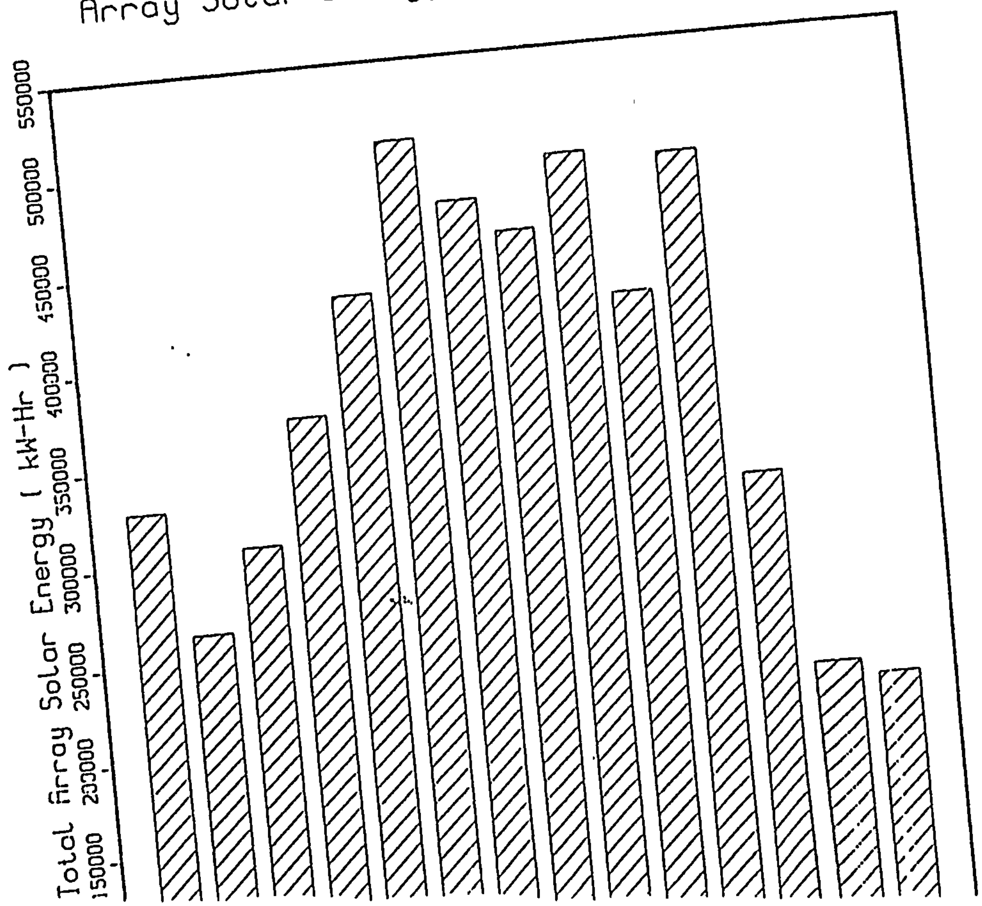
Georgetown 300-kW Flat-Plate Photovoltaic Array

Hours of Operation for each Month, Nov 84 - Dec 85



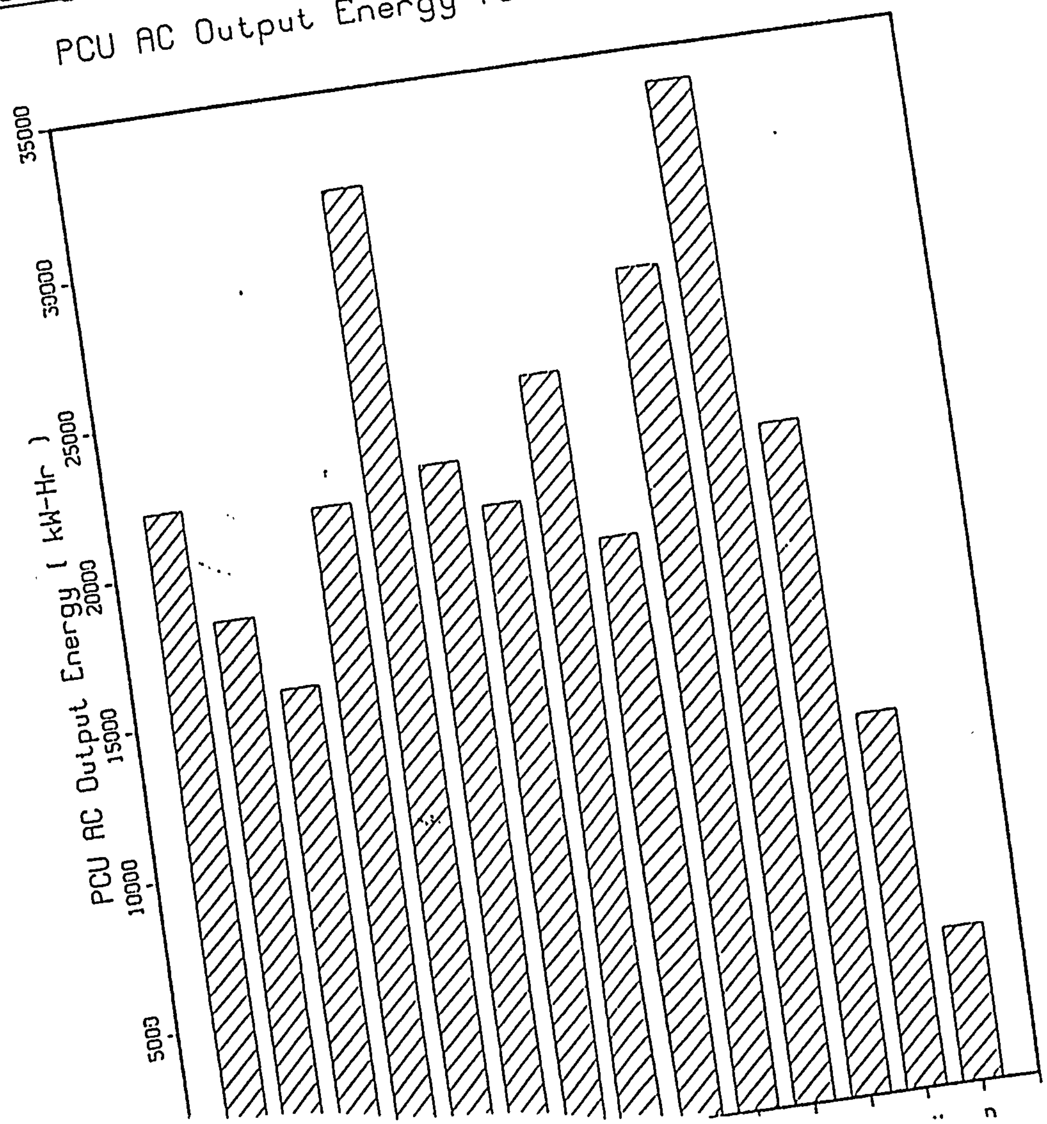
Georgetown 300-kW Flat-Plate Photovoltaic Array

Array Solar Energy for Nov 84 - Dec 85



Georgetown 300-kW Flat-Plate Photovoltaic Array

PCU AC Output Energy for Nov 84 - Dec 85



Summary of December 1985 Events

The photovoltaic system operated without any interruptions o events until December 9, 1985 when the PCU tripped out due to a manuall induced ground fault condition caused by SAIC personnel during arr cleaning experiments. The system was brought back up the next da however, for safety reasons, the PCU was taken off line December The system will be down until the safety considerations have t resolved. The details surrounding the event are recorded in sepa documentation, and details concerning the array cleaning experiment recorded in a separate section in this report.

Summary of December 1985 Performance

This was a poor month for overall system performance beca system was down for more than half of the month. The PCU was s on December 12 and the system was not brought back up. While th was up for the first part of the month, it operated for a to hours and produced a total of 5126 kW-hours of AC electrica The peak array efficiency was 8% and the total PCU efficiency 93%. Considering the limited performance period, these numb to be reasonable.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of December, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	5.83	1775.05	71.00	4.00	*	53.00	74.65	*
2	9.00	15171.65	1089.00	7.18	7.94	1034.00	94.95	244.0
3	9.17	15707.54	1124.00	7.16	8.05	1067.00	94.93	254.4
4	8.67	4342.72	272.00	6.26	*	241.00	88.60	*
5	5.83	2768.63	153.00	5.53	*	133.00	86.93	*
6	7.17	8216.58	572.00	6.96	*	537.00	93.88	*
7	6.17	3114.72	175.00	5.62	*	154.00	88.00	*
8	8.67	13017.03	929.00	7.14	*	879.00	94.62	*
9	5.00	12838.42	531.00	4.14	*	503.00	94.73	*
10	1.50	8127.29	254.00	3.13	*	217.00	85.43	*
11	7.33	1775.05	227.00	12.79	*	205.00	90.31	*
12	6.67	3862.70	125.00	3.24	*	99.00	79.20	*
13	0.67	1094.06	8.00	0.73	*	4.00	50.00	*
14	0.00	13698.04	0.00	0.00	*	0.00	*	*
15	0.00	11945.32	0.00	0.00	*	0.00	*	*
16	0.00	15227.48	0.00	0.00	*	0.00	*	*
17	0.00	15506.57	0.00	0.00	*	0.00	*	*
18	0.00	8953.40	0.00	0.00	*	0.00	*	*
19	0.00	15930.79	0.00	0.00	*	0.00	*	*
20	0.00	1964.84	0.00	0.00	*	0.00	*	*
21	0.00	8171.94	0.00	0.00	*	0.00	*	*
22	0.00	7636.08	0.00	0.00	*	0.00	*	*
23	0.00	10806.61	0.00	0.00	*	0.00	*	*
24	0.00	12514.66	0.00	0.00	*	0.00	*	*
25	0.00	0.00	0.00	0.00	*	0.00	*	*
26	0.00	0.00	0.00	0.00	*	0.00	*	*
27	0.00	0.00	0.00	0.00	*	0.00	*	*
28	0.00	0.00	0.00	0.00	*	0.00	*	*
29	0.00	0.00	0.00	0.00	*	0.00	*	*
30	0.00	0.00	0.00	0.00	*	0.00	*	*
31	0.00	0.00	0.00	0.00	*	0.00	*	*
	81.67	214167.16	5530.00	2.58	8.05	5126.00	92.69	254.4

Summary of November 1985 Events

There were no nuisance ground fault trips this month, indicating that the threshold level of 100 milliamps and ground fault trip delay relay were working properly to eliminate these trips. There was, however, a single trip which occurred on Sunday November 24, 1985. It was discovered the next morning by John Rogers. The PCU tripped out due to a PCU Logic Failure #3. In addition, the frequency monitoring circuit card #24EA displayed a fault condition 5, indicating that it sensed a line frequency below 60 Hz. This momentary error condition tripped the PCU and took it off line on Sunday. The PCU was manually reset, and brought up at 0820 Monday. (This frequency card had been replaced two days earlier, on Friday November 22 by Gene Hickman of Dynalectric.)

There continues to be some concern over the anomalous readings displayed by the AC kilowatt-hour meter. These readings appear to be on the high side and indicate a calibration problem. Occasionally, this creates a situation where the calculated PCU efficiency rises above 100%. On November 14, the PCU was turned off three times so that the AC kW-hour meter could be examined when there was no DC input to the PCU. Each time, both DC and AC kW-hour meters read zero. In October, the PCU was turned off once and the AC kW-hour meter measured 85 kw, while the DC meter measured zero. This situation was not duplicated during this test, indicating that there may be an intermittent calibration problem. Bill Boyson of Sandia National Laboratories has been notified about of the situation.

Summary of November 1985 Performance

The PCU operated for 205 hours this month, producing a total of 12,382 kW-hours of AC energy. Now that the days are getting shorter, the PCU is producing less energy. The peak normalized efficiency continues to be around 8%. With the anomalous recording of November 14 removed from the data, the total efficiency of the PCU is 95.8% Both of these figures have remained constant over the months since system start-up. The recorded peak PCU ground fault current levels never rose above 1 milliampere this month.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of November, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	9.50	2288.59	102.00	4.46	*	101.00	99.02	*
2	8.67	3527.77	206.00	5.84	*	185.00	89.81	*
3	9.17	1953.67	83.00	4.25	*	78.00	93.98	*
4	3.83	1562.94	48.00	3.07	*	39.00	81.25	*
5	7.83	2757.47	148.00	5.37	*	123.00	83.11	*
6	9.50	10985.22	798.00	7.26	8.16	763.00	95.61	257.3
7	9.67	17036.02	1256.00	7.37	7.84	1215.00	96.74	272.2
8	10.17	18431.49	1374.00	7.45	8.01	1343.00	97.74	259.7
9	9.83	18018.44	1339.00	7.43	7.94	1294.00	96.64	260.8
10	10.00	16410.84	1210.00	7.37	7.89	1185.00	97.93	260.1
11	10.00	8674.31	592.00	6.82	7.94	607.00	102.53	257.2
12	5.33	1562.94	51.00	3.26	*	35.00	68.63	*
13	7.17	6608.98	437.00	6.61	*	404.00	92.45	*
14	8.83	9377.62	50525.00	538.78	*	564.00	1.12	*
15	9.17	12224.41	892.00	7.30	*	881.00	98.77	*
16	0.67	993.58	1.00	0.10	*	51.00	5100.00	*
17	8.67	8149.61	570.00	6.99	*	534.00	93.68	*
18	8.33	9790.70	687.00	7.02	*	649.00	94.47	*
19	8.67	10360.04	726.00	7.01	*	688.00	94.77	*
20	9.17	12570.49	888.00	7.06	*	848.00	95.50	*
21	8.67	1797.38	86.00	4.78	*	93.00	108.14	*
22	1.67	1161.04	72.00	6.20	*	37.00	51.39	*
23	0.33	16500.16	2.00	0.01	*	1.00	50.00	*
24	0.00	13753.85	0.00	0.00	*	0.00	*	*
25	6.50	3248.68	186.00	5.73	*	153.00	82.26	*
26	7.67	4219.95	253.00	6.00	*	227.00	89.72	*
27	4.83	2020.65	93.00	4.60	*	78.00	83.87	*
28	3.83	1373.15	35.00	2.55	*	25.00	71.43	*
29	6.83	3494.29	204.00	5.84	*	180.00	88.24	*
30	0.50	870.78	1.00	0.11	*	1.00	100.00	*
	205.00	221725.06	62865.00	28.35	8.16	12382.00	19.70	272.2

Summary of October Performance

The PCU operated for 282 hours this month, producing 22,383 kW-Hrs of AC electrical energy output. The peak array efficiency was 8.24%, recorded on October 5. The peak power at NOCT was 289 kW with an average peak value of 274 kW. There appears to be a problem, however, with the total PCU conversion efficiency. In the past it has been very steady around 96%, but this month it reads 102.7%. This is a result of a few days where the recorded values for AC kW output from the PCU is greater than the DC kW input. On one day this month, it was noted that at 7:55am the PCU AC kW meter was reading 85 kW while the DC kW meter was reading 0. At the same time, the AC kW-Hr counter was incrementing while the DC kW-Hr counter was steady. This problem has not been resolved.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of October, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	11.00	14000.00	948.00			910.00	95.99	
2	7.00	2550.00	173.00			143.00	82.65	
3	5.67	1473.63	86.00	5.84	*	74.00	86.05	*
4	7.83	2891.44	150.00	5.19	*	124.00	82.67	*
5	10.50	11052.21	806.00	7.29	8.24	760.00	94.29	277.0
6	11.00	18744.10	1411.00	7.53	8.18	1350.00	95.68	275.4
7	11.33	20519.15	1533.00	7.47	8.15	1523.00	99.35	279.5
8	10.67	19358.11	1338.00	6.91	*	1280.00	95.67	*
9	11.00	17873.32	1259.00	7.04	7.83	1253.00	99.52	280.8
10	8.67	16533.64	798.00	4.83	*	759.00	95.11	*
11	11.00	7736.53	533.00	6.89	8.10	485.00	90.99	255.9
12	11.33	4566.00	0.00	0.00	*	57.00	*	*
13	11.00	9422.29	0.00	0.00	*	84.00	*	*
14	8.83	10840.09	709.00	6.54	*	715.00	100.85	*
15	7.50	9589.74	676.00	7.05	8.07	644.00	95.27	268.8
16	10.33	19134.83	1455.00	7.60	7.98	1399.00	96.15	271.3
17	10.83	19112.51	1451.00	7.59	8.14	1448.00	99.79	273.3
18	10.00	14189.25	1049.00	7.39	7.95	985.00	93.90	269.8
19	10.00	14222.74	1033.00	7.26	*	985.00	95.35	*
20	6.00	1228.02	30.00	2.44	*	23.00	76.67	*
21	6.50	1373.15	36.00	2.62	*	46.00	127.78	*
22	8.50	2489.54	111.00	4.46	*	830.00	747.75	*
23	8.17	5157.70	319.00	6.18	*	290.00	90.91	*
24	5.83	1830.87	68.00	3.71	*	50.00	73.53	*
25	3.17	0.00	293.10	*	*	279.10	95.22	*
26	10.67	19380.43	1445.00	7.46	7.96	1491.00	103.18	275.1
27	10.50	13988.29	1028.00	7.35	7.83	1315.00	127.92	275.5
28	10.50	12447.69	917.00	7.37	*	911.00	99.35	*
29	10.00	16120.59	1189.00	7.38	8.01	1283.00	107.91	264.3
30	8.83	10326.55	745.00	7.21	8.11	700.00	93.96	289.1
31	7.33	3728.73	214.00	5.74	*	187.00	87.38	*
	281.50	321881.14	21803.10	6.77	8.24	22383.10	102.66	289.1

Summary of September 1985 Events

On Sunday September 8, there was a severe thunderstorm which damaged the receiver at Harbin Hall. The PCU also went down at 3:50pm due to an apparent ground fault trip, however the ODAS never recorded any current over 1 milliampere for the whole day. This was probably a very sharp spike which tripped the PCU between the 1 minute interval recordings. The PCU was reset Monday morning at 7:00, therefore only a couple of hours of operation time was lost. This was the only PCU downtime for the month.

On Wednesday September 11, Mike Preston (Dynalectric) installed a time-delay relay in the PCU ground fault current sensing/tripping circuit. This was done because the PCU had tripped over a very fast DC ground fault spike (or other fast system spike) which was very short-lived. This circuit should prevent the PCU from tripping over extremely short duration DC ground fault currents. Also, it was noted that at no time in September did the ODAS record a ground fault current in excess of 1 milliampere, except on the afternoon of September 11, when at 2:20pm a current of 29.7 milliamperes was recorded. This would have been enough to bring the PCU down with its previous threshold of 25 milliamperes. By 2:30pm the DC ground fault current was back down to less than 1 milliampere where it remained for the rest of the month.

On Friday September 27, Mike Preston replaced the 24EA circuit card from the PCU and sent it to Omnion for Adjustment. The card controls PCU triggering.

Early Saturday morning September 28, the ODAS computer died. There were no more automatic recordings for the last three days of September. HP was notified, but did not arrive before the end of the month, however, the PCU was not affected and readings continued to be taken manually.

Summary of September Performance

The PCU was up and running every day in September, converting energy for a total of 328 hours. The total PCU AC output for the month was 33,853 kW-Hrs with an average conversion efficiency of 96.3%. The average peak array efficiency was about 8% for the month, with a peak of 8.86% reached on September 27. The figures for peak power at NOCT averaged about 281 kW. The peak of 306.2 kW was recorded on September 13.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of September, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	12.00	13854.33	972.00	7.02	7.89	926.00	95.27	274.8
2	11.83	16812.73	1198.00	7.13	7.49	1201.00	100.25	274.0
3	12.00	16756.93	1170.00	6.98	*	1120.00	95.73	*
4	11.83	18688.26	1328.00	7.11	7.55	1274.00	95.93	276.0
5	11.67	19570.21	1392.00	7.11	7.38	1341.00	96.34	274.0
6	11.50	19659.52	1401.00	7.13	7.40	1352.00	96.50	274.8
7	11.33	17437.91	1212.00	6.95	*	1165.00	96.12	*
8	9.50	9143.20	567.00	6.20	*	536.00	94.53	*
9	9.83	12615.14	865.00	6.86	*	893.00	103.24	*
10	10.50	15919.63	1138.00	7.15	*	1151.00	101.14	*
11	8.50	12615.14	484.00	3.84	8.46	467.00	96.49	278.4
42	11.17	21992.78	1662.00	7.56	8.00	1598.00	96.15	287.3
13	11.50	20396.34	1545.00	7.57	8.40	1478.00	95.66	306.2
14	11.50	21791.82	1656.00	7.60	8.06	1590.00	96.01	282.3
15	11.50	21724.82	1637.00	7.54	7.97	1571.00	95.97	295.2
16	11.50	20184.22	1514.00	7.50	7.93	1452.00	95.90	287.3
17	11.17	20251.22	1457.00	7.19	7.89	1395.00	95.74	280.6
18	11.17	15618.22	1151.00	7.37	8.01	1098.00	95.40	273.8
19	11.17	18498.49	1360.00	7.35	*	1300.00	95.59	*
20	11.17	18922.71	1385.00	7.32	7.58	1322.00	95.45	275.5
21	11.00	15607.05	1128.00	7.23	7.92	1078.00	95.57	278.9
22	9.67	6430.37	417.00	6.48	*	384.00	92.09	*
23	9.67	6229.41	403.00	6.47	*	369.00	91.56	*
24	10.33	10505.16	744.00	7.08	*	697.00	93.68	*
25	11.67	18878.06	1388.00	7.35	7.90	1345.00	96.90	275.5
26	9.50	3125.88	164.00	5.25	*	141.00	85.98	*
27	8.00	15037.69	1181.00	7.85	8.86	1106.00	93.65	285.2
28*	12.00	20930.00	1570.00			1530.00	97.45	
29*	12.00	20930.00	1570.00			1530.00	97.45	
30*	11.83	20020.00	1502.00			1443.00	96.07	
	328.00	490147.25	35161.00	7.17	8.86	33853.00	96.28	306.2

* Note: ODAS was down from September 28-30; data was obtained directly from PCU or estimated.

Summary of August 1985 Events

The PCU tripped out three times this month, but was down for a total of only one day. The first trip occurred at 10:55am on Friday August 2nd. This was a repeat of the same PCU logic failure #2 that occurred on July 25. Circuit card 4EA was reset, but repeated attempts to reset the PCU by hitting the start button forced the PCU into logic failure #5. The PCU was finally left in the auto-start position and came up on its own at 11:25am.

There were two DC ground faults this month. The first one occurred early Sunday morning August 18, and caused the PCU to be down for the whole day. It was discovered Monday morning August 19 by John Rogers, and he reset the PCU at 8:45am. The second DC ground fault trip occurred early Wednesday morning August 21. It was discovered at 3:30pm and reset by John Rogers.

On Tuesday August 20, Mike Preston (Dynalectric) replaced the shorted diodes of circuits 52-1 and 52-2 in panel E (#5) under roof B and reconnected the strings to the system. These diodes had burned out previously, and the two strings were removed from the system because they were causing a permanent ground fault. He also replaced the 35-amp harmonic filter capacitor fuses in cubicle D with 40-amp fuses because they had a tendency to blow whenever the system was brought down unexpectantly.

Finally, on Tuesday August 27, some modifications were made to the PCU and ODAS which will hopefully reduce the frequency of ground fault trips. Mike Preston (Dynalectric) installed a new ground fault sensing circuit which was provided by Omnion Engineering Corporation, and adjusted the new ground fault current trip threshold up from 25 milliamperes to 100 milliamperes. This means that if a ground fault current is ever sensed which exceeds 100 milliamperes, the PCU will automatically shut down and stay down until manually reset. On the same day Robert Malinowski (SAIC) installed a ground fault sensing channel for the ODAS computer recording system by measuring the voltage across 48R, one of the six 250 ohm resistors in the neutral line of the PCU. Bill Boyson and Sven Breden

(Sandia National Laboratories) modified the ODAS software to include the recording of the ground fault current channel. This has been added as element number 33 to the ODAS recording data. They also replaced the DVM with a newly calibrated DVM updated some of the ODAS routines.

Summary of August Performance

The PCU operated for 345 hours in August, producing 27,991 kW-Hrs of AC energy. The peak array efficiency of 8.02% was recorded on August 2, and a peak normalized power output of 286 kW was recorded on August 22. The total PCU energy conversion efficiency for the month of August was 96% (same as July). The PCU operated for a record number of hours this month, due in part to the longer summer days, clear weather, and fewer down times. The PCU ground fault current measurements for the last five days never rose above 1 milliampere and the PCU did not trip out after the increase in ground fault trip threshold.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of August, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	11.00	8919.92	618.00	6.93	*	582.00	94.17	*
2	11.67	18788.74	1106.00	5.89	8.02	1068.00	96.56	276.7
3	13.50	13474.76	949.00	7.04	*	904.00	95.26	*
4	12.50	18331.04	1317.00	7.18	7.94	1268.00	96.28	279.0
5	13.67	19246.47	1389.00	7.22	7.66	1343.00	96.69	278.3
6	13.67	11476.43	781.00	6.81	7.78	750.00	96.03	279.7
7	12.83	16176.40	1150.00	7.11	*	1098.00	95.48	*
8	10.83	11175.01	781.00	6.99	7.74	744.00	95.26	282.2
9	12.33	15037.69	1057.00	7.03	7.65	1014.00	95.93	274.4
10	12.00	15953.14	1130.00	7.08	7.99	1084.00	95.93	281.6
11	12.50	15796.83	1104.00	6.99	*	1059.00	95.92	*
12	12.17	21401.09	1553.00	7.26	7.61	1504.00	96.84	285.2
13	12.67	14993.04	1036.00	6.91	*	994.00	95.95	*
14	12.17	17538.39	1216.00	6.93	*	1176.00	96.71	*
15	12.17	18744.10	1313.00	7.00	*	1270.00	96.73	*
16	11.17	8841.76	592.00	6.70	*	559.00	94.43	*
17	10.17	10639.13	749.00	7.04	*	714.00	95.33	*
18	0.00	2668.16	0.00	0.00	*	0.00	*	*
19	10.83	16053.59	1128.00	7.03	7.92	1086.00	96.28	281.7
20	12.17	13240.31	951.00	7.18	7.90	908.00	95.48	282.4
21	3.50	9344.13	205.00	2.19	*	182.00	88.78	*
22	12.17	16656.45	1219.00	7.32	7.83	1163.00	95.41	285.8
23	12.17	17504.91	1271.00	7.26	7.85	1218.00	95.83	280.6
24	11.50	10884.73	766.00	7.04	*	736.00	96.08	*
25	10.83	4085.95	234.00	5.73	*	238.00	101.71	*
26	10.50	8573.83	574.00	6.69	*	537.00	93.55	*
27	7.33	3985.50	640.00	16.06	*	612.00	95.62	*
28	11.83	20429.83	1501.00	7.35	7.71	1446.00	96.34	278.1
29	11.83	16768.09	1201.00	7.16	7.57	1149.00	95.67	278.1
30	11.33	12257.89	840.00	6.85	7.82	781.00	92.98	272.6
31	11.83	11945.32	849.00	7.11	7.60	804.00	94.70	273.0
	344.83	420932.61	29220.00	6.94	8.02	27991.00	95.79	285.8

Summary of July 1985 Events

This month the PCU tripped out five times, shutting down the photovoltaic system until it could be manually reset. Four of the PCU trips were due to DC ground faults, and one trip was due to a PCU Logic Failure #2.

DC Ground Fault trips occur when the DC ground fault current detected from the neutral line to ground exceeds a preset threshold. This threshold is presently set to 25 milliamperes. The first DC ground fault trip occurred on the afternoon of Wednesday July 3. Because of the holiday, it was not discovered until Friday morning July 5 by John Rogers. Since John was instructed not to reset the PCU himself, the system was down until Mike Preston (Fleetwood) was able to come out to the site and reset the inverter on Wednesday July 10. The system was down for a total of 7 days because of this one ground fault.

The next DC ground fault trip of the system occurred two days later at 7:00 am Friday July 12. John Rogers discovered it an hour later, and the system was down for the weekend until it was reset Monday morning at 10:20 by Robert Malinowski. After this trip, John Rogers was instructed to reset the PCU himself after common trips and continue to log the failures in the system log book. The next two ground fault trips occurred on Monday July 29 and Wednesday July 31 and were reset the same day by John Rogers. The July 31 ground fault trip occurred during a very heavy thunderstorm.

The DC ground fault trips are continuing to be a source of nuisance shutdowns, and in July caused the system to be out of service for a total of 11 days. As a result, in August the trip threshold level will be raised to a new value which should greatly reduce the number of occurances of these trips, yet continue to provide adequate personnel and equipment protection. Also, the ground fault current will be measured every minute and recorded every 10 minutes while the PCU is in operation. This should provide more information about the ground fault current problem.

The PCU also tripped out this month at noon on Thursday July 25 due to a PCU Logic Failure #2. It was the first PCU Logic failure #2 to occur since the PEPCO feeder servicing the university temporarily lost power on May 22. Before that, the failures were due to a defective triggering circuit card in the inverter. The cause of this failure is unknown.

Summary of July Performance

The PCU operated for 224 hours in July, producing 19,303 kW-Hrs of AC energy. Peak array efficiency of 8.55% was recorded on July 29, and a peak normalized power output of 295 kW was recorded on July 16. The total PCU conversion efficiency for the month of June was 96%. The figures for total energy are slightly lower this month compared with June because the days are getting shorter, however the array and PCU efficiencies continue to be at approximately the same levels that they have been for the past several months.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of July, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	12.50	9243.65	646.00	6.99	8.47	605.00	93.65	282.4
2	13.00	13508.24	945.00	7.00	*	900.00	95.24	*
3	8.33	15573.57	895.00	5.75	*	861.00	96.20	*
4	0.00	16991.37	0.00	0.00	*	0.00	*	*
5	0.00	17940.28	0.00	0.00	*	0.00	*	*
6	0.00	11867.16	0.00	0.00	*	0.00	*	*
7	0.00	20943.36	0.00	0.00	*	0.00	*	*
8	0.00	17951.47	0.00	0.00	*	0.00	*	*
9	0.00	15651.70	0.00	0.00	*	0.00	*	*
10	11.00	10147.95	633.00	6.24	*	589.00	93.05	*
11	13.00	20965.68	1515.00	7.23	7.57	1464.00	96.63	280.4
12	1.67	11722.03	17.00	0.15	*	13.00	76.47	*
13	0.00	18554.30	0.00	0.00	*	0.00	*	*
14	0.00	18699.42	0.00	0.00	*	0.00	*	*
15	8.50	16857.41	1028.00	6.10	*	988.00	96.11	*
16	13.17	16187.59	1139.00	7.04	7.95	1092.00	95.87	295.5
17	12.67	19771.17	1417.00	7.17	7.80	1364.00	96.26	282.6
18	12.67	18029.60	1235.00	6.85	7.54	1190.00	96.36	275.1
19	12.67	18788.74	1329.00	7.07	*	1284.00	96.61	*
20	13.00	18163.57	1273.00	7.01	*	1228.00	96.47	*
21	12.67	14256.22	970.00	6.80	*	928.00	95.67	*
22	12.00	12771.42	811.00	6.35	*	774.00	95.44	*
23	11.83	22026.27	1452.00	6.59	7.61	1401.00	96.49	280.1
24	12.50	21423.41	1541.00	7.19	7.66	1492.00	96.82	277.3
25	8.50	10360.04	457.00	4.41	*	433.00	94.75	*
26	0.00	13809.68	0.00	0.00	*	0.00	*	*
27	0.00	12079.28	0.00	0.00	*	0.00	*	*
28	0.00	20016.77	0.00	0.00	*	0.00	*	*
29	10.50	11230.82	793.00	7.06	8.55	755.00	95.21	276.4
30	12.50	16142.91	1139.00	7.06	7.58	1096.00	96.22	278.2
31	11.50	12871.91	882.00	6.85	*	846.00	95.92	*
	224.17	494547.00	20117.00	4.07	8.55	19303.00	95.95	295.5

Summary of June 1985 Events

There were three DC ground fault failures this month which brought the system down for a total of 4 1/2 days. On June 3rd, Mike Preston took neutral current readings from all collection panels in order to try to locate the source of the ground fault failures. No problems were discovered because the ground faults occur intermittently. The first one occurred on Wednesday June 12th and was discovered Thursday morning by John Rogers. The next morning, Mike Preston (Fleetwood) reset the PCU and brought it back up. The next time the PCU tripped out due to a ground fault failure was on Sunday June 16th. It was discovered Monday morning June 17th by John Rogers. He reset the PCU and brought it back up. The last ground fault of the month occurred on Monday June 24th. It was discovered Tuesday morning June 25th and was reset Thursday by Mike Preston. There were no other failures of the photovoltaic system this month.

On June 21, Mike Preston checked both monopoles of string 52 at branch circuit panel #5 because it had no voltage present when New Mexico Solar Energy Institute checked it in April. There was still no voltage present. The junction box mounted above the exit at the east end of the roof was then checked, and both the positive and negative monopoles read "0" volts. The neutral had 10 volts present. This problem will be further investigated in July when Hughes arrives.

Summary of June Performance

The PCU operated for 300 hours in June, producing 24,965 kW-Hrs of AC power. Peak array efficiency of 8.16% was recorded on June 20, and a peak normalized power output of 294 kW was recorded on June 21. The total PCU conversion efficiency for the month of June was 95.6%

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of June, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	12.33	22350.00	1642.00	7.35	7.79	1580.00	96.22	274.0
2	12.83	15383.77	1080.00	7.02	*	1038.00	96.11	*
3	9.83	33.49	619.00	*	*	575.00	92.89	*
4	12.67	11342.46	780.00	6.88	*	742.00	95.13	*
5	11.67	5604.24	346.00	6.17	*	312.00	90.17	*
6	12.83	20139.58	1460.00	7.25	7.66	1405.00	96.23	275.6
7	10.67	9366.45	640.00	6.83	*	606.00	94.69	*
8	11.50	16299.20	1177.00	7.22	7.93	1129.00	95.92	275.5
9	12.67	16131.75	1133.00	7.02	*	1087.00	95.94	*
10	12.67	17058.34	1190.00	6.98	7.72	1146.00	96.30	274.0
11	13.50	14390.19	994.00	6.91	*	948.00	95.37	*
12	4.83	14300.90	315.00	2.20	*	300.00	95.24	*
13	0.00	16924.38	0.00	0.00	*	0.00	*	*
14	10.33	15919.63	949.00	5.96	7.93	900.00	94.84	285.4
15	10.67	8919.92	592.00	6.64	*	556.00	93.92	*
16	0.00	11789.03	0.00	0.00	*	0.00	*	*
17	11.83	19279.95	1345.00	6.98	7.69	1292.00	96.06	279.6
18	12.67	9734.86	664.00	6.82	*	624.00	93.98	*
19	12.17	17292.78	1236.00	7.15	7.95	1189.00	96.20	280.1
20	11.83	18130.08	1304.00	7.19	8.16	1254.00	96.17	273.9
21	12.83	15473.09	1078.00	6.97	7.38	1027.00	95.27	293.8
22	12.67	18118.92	1288.00	7.11	*	1238.00	96.12	*
23	12.83	15886.14	1096.00	6.90	7.47	1049.00	95.71	270.6
24	10.33	17114.17	1169.00	6.83	*	1129.00	96.58	*
25	0.00	21736.01	0.00	0.00	*	0.00	*	*
26	0.00	20061.42	0.00	0.00	*	0.00	*	*
27	5.50	14624.63	190.00	1.30	*	169.00	88.95	*
28	12.50	16511.32	1180.00	7.15	7.73	1131.00	95.85	266.4
29	12.67	20753.59	1470.00	7.08	7.67	1415.00	96.26	289.3
30	13.00	16957.89	1174.00	6.92	7.61	1124.00	95.74	267.0
	299.83	457628.19	26111.00	5.71	8.16	24965.00	95.61	293.8

Summary of May 1985 Events

This month, the only problems with the photovoltaic system were two intermittent ground faults detected by the PCU. These ground faults caused the PCU to automatically shut down and remain off until the fault was cleared and the PCU manually re-started. The system was down for a total of 8 days in May due to these DC ground faults. On Friday May 3rd, the PCU tripped out due to the first DC ground fault. John Rogers (GU) tried to reset the system, but the fault remained. On Tuesday May 7th, Bob Malinowski (SAIC) tried to reset the system at 11:00 am, and again the fault would not clear; however, three hours later, Mike Preston arrived (Fleetwood) and the fault was no longer present. The PCU was reset and brought up at 2:00 pm. The system was down for 4 1/2 days.

The second DC ground fault occurred on Friday afternoon May 17th, but was not discovered until Monday morning May 20th by John Rogers (GU). This also caused a 300-amp fuse in cubicle "C" to clear. The next day, Mike Preston (Fleetwood) replaced the blown fuse (2SCR3), reset the PCU, and brought the system back up at noon. The system was down for 3 1/2 days.

Since April 19 when Tom Schoknect (Omnion) replaced the circuit boards 2EA and 14EA in the PCU, the PCU Logic failure #2 has not caused the PCU to unexpectedly trip out. PCU Logic Failure #2 was due to an intermittent firing of circuit board 14EA. A PCU Logic Failure #2 did occur at 1:45 pm on Wednesday May 22, however this time it was due to a failure on the PEPCO feeder servicing the building which caused a momentary interruption of the power. The PCU responded properly by shutting down, and no fuses were blown.

On May 30, Bill Boyson and Mark Yee arrived from Sandia to service the ODAS. They added a pressure transducer to the data acquisition system and exchanged the two pyranometers and DVM with newly calibrated instruments. They also replaced a previously damaged anemometer.

Summary of May 1985 Performance

The system was up this month every day except for the two periods it was down for DC ground fault failures. The system had a total solar energy conversion time of 250 hours and produced 20,893 kW-Hrs of AC power at an average PCU efficiency of 95.67%. A peak array efficiency of 8.31% occurred on May 25, and a peak normalized array power output of 286.6 kW occurred on May 14.

O&M Manual Comments

The O&M Manual provided by Hughes dated August 16, 1984 has been reviewed. Only a few minor problems exist with it in its present form. The troubleshooting section on page 30 concerning PCU Logic Failure #2 has an omission. Under the "cause" heading, the sentence beginning with "4EA and 5EA are phase loss detectors...", 7EA should also be included to make it read "4EA, 5EA, and 7EA are phase loss detectors...". Similarly, under the adjacent "Solution" heading, the first sentence should read "Reset 4EA, 5EA, or 7EA and check the SCR fuses."

The other omission from the manual is a comment about the PCU remote shut down from the Inter-Cultural Center's main building transformer room in the basement. A recently installed switch in the transformer room triggers the PCU controller to crowbar the array. This switch must be activated before the AC to the PCU is removed by opening the main circuit breaker, if possible damage or blown fuses is to be avoided. The switch is properly labeled and a sign explains the proper order for remote shut-down of the PCU from the basement, however there is nothing in the O&M manual concerning the procedure.

Operating personnel from Georgetown University are aware of these omissions, otherwise the O&M Manual provides sufficient information about the inverter. It does not, however, provide any information about other parts of the photovoltaic system such as the array itself, the data acquisition system computer, or the weather station. Present operating personnel are informed about these parts of the system, but future personnel may not have any written information to refer to.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of May, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	11.83	19611.40	1407.00	7.17	7.72	1359.00	96.59	273.4
2	8.33	6368.30	405.00	6.36	*	377.00	93.09	*
3	0.00	12610.04	0.00	0.00	*	0.00	*	*
4	0.00	22877.84	0.00	0.00	*	0.00	*	*
5	0.00	21042.03	0.00	0.00	*	0.00	*	*
6	0.00	18446.59	0.00	0.00	*	0.00	*	*
7	5.83	16712.08	544.00	3.26	7.90	490.00	90.07	257.9
8	12.50	22194.17	1645.00	7.41	8.03	1588.00	96.53	282.1
9	12.67	21383.87	1586.00	7.42	8.19	1530.00	96.47	279.7
10	12.50	19624.03	1406.00	7.16	7.75	1355.00	96.37	279.0
11	12.50	19712.67	1390.00	7.05	7.69	1340.00	96.40	275.8
12	12.00	15559.97	1096.00	7.04	7.91	1051.00	95.89	276.3
13	12.67	20839.48	1510.00	7.25	7.72	1469.00	97.28	285.4
14	12.67	21725.70	1577.00	7.26	7.73	1526.00	96.77	286.6
15	11.17	4899.68	286.00	5.84	*	254.00	88.81	*
16	10.17	3127.18	161.00	5.15	*	133.00	82.61	*
17	5.50	6494.93	130.00	2.00	*	147.00	113.08	*
18	0.00	20776.17	0.00	0.00	*	0.00	*	*
19	0.00	20219.09	0.00	0.00	*	0.00	*	*
20	0.00	21751.03	0.00	0.00	*	0.00	*	*
21	7.33	15154.82	553.00	3.65	*	520.00	94.03	*
22	12.33	18535.23	1201.00	6.48	7.79	1127.00	93.84	278.9
23	8.50	2924.61	148.00	5.06	*	118.00	79.73	*
24	9.83	5304.83	337.00	6.35	*	306.00	90.80	*
25	12.67	21181.32	1530.00	7.22	8.31	1468.00	95.95	276.5
26	12.83	21421.85	1536.00	7.17	7.75	1479.00	96.29	277.6
27	12.83	21269.93	1526.00	7.17	7.62	1467.00	96.13	277.6
28	9.67	11584.53	800.00	6.91	*	767.00	95.87	*
29	12.33	4570.51	277.00	6.06	*	275.00	99.28	*
30	2.67	9039.72	173.00	1.91	*	163.00	94.22	*
31	8.50	8529.18	613.00	7.19	8.30	584.00	95.27	279.8
	249.83	475492.80	21837.00	4.59	8.31	20893.00	95.68	286.6

Summary of April 1985 Events

On April 8, Bob Malinowski inspected the solar control room and discovered that the 12 fuses protecting the DC filter capacitors in the "A" cabinet were still missing. Omnion Power Engineering Company was expected to service the inverter sometime this month. These fuses, however, offer redundant protection to the DC input circuitry of the PCU, and are therefore not essential to the operation of the inverter. The tape transport drives of the data acquisition computer were also cleaned. The weather station was examined and found to be in good condition, except for the missing cup from the anemometer. This does not provide a critical measurement, and Sandia has been informed and plans to replace it on the next visit to the site. The pyranometer had very little dust residue on it and it was removed. The modules still looked very dirty, and rubbing a small section with a white cloth removed a dark black residue which is believed to be from airplane exhaust.

From April 8th through the 10th, Tom Schoknect from Omnion Power Engineering Company was at the site servicing the inverter and trying to determine the cause of frequent fuse failure in the unit. He installed a time-delay module to the relay CB in order to delay the crowbar relay 13M when the array is shorted. This causes the DC bus to be disconnected from the inverter input circuitry before the array is shorted and should prevent the fuses from blowing due to transients. Tom also replaced the logic circuit boards 2EA and 14EA with new boards.

On Saturday April 13, the inverter was tripped and the system was shut down. On Monday morning April 15 it was discovered that the inverter tripped due to logic failure #2, and Mike Preston of Fleetwood Testing Company was notified. Mike came out to the site that morning and found that 11 of the 12 12-amp fuses in cabinet "A" and 4 of the SCR 300-amp fuses in cabinet "C" were blown. These were replaced and the inverter was brought up. Mike then turned off 9 of the 10 branch circuits, leaving brach circuit #1 connected and shut the PCU off. This caused the 12-amp fuse #F12 the blow. The fuse was replaced and the inverter was brought back up to full power at 2:15pm.

Two days later on Wednesday April 17, the inverter went down again due to the same logic failure #2. On Thursday morning April 18, John Rogers discovered that 4 of the 12 SCR fuses ($50 each) were blown and that there were no more spares present. He notified Mike Preston of Fleetwood Testing Company and Dave Porter of Omnion Company. Friday April 19, Tom Schoknect returned from Omnion to repair the inverter. He replaced the circuit boards 2EA and 14EA with the original boards that were removed on his visit the week before. These original boards had revisions made at the factory which were supposed to reduce the intermittent three-phase SCR firings which cause logic failure #2 to trip the inverter. He also replaced the blown fuses and brought the inverter back up and stayed until Saturday to observe the inverter.

On Monday April 22, two representatives of the New Mexico Solar Energy Institute arrived at the site for three days of testing. Each branch circuit and string was examined for possible defects and open circuit voltage, short circuit current, and I-V curves were measured for each string. String 4-1 was found to have an open circuit; string 51-2 was found to have a very low current (0.2 amps where the average was about 2.0 amps); and three breakers were found to be defective. NMSEI will provide a complete report of their findings.

On Wednesday April 24, after all the testing was completed, the inverter tripped out in the presence of John Rogers due to a ground fault. He discovered that the inverter would not reset and therefore he removed all AC power from the inverter. When the power was restored, logic failure #2 was indicated on the display and the inverter still would not reset. This was the first time that logic failure #2 was present without the blowing of any fuses. The inverter remained down for 5 days.

Mike Preston returned on Tuesday April 30 and discovered a DC ground fault present with strings 52-1 and 52-2 in branch circuit #5 located on roof "B". In order to remove the ground fault condition, the neutral conductor had to be removed from the bus and the two strings turned off. The inverter was then brought up. (Omnion claims that the failure was due to the array and not the inverter.)

New Data Sheets

There is only one pyranometer located in the plane of the array on the roof with the weather station. This is the Sandia pyranometer which has been there for about a year. It is not the same pyranometer provided by Hughes which was used for the acceptance tests in August of 1984. Since data has been recorded using the Sandia pyranometer and this pyranometer measures about 6% more insolation than the Hughes pyranometer measured last summer, data recorded using this pyronometer has been adjusted to 94% of the reading to maintain consistency with the data recorded during the acceptance tests. This has been determined to be a reasonable thing to do for a variety of reasons. The Hughes pyranometer had been calibrated just before the acceptance tests using SAIC approved DSET calibrations. Also, Bill Boyson verified that 7% variations were not uncommon amoung calibrated pyranometers, and that there is no absolute standard by which pyranometers are calibrated. Finally, the New Mexico Solar Energy Institute brought their own calibrated pyranometer out to the site on April 22 and found that their measurements were about 7% lower than the Sandia pyranometer.

Data sheets for November through April were generated using the new insolation values. The system was up and operating for 225.17 hours in April and produced 22,513 kW-Hrs of AC output energy. The peak power at NOCT for the month was measured as 291 kW. A new efficiency column was added to the summary charts. This is the peak array efficiency and is only measured when the time is between 10am and 2pm and the system is producing more than 200kW. The peak array efficiency is about 9%. This number is always higher than the overall array efficiency because the overall array efficiency includes the very early morning and late evening hours when the sun is at a low angle and array efficiency is very low.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of April, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Day Efficiency	Array Peak Efficiency	PCU AC Output Energy (kW-Hr)	PCU Day Efficiency	Peak NOCT Power (kW)
1	11.00	17952.83	1379.00	7.68	8.94	1325.00	96.08	280.8
2	11.50	15876.48	1189.00	7.49	8.71	1139.00	95.79	273.0
3	9.17	9887.98	735.00	7.43	8.74	698.00	94.97	278.0
4	11.67	15534.65	1161.00	7.47	8.51	1113.00	95.87	278.2
5	11.17	19674.68	1487.00	7.56	8.20	1439.00	96.77	290.9
6	10.50	17826.23	1373.00	7.70	8.45	1325.00	96.50	280.2
7	10.00	10736.24	794.00	7.40	8.46	755.00	95.09	283.1
8	9.50	20320.37	1384.00	6.81	8.50	1315.00	95.01	274.7
9	9.33	12799.95	459.00	3.59	*	397.00	86.49	*
10	10.67	23194.35	1209.00	5.21	8.43	1134.00	93.80	276.8
11	11.67	13293.71	979.00	7.36	*	933.00	95.30	*
12	12.00	20193.77	1512.00	7.49	8.01	1456.00	96.30	281.3
13	6.00	17648.98	650.00	3.68	8.03	621.00	95.54	279.7
14	0.00	12597.38	0.00	0.00	*	0.00	*	*
15	3.83	7457.13	176.00	2.36	*	154.00	87.50	*
16	11.33	11293.31	795.00	7.04	*	757.00	95.22	*
17	7.33	22801.86	1223.00	5.36	8.13	1183.00	96.73	279.4
18	0.00	22029.58	0.00	0.00	*	0.00	*	*
19	1.83	20814.16	74.00	0.36	*	37.00	50.00	*
20	12.00	20067.17	1429.00	7.12	7.61	1383.00	96.78	278.1
21	12.00	19408.82	1386.00	7.14	*	1337.00	96.46	*
22	11.17	19307.52	996.00	5.16	*	959.00	96.29	*
23	12.00	18560.56	1285.00	6.92	*	1235.00	96.11	*
24	7.83	5469.42	293.00	5.36	*	267.00	91.13	*
25	0.00	15547.31	0.00	0.00	*	0.00	*	*
26	0.00	21852.33	0.00	0.00	*	0.00	*	*
27	0.00	15357.40	0.00	0.00	*	0.00	*	*
28	0.00	17041.26	0.00	0.00	*	0.00	*	*
29	0.00	22244.79	0.00	0.00	*	0.00	*	*
30	11.67	22004.25	1661.00	7.55	7.81	1551.00	93.38	280.1
	225.17	508794.47	23629.00	4.64	8.94	22513.00	95.28	290.9

Summary of the March 1985 Events

The pv system was never down in March, and produced the highest level of electricity for a given month so far. This amounted to a total of 31,813 kW-Hrs of electricity. The peak power at NOCT of 286.8 kW was recorded on March 3. A high level of array efficiency of 7.24% was achieved because the sun is starting to get higher in the sky.

The as-built drawings provided by Hughes were reviewed this month. These drawings consist of 4 sets of architectural drawings. The first set by Kawneer is a complete set of actual array structure drawings. Another set of the Custom Walls and Windows also shows the complete custom gutters, flashing, snow guards, and other custom roof requirements. A third set is a complete set of Inverter Room Plans and module grid layout. All of these drawings appear to be complete.

Finally, the fourth and probably most useful set of drawings for the operations and maintenance of the system, is the electrical wiring diagram of the pv system by Dynalectric. These drawings show the Inverter Room wiring as well as electric closets on other floors which contain junction boxes for the system. They do not have the complete detail of the sensor wiring, but they do show the complete overall system wiring. Missing from the drawing was the new Shunt Trip which was installed last month, but this is a minor addition.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of March, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	10.00	15340.95	1134.00	7.39	1086.00	95.77	264.7
2	10.67	19879.95	1469.00	7.39	1413.00	96.19	263.4
3	10.83	21307.64	1586.00	7.44	1524.00	96.09	286.8
4	3.67	1481.57	23.00	1.55	12.00	52.17	*
5	10.50	22546.76	1691.00	7.50	1635.00	96.69	268.8
6	11.00	23449.19	1778.00	7.58	1708.00	96.06	263.5
7	10.67	13334.11	970.00	7.27	921.00	94.95	*
8	8.17	2680.29	134.00	5.00	111.00	82.84	*
9	10.67	22546.76	1682.00	7.46	1621.00	96.37	263.7
10	11.00	22802.68	1701.00	7.46	1642.00	96.53	265.8
11	9.67	6424.61	417.00	6.49	385.00	92.33	*
12	8.67	14573.23	1063.00	7.29	1021.00	96.05	262.3
13	10.17	18048.20	1333.00	7.39	1280.00	96.02	266.8
14	9.50	14196.10	1046.00	7.37	1002.00	95.79	262.2
15	11.00	23274.10	1759.00	7.56	1695.00	96.36	259.7
16	11.17	21334.58	1573.00	7.37	1514.00	96.25	276.1
17	11.00	19893.43	1506.00	7.57	1442.00	95.75	267.8
18	11.17	23637.76	1791.00	7.58	1721.00	96.09	255.7
19	11.17	22573.70	1683.00	7.46	1616.00	96.02	264.6
20	11.17	10734.63	724.00	6.74	685.00	94.61	*
21	10.83	14236.51	1023.00	7.19	973.00	95.11	*
22	9.17	3461.47	191.00	5.52	165.00	86.39	*
23	8.33	2559.07	121.00	4.73	98.00	80.99	*
24	7.67	2680.29	125.00	4.66	104.00	83.20	*
25	10.83	16620.49	1213.00	7.30	1160.00	95.63	261.7
26	11.50	23961.00	1757.00	7.33	1688.00	96.07	261.3
27	11.67	22250.46	1587.00	7.13	1531.00	96.47	261.4
28	11.33	20149.31	1425.00	7.07	1379.00	96.77	263.3
29	10.17	6909.50	434.00	6.28	406.00	93.55	*
30	10.00	3905.95	211.00	5.40	183.00	86.73	*
31	7.67	2612.95	113.00	4.32	92.00	81.42	*
	311.00	459407.25	33263.00	7.24	31813.00	95.64	286.8

Summary of February 1985 Events

The pv system was down twice in February--once because of a PCU failure, and once for maintenance.

On Monday morning February 11, it was discovered that the PCU had gone down over the weekend for a Logic Failure #2. The 12 fuses which would normally have blown were not in the PCU at the time. The system remained down until January 14 when Omnion advised that it is still acceptable to operate the PCU without the fuses. No one from Omnion has been to the site this year.

On Friday, February 15, Mike Preston installed and tested a Shunt Trip in the basement of the Inter-Cultural Center in the presence of John Rogers who witnessed the successful test. This Shunt Trip allows authorized personnel to shut the pv system down gracefully from the basement by first tripping the array shunt, then opening the PCU power circuit breakers. Previously, if the breakers had been opened without first shorting the array, a back emf was produced by the sudden change in PCU current which often blew the PCU MOV's.

The pv system produced a total of 21,599 kW-Hrs of electricity in February and recorded a peak power at NOCT of 269.1 kW.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of February, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	5.17	1737.47	61.00	3.51	44.00	72.13	*
2	6.17	1885.63	71.00	3.77	53.00	74.65	*
3	9.83	17293.95	1266.00	7.32	1206.00	95.26	261.9
4	9.67	16970.70	1286.00	7.58	1222.00	95.02	262.6
5	7.50	2639.89	125.00	4.74	106.00	84.80	*
6	8.50	8229.45	564.00	6.85	529.00	93.79	*
7	9.83	18829.40	1387.00	7.37	1323.00	95.39	254.5
8	9.67	20741.95	1459.00	7.03	1387.00	95.07	245.8
9	1.00	20809.30	28.00	0.13	22.00	78.57	*
10	0.00	20607.27	0.00	0.00	0.00	*	*
11	0.00	14465.49	0.00	0.00	0.00	*	*
12	0.00	2464.79	0.00	0.00	0.00	*	*
13	0.00	11960.31	0.00	0.00	0.00	*	*
14	3.50	13334.11	242.00	1.81	212.00	87.60	257.0
15	9.50	18883.25	1248.00	6.61	1184.00	94.87	264.5
16	10.00	18869.78	1420.00	7.53	1360.00	95.77	264.3
17	9.17	7865.79	533.00	6.78	498.00	93.43	*
18	10.50	20526.44	1528.00	7.44	1467.00	96.01	267.8
19	10.00	14290.40	1041.00	7.28	997.00	95.77	258.3
20	10.33	20203.20	1527.00	7.56	1468.00	96.14	269.1
21	10.33	17671.07	1301.00	7.36	1247.00	95.85	264.7
22	9.67	12418.23	871.00	7.01	833.00	95.64	*
23	10.00	17334.36	1269.00	7.32	1224.00	96.45	268.7
24	10.17	17980.85	1309.00	7.28	1266.00	96.72	268.4
25	9.67	11704.39	837.00	7.15	803.00	95.94	*
26	8.33	4431.23	262.00	5.91	238.00	90.84	*
27	10.33	18357.97	1389.00	7.57	1340.00	96.47	265.7
28	10.67	21738.65	1635.00	7.52	1570.00	96.02	268.6
	209.50	394245.33	22659.00	5.75	21599.00	95.32	269.1

Summary of January 1985 Events

In January, the pv system went down five times. On Friday, January 11, the PCU was tripped for Logic Failure #2. This is the balance detector circuit. The twelve 12-ampere fuses in cabinet A were blown. These fuses protect the filter capacitors. The fuses were replaced and the system was turned back on by Mike Preston of Fleetwood Testing Company.

The following Monday morning it was discovered that the PCU had gone down over the weekend as a result of a DC Ground Fault Detection. The ground fault current trip level had been set at 12 mA since September 1984. The system was reset and started up again only to have a repeat of the Grounf Fault Detection Trip two days later on January 16 and again on January 17. It has been hypothesized that the snow on the array in January may have contributed to the ground faults. Dave Porter of Omnion was consulted at this point and with the agreement of Niel Marshall of Hughes, Mike Preston set the ground fault current trip level to 25 mA. No DC Ground Fault Detection Errors have been recorded since then.

On Tuesday, January 22 the PCU tripped again for Logic Failure #2 and the 12 fuses were blown again. This time they were replaced with 12-amp KTK time delay fuses. However, on Monday, January 28 the 12 time delay fuses were blown with a Logic Failure #2 of the PCU again. This time the 12 spares were not put in at Omnion's suggestion. They said the fuses provided redundant protection and the PCU could operate satisfactorily without them. Omnion personnel were expected to arrive sometime at the site to examine the PCU, but did not arraive in January.

The summary charts indicate the system down time. No energy was produced on January 12, 13, 17, and 27 due to system failures and no energy was produced on January 31 due to weather. The total January output energy of the pv system was 15,734 kW-Hrs and on January 22 a peak power at NOCT of 267.5 kW was recorded.

A letter from Hughes dated 3 January 1985 suggests a list of annual maintenance tasks. This list has been reviewed and appears to be complete. I believe that the annual maintenance list should be made a semi-annual maintence list with inspections made just after winter and in the fall. Also, it is suggested that performance data be reviewed to insure the PCCS is properly operating. This can be done by examining these monthly summary reports. PV module cleaning is still a problem and has not been resolved. After long periods without precipitation, the array is noticibly coated with a residue which may require a lot a rain to eliminate.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of January, 1985

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	6.67	3111.29	155.00	4.98	136.00	87.74	*
2	4.67	1360.35	38.00	2.79	22.00	57.89	*
3	5.17	1521.97	51.00	3.35	35.00	68.63	*
4	4.17	1481.57	36.00	2.43	24.00	66.67	*
5	8.17	11717.86	933.00	7.96	888.00	95.18	255.5
6	9.00	16351.13	1186.00	7.25	1135.00	95.70	264.0
7	8.00	8700.84	604.00	6.94	569.00	94.21	*
8	8.67	12000.69	867.00	7.22	824.00	95.04	255.2
9	9.17	18102.06	1325.00	7.32	1263.00	95.32	255.7
10	3.50	2814.98	94.00	3.34	80.00	85.11	*
11	2.33	6236.04	92.00	1.48	66.00	71.74	*
12	0.00	16149.09	0.00	0.00	0.00	*	*
13	0.00	10815.46	0.00	0.00	0.00	*	*
14	9.17	17293.95	1235.00	7.14	1177.00	95.30	259.1
15	9.17	18290.62	1328.00	7.26	1267.00	95.41	257.4
16	8.67	17590.25	1272.00	7.23	1213.00	95.36	257.5
17	0.00	3124.76	0.00	0.00	0.00	*	*
18	1.67	2666.82	44.00	1.65	23.00	52.27	*
19	7.33	8323.71	544.00	6.54	510.00	93.75	249.2
20	6.83	12229.67	782.00	6.39	736.00	94.12	210.2
21	1.17	17347.80	26.00	0.15	19.00	73.08	*
22	8.33	16499.28	1162.00	7.04	1108.00	95.35	267.5
23	9.50	18762.04	1389.00	7.40	1325.00	95.39	263.4
24	8.67	7192.33	497.00	6.91	462.00	92.96	*
25	7.17	7784.97	543.00	6.97	510.00	93.92	254.7
26	1.17	18182.88	44.00	0.24	34.00	77.27	*
27	0.00	6262.99	0.00	0.00	0.00	*	*
28	3.83	9616.72	175.00	1.82	153.00	87.43	*
29	9.50	18896.72	1236.00	6.54	1170.00	94.66	259.1
30	8.83	14249.99	1032.00	7.24	985.00	95.45	257.3
31	0.00	1185.25	0.00	0.00	0.00	*	*
	170.50	325864.08	16690.00	5.12	15734.00	94.27	267.5

Summary of December 1984 Events

On December 4, Mike Preston of Fleetwood Testing Company installed the three 450-ampere fuses in the basement of the Inter-Cultural Center to protect the PCU power cables running up to the solar control room. The system was down for about one hour that day for the installation. Otherwise, the system was never down for maintenance or failures.

A comparison of the bar charts for solar energy and array output energy shows a very close similarity, indicating that the system was up the whole time. The system produced 18,262 kW-Hrs of electricity and had a peak power at NOCT of 273.2 on December 4.

On December 15, SAIC received from Hughes a final copy of the Final Report on Acceptance Test and Evaluation for the Georgetown University PHENEF Project, a PHENEF System Safety Analyses Summary, and two pv array Operator's Manuals. These have been reviewed and have been found to satisfactorily address the pv array itself. The solar control room, however, still lacks a final version of the Operator's Manual. Since this is the heart of the system, and the most likely place for an operator to work on the system, it is important that the O&M Manual be completed soon.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of December, 1984

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	9.17	12458.65	921.00	7.39	876.00	95.11	268.6
2	9.17	10249.76	720.00	7.02	678.00	94.17	*
3	5.50	4633.27	268.00	5.78	243.00	90.67	*
4	9.00	11313.79	817.00	7.22	775.00	94.86	273.2
5	7.17	3501.88	203.00	5.80	180.00	88.67	*
6	8.83	9441.63	637.00	6.75	597.00	93.72	*
7	9.17	15691.14	1158.00	7.38	1102.00	95.16	265.4
8	9.17	15516.05	1113.00	7.17	1062.00	95.42	264.8
9	8.67	15745.02	1139.00	7.23	1091.00	95.79	*
10	6.67	6896.03	473.00	6.86	444.00	93.87	*
11	7.83	5091.22	306.00	6.01	280.00	91.50	*
12	8.50	8027.41	541.00	6.74	505.00	93.35	*
13	8.17	11300.32	793.00	7.02	758.00	95.59	*
14	6.83	7434.78	495.00	6.66	467.00	94.34	*
15	7.67	7973.53	515.00	6.46	487.00	94.56	*
16	4.83	1629.72	50.00	3.07	36.00	72.00	*
17	8.00	12566.38	860.00	6.84	825.00	95.93	*
18	8.00	9576.31	648.00	6.77	616.00	95.06	*
19	6.33	3313.32	184.00	5.55	164.00	89.13	*
20	8.00	4835.30	306.00	6.33	277.00	90.52	*
21	2.00	1117.91	20.00	1.79	14.00	70.00	*
22	8.33	9522.45	650.00	6.83	616.00	94.77	260.4
23	8.67	16122.15	1154.00	7.16	1102.00	95.49	261.1
24	8.17	8539.22	578.00	6.77	543.00	93.94	*
25	8.83	16593.58	1213.00	7.31	1160.00	95.63	257.1
26	9.00	15798.91	1145.00	7.25	1095.00	95.63	262.2
27	8.33	7407.84	517.00	6.98	481.00	93.04	*
28	8.00	8269.83	557.00	6.74	523.00	93.90	*
29	9.00	15920.12	1107.00	6.95	1065.00	96.21	*
30	5.83	3084.34	170.00	5.51	151.00	88.82	*
31	5.33	1750.95	64.00	3.66	49.00	76.56	*
	238.17	281322.82	19322.00	6.87	18262.00	94.51	273.2

Summary of November 1984 Events

November 1984 is the first month that Boeing Computer Services successfully collected data on the entire photovoltaic array. SAIC has established a link with the ODAS computer so that data can be transmitted directly to SAIC on a daily basis and reduced to a form desirable to Georgetown University. The data reporting was outlined in the October monthly report. This month presents the details of the reporting.

The performance summary consists of one chart and three bar graphs. The chart summarizes the major important characteristics of the operation of the photovoltaic array on a daily basis. The first column represents the day of the month. The second column displays the total number of hours that the PCU was converting the array dc energy into usable ac energy, with a monthly total at the bottom. The third column shows the total solar energy incident on the solar collection area of the array. (It does not include the solar energy hitting support structures.) This column represents the total daily kilo-watt-hours of solar energy including the energy incident on the array when the pv system is not up. Therefore this number is the total solar energy available to the system for conversion. A monthly total is at the bottom.

The fourth column of the performance summary chart is the array energy in kilo-watt-hours. This is the dc energy converted by the solar modules for the entire day and represents the input energy to the PCU inverter. The next column, the array efficiency, is the ratio of the array dc energy to the total solar energy available to the system. At the bottom of these columns is the total monthly array dc energy produced and the monthly efficiency.

The sixth column is probably the most important column. It shows the total daily PCU output ac energy in kilo-watt-hours. This is the energy that directly offsets the energy requirements of the Inter-Cultural Center and surrounding buildings. The monthly total is at the bottom of this column. The next column displays the PCU efficiency as a ratio of the PCU output energy to the array input energy. The monthly efficiency is located at the bottom of this column.

The last column of the monthly pv system performance chart reqiures some explanation. When the array acceptance tests were performed on August 22, 1984, 26 data points were taken to determine the array peak NOCT power in kilo-watts. ' The Hughes Final Report Acceptance Test and Evaluation for the Georgetown University PHENEF Project describes in detail the test procedure for determining the power at NOCT. The following describes how a similar test can be made on the array remotely each day

During the acceptance tests, a number of conditions had to be satisfied before a data point was accepted. The array had to be clear of shadows, the solar energy had to be stable and above 600 watts per square meter, and the cell temperatures had to be stable for three minutes. The data collected included the cell temperatures, instantaneous array current and voltage, solar incident insolation, and array short circuit current. All of this information can be collected remotely, except array short circuit current. However, the short circuit current can be accurately approximated as a constant multiplied by the array peak operating current. To check this, the 26 array acceptance data points were used to determine the ratio of array peak operating current to array short circuit current and this average came to 0.859 with a standard deviation of only 0.008. Therefore this number was confidently used in calculating the peak NOCT power of the array. The 20 cell temperature points were also used with the exact same weighting factors chosen by Hughes for the acceptance tests.

In order to chose the proper times to accept a valid data point, the software decides every 10 minutes that the system is up whether certain conditions have been met. Since the qualifying data points were all taken at about 800 W/M 2 or above, the program checks the solar insolation and requires that both the instantaneous and 10 minute average solar insolation are above 800 W/M 2. This ensures stability as well as sufficient levels. Also, to make sure the PCU is operating properly, the output energy must be greater than 200 kW. To prevent taking any data while the array is shaded, only points between 10:00 am and 2:00 pm and considered. The peak power at NOCT is calculated using the same Hughes equation and constants:

P(NOCT) = Va - Cv(Ta - Tr) Ia - Ci(Ta - Tr) 1 + 1/b (1000/Ea - 1)

This calculation is made every 10 minutes throughout the day that all of the the previously stated conditions are met. The number in the table represents the peak daily value for the peak power at NOCT. In other words it is the highest value recorded at any time during the day for the peak power at NOCT. Therefore the true value for the peak power at NOCT must be no higher than this number. If at no time during the day all of the required conditions were met, then a * is placed in the column. The number at the bottom of the column represents the peak value recorded in the month.

There is only one other difference between the way the peak power at NOCT is calculated in the program and the way it was done at the acceptance tests in August. In August, a Hughes pyranometer was used to determine the solar insolation on the array. This pyranometer was removed on November 12 by Bill Boyson of Sandia Laboratories. Since then the Sandia pyranometer has been the only one operating in the system. The Hughes pyranometer consistently provided a reading which was about 7% lower than the Sandia pyranometer when they were both in the system. This would tend to inflate the peak power at NOCT values by about 7% relative to the values which would have been calculated had the Sandia pyranometer been used. Bill Boyson believes the Sandia pyranometer is more accurate because the calibration is made with the average sun angle considered.

The three bar charts included with the monthly performance summary simply provide a graphical representation of columns 2, 3, and 6--the total daily hours of operation, total daily solar energy, and total daily PCU output energy.

A few comments are required to explain some of the anomolies on the November charts. The first five days, Boeing was still getting the ODAS calibrated and therefore some of the data was lost. The apparent high array efficiency on November 12 and 13 was due to Bill Boyson's temporarily removing the pyranometers, thus the ODAS recorded a value for array solar energy which was lower than what was actually incident on the array.

The pv system produced a total of 22,091 kW-Hrs for November and on November 21 a peak power at NOCT value of 286.8 kW was recorded.

On November 27, Mike Preston of Fleetwood Testing and Bob Malinowski of SAIC met at the site and decided it was necessary to install three 450-ampere fuses in the basement of the Inter-Cultural Center to protect the PCU power cables leading from the basement to the solar control room.

Beginning on November 1, a log has been kept in the solar control room. In it, any down time for any reason (including tests and demonstrations) is to be recorded so that data can be reconciled if it appears anomolous. Also, the array input energy and PCU output energy values displayed by the PCU on mechanical counters is to be recored daily in the log in case the ODAS fails and data is lost. The system did not go down in November.

Performance Summary of the Georgetown 300-kW Photovoltaic Array for the Month of November, 1984

Day	Hours of Operation	Array Solar Energy (kW-Hr)	Array DC Energy (kW-Hr)	Array Efficiency	PCU AC Output Energy (kW-Hr)	PCU Efficiency	Peak NOCT Power (kW)
1	0.00	3286.38	0.00	0.00	0.00	*	*
2	0.00	3569.24	0.00	0.00	0.00	*	*
3	0.00	17469.04	0.00	0.00	0.00	*	*
4	0.00	7596.40	0.00	0.00	0.00	*	*
5	0.00	269.38	0.00	0.00	0.00	*	*
6	5.50	10909.72	347.00	3.18	304.00	87.61	*
7	8.67	19354.68	1125.00	5.81	1077.00	95.73	273.0
8	9.67	17671.07	1329.00	7.52	1274.00	95.86	274.7
9	9.50	14775.26	1114.00	7.54	1067.00	95.78	279.9
10	9.83	15394.84	1158.00	7.52	1112.00	96.03	270.8
11	5.33	2909.26	159.00	5.47	141.00	88.68	*
12	7.83	6963.36	947.00	13.60	912.00	96.30	270.7
13	8.17	2074.19	436.00	21.02	402.00	92.20	*
14	9.83	19704.86	1506.00	7.64	1449.00	96.22	270.9
15	9.17	10775.04	775.00	7.19	737.00	95.10	263.9
16	9.17	11421.53	828.00	7.25	790.00	95.41	268.6
17	9.50	14344.28	1076.00	7.50	1028.00	95.54	272.6
18	7.17	2262.76	112.00	4.95	90.00	80.36	*
19	7.17	2222.35	102.00	4.59	81.00	79.41	*
20	9.50	18371.45	1389.00	7.56	1331.00	95.82	269.6
21	9.50	16997.62	1271.00	7.48	1216.00	95.67	286.8
22	9.50	18357.97	1373.00	7.48	1316.00	95.85	272.0
23	9.50	16580.10	1183.00	7.14	1131.00	95.60	265.8
24	9.33	16755.20	1244.00	7.42	1186.00	95.34	273.7
25	9.17	16741.73	1214.00	7.25	1164.00	95.88	268.0
26	9.17	15691.14	1129.00	7.20	1081.00	95.75	*
27	8.33	10990.55	825.00	7.51	787.00	95.39	*
28	6.83	5481.79	353.00	6.44	329.00	93.20	*
29	9.17	13253.31	952.00	7.18	899.00	94.43	268.5
30	9.17	16809.05	1238.00	7.37	1187.00	95.88	271.2
	215.67	349003.56	23185.00	6.64	22091.00	95.28	286.8

Summary of October 1984 Events

Last month the PCU inverter tripped on three weekends due to an Overcurrent Trip. In October, the PCU tripped only once as a result of an Overcurrent Trip. This Occurred on October 2nd. As a result, the circuitry for the Overcurrent Section was calibrated by Fleetwood Testing Company with specifications and instructions provided by Dave Porter of Omnion Company, the manufacturer of the Windworks Inverter. This included the calibration of the OCS Transducer and the replacement of three current transformers, three overcurrent relays, and a three-section transformer. Since this adjustment of the inverter, no Overcurrent Trips have been recorded.

On the weekend of October 27-28, the PCU inverter tripped out due to a Ground Fault Detection. This also occurred once last month before the Ground Fault Section was calibrated and tested. This time the Ground Fault Detection resulted in the loss of twelve 300-ampere fuses in the SCR bridge circuitry and the corresponding twelve 12-ampere fuses in the DC circuitry.

On October 15, at a meeting with Dennis Shaff at Georgetown University, SAIC personnel outlined the SAIC Phase III Tasks. The enclosure describes the computer data acquisition software that was to be developed by SAIC to provide monthly information on the performance of the photovoltaic system. Data acquisition from the Boeing Computers Services Computer link with the On-Site Data Acquisition System maintained by Sandia National Laboratories was to begin on November 1, 1984.

SAIC Phase III Georgetown Photovoltaic System Tasks

Data Collection

SAIC will establish a computer link with the On-Site Data-Acquisition System (ODAS) Computer at Georgetown in order to collect data needed to monitor the performance of the photovoltaic array. This data will be collected weekly and reduced for monthly status reports. Other data collected will include events which affect the performance of the array. These include power shutdowns, failures, array cleaning or adjustments, or testing which may temporarily reduce system output.

Reporting

A general operational history will be maintained and monthly Status Reports will be delivered to Georgetown University. The operational history will be a continuation of the system log started by Hughes. Also, an Event Report will be generated each time an event occurs which affects the PV system. If the event is determined to be of great significance, a memo will be forwarded to Georgetown University immediately, accompanying the Event Report, otherwise it will be included in the monthly Status Report.

Each month a system status report will be prepared from the data collected and any event reports written. The data summary will contain reduced data collected from the ODAS and compiled in tabular or chart form. It will include

- Total solar energy incident on the array
- Total dc energy produced by the array
- Total ac energy output by the power conversion unit (PCU)
- System efficiency
- PCU efficiency
- Hours of operation
- Rated power of the array at NOCT

The Hughes algorithm using weighted array temperatures and measurements will be used to calculate the rated power of the array. This is the same one that was used for the system acceptance tests and is the same one that will be used in the final systen audit on August 24, 1985. Therefore, the system performance will be monitored so that any problems can be detected early, and the rated power of the array at the time of the final system audit should be predictable.

O&M Manual and Training

The Phase III Operations and Maintenance Manual from Hughes will be reviewed by SAIC. After final acceptance of the manual, SAIC will meet with Georgetown University personnel to go over training and answer any questions concerning the operation and maintenance of the PV system.

Final System Audit

SAIC will assist the Department of Energy in performing the final PV system energy audit on August 24, 1985 and determine the rated system power at NOCT.