CONTRACTOR REPORT

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Detailed Residential Electric Load Determination

The BDM Corporation
1801 Randolph Road NE
Albuquerque, NM 87106

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185
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Abstract

Data on residential loads has been collected from four residences in real time. The data, measured at 5-second intervals for 53 days of continuous operation, were statistically characterized. An algorithm was developed and incorporated into the modeling code SOLCEL. Performance simulations with SOLCEL using these data as well as previous data collected over longer time intervals indicate that no significant errors in system value are introduced through the use of long-term average data.

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FOREWORD

This final report, BDM/A-82-299-TR-R1, is submitted by The BDM Corporation (BDM) documenting work performed for Sandia National Laboratories under Contract 62-3977.

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The Georgia Power Company - Atlanta, GA

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Public Service Company of New Mexico - Albuquerque, NM

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CHAPTER I
EXECUTIVE SUMMARY

A. INTRODUCTION

A residential load profile is the pattern of electric use in a residence over a period of time. Utilities routinely monitor residences and use these profiles to analyze the demand for electricity by a particular class of user. A profile is created by monitoring the load over a time interval. When a utility constructs a profile, the time interval used is usually between 15 minutes and 1 hour. While this interval is adequate for utility requirements, it is too large to reveal the instantaneous behavior of the load. Before the completion of this program, it was generally assumed that use of this long-time constant data in residential PV system simulations significantly underestimated the interaction between a PV system and the utility and produced large errors in calculating the fractions of energy provided by an array to a load, or that which was purchased from or sold back to a utility. The measurement of the instantaneous behavior of a residential load was required so that more accurate models of residential usage and PV system performance may be developed to predict the energy demanded by a residence and that which is provided by a PV array or by the utility. The Detailed Residential Electric Load Determination Program was initiated to measure residential electric loads at instantaneous intervals and to determine the effects of using instantaneous load data in annual residential PV power systems performance simulations.

Prior performance predictions of residential PV power systems had to be conducted using models that could accept only hourly time-averaged load data which does not reveal the instantaneous load behavior caused by residential appliance usage. Other studies of the effects of instantaneous loads have used statistical approaches involving the complete characterization of the residential load based on the probabilities of various household appliance usage for average durations and individual

appliance load requirements. These statistical studies have assumed a high occurrence of instantaneous load profiles and, consequently, significant impacts of instantaneous loads on annual residential PV system performance.

Other attempts to directly measure loads at instantaneous intervals had been taken on very small samples, on one residence for 3 days. While these data did reveal greater PV system utility interaction at smaller monitoring intervals, the sample size was too limited to support firm conclusions.

The objectives of the Detailed Residential Electric Load Determination Program were to measure real, instantaneous load data, and to develop a statistical model based on these measured data to predict residential electric demand. Residential load data are currently being collected at 15-minute intervals by utilities throughout the nation. With this large data base the statistical model can be used to predict the instantaneous load demand for PV systems in any area of the country. For performance predictions the statistical model was incorporated into SOLCEL, a Sandia National Laboratories-developed (SNLA) computer simulation code designed specifically for the analysis of PV systems.

Residential electric load patterns were directly measured at 5-second intervals on four residences selected in the northeast, southeast, and southwest regions of the country. A summary of the program is shown in figure I-1. A load data base consisting of 5,080 complete, continuous, 15-minute intervals, was established (1,270 hours or 53 days of data). Load data were collected for a 2-week period during the summer and again for a 2-week period in the winter on each of the selected residences. To date, this data base is the largest source of instantaneous load data available.

A major finding of this program was the limited occurrence of active load profiles. An active profile exhibits a high energy level above the 15-minute average, high squared multiple correlation (which means the model adequately explains variability), and usually occurs between 5:30 AM and midnight. Inactive profiles, in contrast, are steady state

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Figure I-1. Program Summary

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loads that closely follow the 15-minute time-averaged data and occur mostly during the night, mid-morning and afternoon. Sample active and inactive profiles are shown in figures I-2a and I-2b.

After the load data were statistically characterized, only 734 intervals out of the 5,080 intervals in the data base possessed the characteristics (described above) statistically identifying them as an active profile and differentiating them from the 15-minute time-averaged load. This limited occurrence of active profiles substantially reduced the probability that an active profile would occur when the statistical model was exercised and annual system performance simulations conducted.

In the test cases that were run for performance comparisons using the instantaneous load model, the PV array supplied 33.3 percent of the energy demanded by the residence on an annual basis. This represents the most accurate prediction of the actual PV fraction. These results were then compared with the results obtained using 15-minute and hourly time-averaged data.

As can be seen from table I-1, less than a 2 percent decline is obtained using hourly data when compared to the use of instantaneous data. Even operating the model with twice the probability of the occurrence of an active profile produces little difference in the amount of energy provided by the array.

TABLE I-1. RESULTS FROM SOLCEL SIMULATIONS ANNUAL DIRECT FRACTION

ANNUAL PERCENT LOAD SUPPLIED				
	MODEL	15 MIN	HOURLY	MODEL WITH TWICE PROB.
PV DIRECT FRACTION	.333	.339	.346	.327

This comparison did not address the effects of array size or of increasing the probability of an active load beyond 0.4. When array size

ALBUQUERQUE 2
MONDAY 1/18/82

ALBUQUERQUE
FRIDAY 1/1/82

Figure I-2a. Sample Instantaneous Load Profiles

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NEWARK, NJ
FRIDAY 7/17/81

I-6

NEWARK, NJ
WEDNESDAY 2/3/82

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Figure I-2b: Sample Instantaneous Load Profiles (Concluded)

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is considered and the probability of an active load is increased, only for very small array sizes and unrealistically active loads do instantaneous load data produce a significant decline in the PV fraction. This effect is shown in figure I-3. The probability of an active load is increased from 0, or 15-minute load data, to 1, or a continuously active load. The observed probability of an active load was 0.2 obtained from the measured data. A probability of 0.4 was considered an extreme active case for load variability. The probability was extended to 1 to determine sensitivities. Array size was increased from 1 to 9 kW.

The conclusion can thus be made that 15-minute time-averaged data are adequate for predicting the annual performance of a residential photovoltaic system for realistically sized arrays and load activity. Instantaneous data are not required.

The Detailed Residential Electric Load Determination program has produced several unique products. These are

- (1) A statistical model incorporated into SOLCEL that can convert time-averaged load data already available from utilities into instantaneous data for performance simulation and analysis.
- (2) A total of 53 days of continuous, instantaneous residential load data collected on four residences in different regions of the country incorporated into a data base and available on the SNLA computer.
- (3) An improved SOLCEL simulation capability using 15-minute time-averaged load data and the instantaneous load model. This allows the use of SOLCEL with standard time-averaged data currently collected by utilities.
- (4) A reliable, remote-site, instantaneous load monitoring system that can be mounted directly on a residence or utility pole and transmit load data via telephone lines. The system can be used for additional residential or commercial monitoring.

ANNUAL AVERAGE

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Figure I-3. PV Performance Versus Array Size for Various Probabilities of an Active Profile

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B. PROGRAM OVERVIEW

1. Overview

Included in this phase of the program were the following four tasks:

- (1) A survey of utilities and other sources to determine the availability of instantaneous residential electric load data
- (2) A direct measurement program of residential electric loads at instantaneous intervals if load data from utilities were unavailable
- (3) The development of a statistical model, based on the direct measured data, which could be used to predict the behavior of instantaneous loads using time-averaged load data
- (4) PV system performance comparisons using the instantaneous model, and time-averaged load data

Chapters II through VI contain detailed information on these tasks. In addition, several appendices present information on the load data base access and format, SOLCEL execution procedures, profile plots, and the monitoring system schematics.

Two additional tasks involving powerline waveform quality monitoring and PV system-utility interactions were also conducted under this program. These will be reported separately.

2. Utility Surveys/Direct Measurement

A comprehensive survey was completed of the two largest utilities in each state of the northeast, southeast, and southwest regions of the country. A total of 51 utilities were contacted to determine the extent of residential load monitoring programs, sample size, and sampling interval. The utility survey revealed that most of the utilities have instituted residential load monitoring programs for reporting load data under Public Utilities Regulatory Policy Act of 1978 (PURPA). Time-averaged intervals of 15 to 30 minutes are considered adequate by the utilities for reporting purposes. No sources of instantaneous load data were identified from utilities, utility organizations, or government research projects.

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A direct measurement program was then initiated to develop a sample of instantaneous residential electric loads on typical residences in these regions. The Public Service Company of New Mexico, Georgia Power, Atlanta, Georgia, and the Public Service Electric and Gas Company of Newark, New Jersey, were selected for participation in the program. Residences were selected by the utility to obtain a typical residence from their current residential monitoring program. Selection was made on the basis of electrical consumption that approximated the sample mean for residences from utility load data base. Four residences were instrumented, two in Albuquerque and one each in Atlanta and Newark.

For the instantaneous load data collection, a hardware package capable of measuring loads at intervals of approximately 5 seconds was developed. The data acquisition hardware consisted of two major sections, the measurement equipment and the computer controller. Measurement equipment was located at each of the four monitored houses. A weatherproof box built to NEMA specifications housed the complete measurement system consisting of current loop transformers connected to a Scientific Columbus Joule Electronic Meter (JEM) where data were measured in units of kVAh. After digitization within the JEM, the accumulated data were collected at regular intervals by the computer/controller via telephone lines. The computer/controller was an HP-85 desktop computer chosen for both its data-collection and analysis capabilities. Data accumulated in the HP-85 were stored on 5-inch floppy disks.

Data collection software included data acquisition, analysis, and transfer programs. An analysis program plotted the data on the HP-85's CRT and a hard copy was obtained from a built-in thermal plotter. In addition, a data transfer program transferred the data to the SNLA computer network. Sample load plots obtained from the HP-85 printer are shown in figures I-2a and I-2b. The sample plots shown in figure I-2a show a sample of an active load profile. This type of profile, however, was present in only 734 of the 5,080 intervals in the load data base.

More typical of the data base is the sample load profile for the Newark residence (2/3/82) shown in figure I-2b where the instantaneous load and time-averaged load are not statistically different.

3. Statistical Load Model

The statistical load model was then developed to serve as a mathematical operator that converts real-time-averaged data into instantaneous data. Originally, the model was planned to take the form of a multiple linear regression prediction equation. However, analysis has shown that the instantaneous profiles are driven by particular appliances. Since a large sample of instantaneous appliance loads would be required to adequately model their input to the load profile (much larger than feasible for this project), an alternative modeling methodology was developed.

Each 15-minute interval was characterized by periodic regression analysis (sums of sine and cosine curves). The coefficients of these regression equations characterize the 15-minute profiles and classify and distinguish the significantly different profiles. Cluster analysis and classification analysis were used to group profiles together. The real 15-minute interval of load data closest to the group average was selected to preserve the instantaneous nature of the data. Thirteen representative profiles were selected from the load data base for inclusion into the model.

The statistical model and the load prediction scheme were structured into an algorithm to predict the type of instantaneous profile to use based on the 15-minute time-averaged load. This algorithm was incorporated into the SOLCEL photovoltaics analysis computer code. SOLCEL performs the system simulation using a full year of real load solar and weather data to calculate the percent of energy provided to the residence by a PV array, by the battery storage system, and by the utility. Prior performance simulations using SOLCEL could only be performed using hourly load data. The code will now accept hourly and 15-minute load data. The SOLCEL code with the statistical model was exercised to determine the effect of instantaneous loads versus time-averaged loads for calculative PV fractions.

4. Performance Comparisons

SOLCEL simulations were performed using the statistical model to calculate the annual performance of a residential PV system. These simulations were performed to examine the sensitivities of the PV fraction to variations in the time-averaged load data, array size, and probability of occurrence of an active profile. Annual performance was simulated using 1 year of real load data at a 15-minute interval and a year of solar radiation and weather data for Albuquerque, New Mexico. The simulation was performed using 15-minute interval data with the instantaneous load model and 1-hour interval data. Simulations were also performed using 15-minute interval data with the instantaneous load model but with double the probability of an active profile occurring.

The performance comparisons are shown in table I-1. The use of the instantaneous model, which gives the most accurate prediction, produces a PV fraction of 33.3 percent. The use of 15-minute load data produces a decline of less than 1 percent in the fraction of the load met by the array. Using hourly load data the PV fraction declines by less than 2 percent. The model using twice the probability of an active profile produces a decline in the PV fraction by 1.9 percent.

The sensitivity of the PV fraction to variations in the probability of the occurrence of an active profile and the size of an array is shown in figure I-3. This figure shows that the PV fractions change as both the probability of an active load and array size are varied. Very little change occurs in the PV fraction between inactive loads, 0 probability, and extremely active loads, 0.4 probability (twice the observed probability from the measured data). Only for the very small array (1 kw) and an unrealistically active load (probability of 1) do instantaneous data significantly affect PV fractions.

CHAPTER II
LOADS AND MODELS

A. INTRODUCTION

The designer of a photovoltaic (PV) system must be able to predict the total energy that will be produced by an array and the fractions of energy that will be used directly by the load or purchased from (or sold to) the utility. These performance predictions are required so that a system can be properly sized to meet the demand and so that the economic worth of the system can be determined. In the past, the simulation models used for these performance predictions required the use of hourly time-averaged load and insolation data because no sources of instantaneous data were available. It was generally thought that the use of instantaneous load data, either statistically developed or directly measured, would produce more accurate estimates of PV fractions, that is, the amount of energy supplied by an array to a load. The consensus prior to the initiation of this program was that the use of hourly time-averaged data to simulate the annual performance of a PV system in a residential application would produce errors in calculating these fractions of energy.

The issue of using instantaneous load data versus time-averaged data to predict energy fractions can be simply illustrated by figure II-1. This figure shows a hypothetical PV system power output, assumed to be constant, and a load at three different time intervals: instantaneous, 15 minute, and 1 hour. As the time interval becomes larger, the amount of variability in the load and the PV fractions decline until, at the longer time interval, little interaction takes place between the PV array, the residential load, and the utility. Two approaches were subsequently undertaken to determine the effect of using instantaneous data in the simulation of the annual performance of a residential PV system.

The first approach was purely statistical, involving the probabilistic distribution of residential appliance usage. By estimating the

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Figure II-1. Time-Averaged Versus Instantaneous Load Data

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power used by a standard complement of residential appliances and the probability of appliances being on or off at a specific time, a statistical distribution was constructed and synthetic instantaneous profiles developed. These profiles were applied to residential load PV systems interactions and the PV fractions calculated. This probabilistic approach led to a higher calculation of the activity of a load and therefore produced more significant effects on PV fractions when comparing smaller time interval data. This work, by Sillman (ref. 1) at the Solar Energy Research Institute, and Lathrop (ref. 2), Clemson University, was completed prior to the detailed measurement of instantaneous loads and represented the best characterization of instantaneous load/PV system interaction available at the time.

The second approach was to measure directly the load patterns of a variety of residences to determine the actual behavior of an instantaneous load. Hart (ref. 3), at the Northeast Residential Experiment Station, measured at 5-second intervals the array output and load demand for 3 days on one prototype PV residence and a separately-monitored residential load. Recognizing the small scope of his sample, Hart calculated a large variation in the amount of energy sold back to the utility, depending upon the day. His report recommended collecting more load data during different seasons and from a variety of residences to determine the significance of instantaneous data on PV system/utility interaction. Hart's work was also completed prior to the publication of the results obtained in the Detailed Residential Electric Load Determination Program (DRLD) and reported here.

As part of the DRLD program, four residences in three regions of the country were instrumented and the load measured at 5-second intervals. Each residence was continuously monitored for 2 weeks during the summer and winter to obtain seasonal load variations. The load data were then statistically analyzed and incorporated into a probabilistic model and performance predictions conducted to determine the amount of energy supplied by an array to a load.

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Several major conclusions have emerged from this effort. These conclusions, briefly summarized here, are discussed in greater detail in the following chapters.

First, the measured activity of the loads was less than previously believed. Active profiles had a low occurrence in the measured data sample--less than 20 percent. Again, an active profile exhibited a high energy level above the 15-minute average, a high squared multiple correlation, and occurred between 5:30 a.m. and midnight. Inactive profiles closely followed the 15-minute time average. (Refer to figures I-2a, I-2b).

Second, varying the time constant from 1-hour time-averaged load data to 15-minute average load data to instantaneous data produced a very small decline in the fraction of the energy provided by the PV array to the load on an annual basis (refer to table I-1). Furthermore, these percentages were relatively insensitive to increasing or decreasing the size of the array or to varying the probability of the occurrence of an instantaneous load (refer to figure I-3). In the sensitivity analyses, the probability of an active load was varied from 0 (load following the 15-minute average) to 1 (load always active). The array sizes were varied from 1 kW to 9 kW.

The conclusion drawn from these measured data is that, for realistically-sized arrays and normal load applications, the use of 15-minute data is adequate for the annual performance calculation of the percentage of array power supplied to a load by the PV array.

B. LOAD MODELING

1. Modeling Approach

The goal of the DRLD project has been to develop the capability to predict instantaneous residential load for typical residences in the northeast, southeast, and southwest, and then to assess the need for use of shorter time intervals in the modeling and analysis of photovoltaic system performance. With most of the instantaneous variability of

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residential load due to major appliance loads and usage practices, except for the instantaneous motor starts that have little or no effect on the array output-load match-up, consideration was initially given to estimating frequencies and durations of appliance usage in combination with average appliance loads to form an instantaneous load simulation model. This approach was rejected due to the subjectivity which would enter into the estimation of the frequencies and duration of appliance usage. The selected approach was to establish a 5-second interval data base of measured load data and to develop a prediction model of instantaneous load from the collected data. The prediction model would then serve as a mathematical operator which converts real 15-minute time-averaged data into instantaneous load data.

The largest collection to date of near-instantaneous (5-second) load data from typical residences was accumulated under this program. From this data base, a statistical prediction model of instantaneous load demand, operating on 15-minute time-averaged load data, was developed and incorporated into the SOLCEL Photovoltaic Analysis Program. Fundamentally this prediction model uses the frequency of occurrence in the data base of active instantaneous load profiles, in comparison to the 15-minute time average and frequencies of occurrence of the different types of active profiles. These active profiles were characterized by periodic regression analysis and categorized using cluster analysis and contingency table layouts into 13 distinct profile types which match major appliance usage.

Classifying the active profiles into distinct types supports the conclusions that the variability of residential load is driven by major appliances. In fact, the different profile types can be matched to specific appliances or to simultaneous usage of more than one appliance. However, instantaneous load profiles for specific appliances are simply not available beyond the limited appliance characterizations accomplished during the data collection phase of this program on one residence. The profiles obtained are presented in chapter IV and discussed briefly in the following paragraphs. Further, given the many types, brands, and

efficiencies of appliances, development of specific appliance load profiles would not be practical.

A sample profile of two major residential electrical appliances is shown in figure II-2. This figure was obtained by plotting the directly measured 5-second data collected on the second monitored residence in Albuquerque. For the purposes of clarity, the data have been plotted at 15 seconds. These profiles are part of the distinct profile groups identified and incorporated into the statistical model. The figure shows the instantaneous profile and the 15-minute time-averaged profile which a utility would collect.

The power being consumed is shown on the abscissa in units of kVA. The time interval shown on the ordinate is 1 hour from (12:00 to 13:00 hours) divided into 5-minute increments. Through the appliance characterization, it was possible to identify the two appliance cycles shown in the figure. The first profile (on the left) is an electric dryer. The characteristic cycle time of the heating element in the dryer is approximately 2.5 minutes. The second profile (on the right) is an electric oven cycling approximately every 5 minutes.

The 5-second interval load data base collected for this program did not include any all-electric residences. The residences monitored were selected by the respective utility companies as being in the most typical usage class which was diversified load. All four residences use electric appliances and two contain electric forced-air-conditioning. The only major appliances not electrically powered in any of the residences are space heating and water heating; all residences contained gas space heating and water heating. However, both space heating and water heating would be expected to have operation cycles similar to electric ovens and dryers (shown in figure II-2) and would add only additional electrical consumption to the overall base load rather than increase load variability on a 15-minute interval basis. By varying the probability of active profiles to a completely active load, the expected load variability of an all electric residence is fully accounted for.

Figure II-2. Instantaneous Load Profile

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Major findings of the DRLD Program are that active profiles do not occur as frequently as expected, and that long-term photovoltaic system-load match-ups are not significantly affected by using 15-minute time-averaged load data. These results were determined by exercising the statistical model through several SOLCEL simulations (see chapter VI). However, these results differ from the findings of three other projects recently completed, all of which are for all-electric residences. Analysis using the SOLCEL/Statistical Model spanned the complete range of active profiles from 0 probability (load completely inactive) to 1 (load completely active) and array sizes. Although these results are not based on all-electric residences, the results are valid in the all-electric case for the reasons discussed above. The observed occurrence of active load profiles in the measured data was a probability of occurrence of .2. Doubling this probability to .4, a reasonable estimate of the load variability in an all-electric residence, had less than a 2 percent effect on PV fractions.

2. Modeling Strategies

Both Sillman (ref. 1) and Lathrop (ref. 2) utilized the load modeling strategy of estimating probabilities of appliance usage and average durations of use and electrical demand. Sillman addressed the on-site use and sell-back potential for photovoltaic systems in residential applications. Lathrop analyzed the potential for load-management in residential applications. Both projects required the development of a load prediction scheme and used event paced simulations, with events being the use of individual appliances determined from the estimated probabilities. (As mentioned previously, this strategy was considered in the early stages of the DRLD project, but estimating the probabilities of appliance usage was not considered feasible. Indeed, estimating typical appliance usage practices would require quite a large sampling of residences and particular appliances.)

Results from both projects indicated that PV fractions were significantly overestimated in particular situations using 15-minute time-averaged load data and therefore a smaller time interval was

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required to accurately address their particular objectives. In using time-stepped simulations based on probabilities for several appliances, even slight overestimation of the individual probabilities used can result in large overestimation in the aggregate over long periods. Even though Sillman varied the probabilities over a range, the developed load profiles appear more variable than the majority of actual data collected under the DRLD project. The same higher variability appears in the Clemson University project (ref. 2).

The load measurement work completed by Hart (ref. 3) suggests that PV fractions and other PV system performance information may contain large errors using time-averaged load data. This project collected a small sample of 5-second interval load data and array output data from a residence in the Northeast Residential Experimental Station (NE RES). From Hart's sample, an approach using a few days of data led to results showing a potentially large loss of information using time-averaged load data and array output data.

On an individual day, especially a day with large fluctuations in insolation, the errors due to time-averaged data may indeed be large, especially when percentage errors of small measures are being observed. In the DRLD project the results are for an entire year over which many of the individual days do contain somewhat large errors. Other days contain very little error because the array either meets almost all of the load or very little of the load. Secondly, in the NE RES data, for the "most representative" worst day, the percent load satisfied by the PV array is extremely small--8.54 percent--which resulted in the utility providing most of the load requirements and very little sell-back. Of the amount sold back to the utility, any error due to time interval appears large due to the small total amount. The resultant error is less than 1 kWh, but on a percentage basis the amount sold back to the utility--as estimated from 15-minute interval data--is underestimated by 15 percent. Further, when comparing 15-minute interval results to 5-second interval results, the amount of energy bought from the utility is underestimated by only 3.3 percent, even though the amount is slightly less than 1 kWh.

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This leads to an overestimation of the PV fraction, with 15-minute interval results showing the array provided 4.6 kWh compared to 2.7 kWh for 5-second intervals, or 14.7 percent versus 8.5 percent. Again, the error appears very large, but the actual amount of the error is extremely small when an entire year is taken into account and where these results are seen as a "worst case."

A final issue is that the Hart results (ref. 3) include 5-second interval array output data which are highly variable, perhaps due to weather on that winter day in the northeast region. The DRLD modeling used hourly insolation data for the year span of the simulations, and the weather data were for Albuquerque, New Mexico, the southwest region.

REFERENCES

1. Sanford Sillman, On-Site Use and Sellback in Residential Photovoltaic Systems Based on Monitored Load Data, SERI/TP-254-1739, Golden, Colorado, October 1982.
2. Jay W. Lathrop, "Investigation of Load Management Strategies for Residential Photovoltaic Systems," Proceedings, Third Photovoltaic Systems Definition and Projects Integration Meeting, Sandia, 1982.
3. George W. Hart, The Effect of Data Sampling Rate on Utility Interaction Calculations, DOE/ET/20279-212, Lexington, Massachusetts, October 1982.

CHAPTER III
SURVEY OF UTILITIES AND RESIDENTIAL SELECTION

A. INSTANTANEOUS LOAD DATA INVENTORY

A comprehensive telephone survey was conducted of the two largest utilities in each state in the three regions of concern, the Northeast, Southeast, and Southwest. A total of 51 utilities were contacted by telephone to determine residential load monitoring activity and the availability of instantaneous residential load data. Each utility was asked about load monitoring programs, including the sampling interval and the sample size of residences being monitored. A summary of the survey is shown in table III-1.

As can be seen from the table, many utilities are measuring residential load data directly. The utilities are required under Public Utilities Regulatory Policy Act (PURPA) of 1978 to gather and report representative load data for large rate classes. This requirement provides a very large data base of time-averaged load data that can be used in SOLCEL with the statistical model for residential PV system simulation.

The general conclusions of the survey were that the majority of the utilities are monitoring an average residential sample of approximately 300 homes at a time-averaged interval of 15 or 30 minutes which is adequate for PURPA requirements; however, no utility was monitoring residences at smaller intervals. Utilities did, however, indicate a strong interest in the results of the program and a willingness to cooperate with the direct measurement task.

In addition to the survey of utility companies, other sources were contacted to determine the availability of instantaneous data. These sources included the Edison Electric Institute, the Electric Power Research Institute, the Association of Edison Illuminating Companies, the Federal Energy Regulatory Commission, and load recorder manufacturers. A literature search was initiated for residential electric load research

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TABLE III-1. SUMMARY OF UTILITY TELEPHONE SURVEY

UTILITY COMPANY CONTACTED	RESIDENTIAL SAMPLE SIZE	MEASURED UNITS	DATA INTERVAL	HARDWARE USED	WILLING TO PARTICIPATE	*SUBSIDIARY OF	COMMENTS
1. ALABAMA POWER COMPANY	285	P/I	15	TAPE	YES	*SOUTHERN CO. SERVICES	
2. SOUTHERN ELECTRIC GENERATING COMPANY							
3. ARIZONA PUBLIC SERVICE COMPANY			15				
4. TUCSON GAS & ELECTRIC COMPANY			15				
5. ARKANSAS-MISSOURI POWER COMPANY							NOT DOING MEASUREMENT CONSOLIDATING WITH ARKANSAS POWER & LIGHT
6. ARKANSAS POWER & LIGHT	260	P/I	15	TAPE	YES		
7. CONNECTICUT LIGHT AND POWER COMPANY							
8. HARTFORD ELECTRIC LIGHT COMPANY							MONITORING BY CONNECTICUT POWER & LIGHT
9. DELMARVA POWER & LIGHT COMPANY	700	P/I	15	TAPE			
10. POTOMAC ELECTRIC POWER COMPANY	250	P/I	15	TAPE	YES		
11. FLORIDA POWER & LIGHT COMPANY	1.8 MIL	P/I	15	TAPE	YES		
12. FLORIDA POWER CORP.	UNK	P/I	15	TAPE	YES	WILL BEGIN IN 1981	
13. GEORGIA POWER COMPANY	300		15/30	TAPE	YES	*SOUTHERN CO. SERVICES	
14. SAVANNAH ELECTRIC AND POWER COMPANY	200		15	TAPE	YES		
15. LOUISIANA POWER AND LIGHT COMPANY	354		15		YES		
16. GULF STATES UTILITIES COMPANY	340	kW	15		YES		
17. BANGOR HYDRO-ELECTRIC COMPANY							NOT DOING MEASUREMENT
18. CENTRAL MAINE POWER CO.	337		15	TAPE	YES		
19. BALTIMORE GAS & ELECTRIC COMPANY	225	kW	15	TAPE	YES		
20. POTOMAC EDISON COMPANY							NOT DOING MEASUREMENT
21. BOSTON-EDISON COMPANY			15				
22. NEW ENGLAND POWER CO.	250	kW	15	TAPE	YES		
23. MISSISSIPPI POWER CO.	200	kW	30	TAPE	YES	*SOUTHERN CO. SERVICES	
24. MISSISSIPPI POWER & LIGHT COMPANY							UNWILLING TO ANSWER QUESTIONS
25. PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE	105	kW	30	TAPE	YES		
26. GRANITE STATE ELECTRIC							*NEW ENGLAND POWER CO. NOT DOING MEASUREMENT
27. PUBLIC SERVICE ELECTRIC AND GAS COMPANY		kW	15	TAPE	YES		

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TABLE III-1. SUMMARY OF UTILITY TELEPHONE SURVEY (Concluded)

UTILITY COMPANY CONTACTED	RESIDENTIAL SAMPLE SIZE	MEASURED UNITS	DATA INTERVAL	HARDWARE USED	WILLING TO PARTICIPATE	COMMENTS
						*SUBSIDIARY OF
28. JERSEY CENTRAL POWER & AND LIGHT COMPANY						NOT DOING MEASUREMENT *GENERAL PUBLIC UTILITIES
29. PUBLIC SERVICE COMPANY OF NEW MEXICO		kw	15	TAPE	YES	
30. NEW MEXICO ELECTRIC SERVICE COMPANY						NOT DOING MEASUREMENT
31. NIAGARA MOHAWK POWER CORPORATION	100	kw	15	TAPE		
32. CONSOLIDATED EDISON CO. OF NEW YORK, INC.	400	kw	15	TAPE	YES	
33. AMERICAN ELECTRIC POWER			15			
34. DUKE POWER COMPANY	220		15	TAPE	NOT REALLY	
35. CAROLINA POWER & LIGHT COMPANY	400		15	TAPE	YES	
36. OKLAHOMA GAS & ELECTRIC COMPANY	714	kw	15	TAPE	YES	15 kw P/V DEMO.
37. PUBLIC SERVICE COMPANY OF OKLAHOMA	185	kw	15	TAPE	YES	
38. PHILADELPHIA ELECTRIC COMPANY	390	kw	30	TAPE	--	
39. PENNSYLVANIA POWER & LIGHT COMPANY	320	kw	30	TAPE	YES	
40. BLACKSTONE VALLEY ELECTRIC COMPANY	282		15	TAPE	YES	
41. NARRAGANSETT ELECTRIC COMPANY	250	kw	15	TAPE	YES	*NEW ENGLAND POWER SERVICES COMPANY
42. LOCKHART POWER COMPANY						NOT DOING MEASUREMENT
43. SOUTH CAROLINA ELECTRIC AND GAS COMPANY	300	kw	15	TAPE	YES	
44. KINGSFORT POWER COMPANY	120		30	TAPE		*AMERICAN ELECTRIC POWER SYSTEM
45. TENNESSEE VALLEY AUTHORITY	500	kw	15	TAPE	YES	SAMPLE SIZE IS TOTAL IN COMMERCIAL, INDUSTRIAL, RESIDENTIAL
46. HOUSTON LIGHTING AND POWER COMPANY			15			
47. TEXAS POWER & LIGHT CO.	250	kw	15	TAPE	YES	
48. VERMONT ELECTRIC POWER COMPANY INC.						NOT DOING MEASUREMENT
49. VIRGINIA ELECTRIC & POWER COMPANY	322		30	TAPE	YES	
50. APPALACHIAN POWER CO.	170	kw	15/5	TAPE		*AMERICAN ELECTRIC POWER COMPANY
51. MONONGAHELA POWER CO.						REFERRED TO ALLEGHENY POWER SERVICE COMPANY

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through the National Technical Information Service. Since the survey of utility companies and other data sources did not uncover any sources of instantaneous load data, the direct measurement program was begun.

B. SELECTION OF PARTICIPATING UTILITIES AND RESIDENCES FOR DIRECT MEASUREMENT

The Public Service Company of New Mexico (PNM), Albuquerque, New Mexico; Public Service Electric and Gas Company (PSE&G), Newark, New Jersey; and the Georgia Power Company (GP), Atlanta, Georgia were selected for participation in the program. These utilities were selected on the basis of their willingness to participate in the program, the extent of their residential load monitoring programs, their involvement in load management and load research, and their ability to provide regional representation.

Individual residences were selected by the utilities as typical of residences in each service area and on the basis of electric consumption. In addition, the selected residences were already part of the utility's existing load monitoring program so that parallel utility time-averaged data could be compared with the instantaneous data collected under the program.

C. RESIDENTIAL CHARACTERISTICS

PNM provided a list of 10 residences from their load monitoring sample for consideration. These residences were selected by the utility as being typical of their service area. In addition, time-averaged load data for 1 year were available on each residence for comparison with the instantaneous data. Each homeowner was contacted and asked to participate in the load monitoring program. The two residences finally selected represent a mix of new and older residential construction. However, as is typical of residences in PNM's service area, both residences use natural gas for domestic water heating and space heating and evaporative

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air conditioners for cooling. The instrumentation was directly mounted to the residences in Albuquerque because the cooperation of the individual homeowners was required for equipment test and calibration, residential appliance characterization, and the power line waveform quality measurements.

In contrast, PSE&G and GP selected residences but did not want the homeowner involved in monitoring activities. The load monitoring instrumentation was mounted directly on the utility service pole. The residences in Newark and Atlanta, as is typical of residences in these areas, also use natural gas for domestic hot water and space heating, but use central air conditioning.

The characteristics of the four monitored residences are shown in table III-2.

TABLE III-2. RESIDENTIAL CHARACTERISTICS

	Albuquerque #1	Albuquerque #2	Atlanta	Newark
Space ft ²	1,200	1,950	2,500-3,000	4,300*
Age	25	2	16-20	-
Heating	Gas	Gas	Gas	Gas
Cooling	Evaporative	Evaporative	3TN Central AC	6TN Central AC
Domestic Hot Water	Gas	Gas	Gas	Gas
Appliances				
Electric Range	X	X	X	Gas
Microwave	-	-	X	-
Dishwasher	-	X	X	X
Clothes Dryer	-	Electric	Electric	Gas
Washer	X	X	X	X
Refrigerator/ Freezer	X	X	X	X
Freezer	X	-	X	-
Color Television	X	X	X	-
Occupants	3	4	3	4

*includes 1,300 ft² basement

CHAPTER IV
DIRECT MEASUREMENT

A. DATA ACQUISITION SYSTEM - OVERVIEW

The data acquisition system consisted of two major elements: an instrumentation package located at the monitored houses and a centralized data collection and analysis facility.

The instrumentation package at each house was a complete, automated, self-contained system. It measured the power being consumed by the house, conditioned the data, and sent it in digital form over telephone lines to the central facility (see figure I-1).

This system configuration had several advantages. First, it allowed the instrumentation located at the monitored houses to be put in a weather-proof (NEMA 3) enclosure and mounted on the outside of the house. This proved to be a very "clean" installation whose appearance was not significantly different from the circuit-breaker boxes located on a typical home. The enclosures, meter, modem, and computer controller are shown in figure IV-1.

The second advantage of this configuration was that it did not require the presence of test personnel at the monitored home to acquire data. This ensured that the activities and energy consumption of the home being monitored were not affected by the presence of test personnel and also made data collection more convenient at the sites remote from the data recording facility.

The current and voltage being consumed by the homes was measured by a Joule Electronic Meter (JEM). This is a single-function, two-element kVAh meter that provides both a digital and an analog pulse output. It has two inputs for ac voltage and two inputs for ac current. The JEM instantaneously measures current and voltage. Each input is instantaneously squared which produced a dc component proportional to the average square of the signal being sampled. After some filtering and amplification, the squared voltage and current proportional signals are multiplied

IV-2

SWITCH BOX AND POWER
SENSORS (CURRENT
TRANSFORMERS)

JEM-1 METER & MODEM

PACKAGED ENCLOSURES

HP 85 DATA ACQUISITION
SYSTEM @ BDM IN ABQ

Figure IV-1. Detailed Residential Load Data Acquisition and Load Monitoring System

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and the product square rooted. The resultant signal is then proportional to the square root of the product of the average squared current and average squared voltage. This result gives true rms voltamperes. The simplified equation of the function is:

$$VA_{rms} = \sqrt{\int v^2(t) \times \int i^2(t)}$$

Additional circuits provide an analog output signal and an input to an integrator which generates kVAh pulses. The voltage inputs of the JEM were connected directly to the two hot wires of a standard three-wire, single-phase residence service. Current inputs for the meter were acquired using step-down current transformers. Because of the 10-amp maximum current input of the JEM, two square-D model 5N201 current transformers (each rated at 200:5 amperes) were connected in parallel to monitor each of the hot wires of a standard three-wire power drop (see appendix D for the system's schematic wiring diagrams).

TEK-COM modems were used on both the JEM and computer ends to interface the equipment with the phone lines. A 20-milliamp current loop interface was used to connect the JEM to the modem, and an RS-232C interface connected the HP-85 to the modem. The modem connected to the JEM was a 300/ baud auto-answer modem that was able to answer the phone when the modem on the HP-85 queried it. The modem on the HP-85 had an intelligent dialing feature capable of storing five telephone numbers, any one of which could be dialed as instructed by the controlling computer.

The modem JEM meter combination and switchgear were housed in a weather-proof NEMA case mounted on the sides of the Albuquerque houses and on telephone poles at the Atlanta and Newark houses. A NEMA 3-R enclosure was used for the switchgear and a NEMA 12-R enclosure for the JEM and modem. The enclosures were designed to provide an overall power switch that permitted safe access to the power line connection points for direct residential mount applications, a GFI power outlet for use with test equipment, surge protection, temperature control for the enclosures

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containing the JEM and the modem units, and outlets which were used for power line waveform quality monitoring. The design met the National Electric Code and state codes and used UL approved components.

A thermostatically controlled heating blanket combination was used in the meter modem enclosure to maintain operating temperature for the instrumentation. Temperatures within the box were maintained at between 65° and 90°F. For the cases where the boxes had to be mounted in direct sunlight, a flat metal plate covered the front surface of the box and was separated by an air space of approximately 1/2 inch. This resulted in a thermal "chimney effect" that aided in carrying away excess heat that could build up in direct sunlight or summer heat.

The autodialing modem connected to the HP-85 computer was capable of storing and recalling up to five telephone numbers in a non-volatile memory. Commands to the autodialing modem, in addition to communication with the JEM at the house being monitored, were completed through an RS-232C interface. Terminal emulator software was used to maintain and update the telephone-number list within the modem.

The HP-85 computer/controller system was programmable in the Basic computer language. The HP-85 has 32k of internal random access program memory (RAM). The HP-85 also has a built-in cassette tape drive which facilitates internal program storage. Collected data were plotted using the HP-85's built-in graphics capability. In addition, a thermal printer easily generated a hard copy either of text or graphics. Once collected, data were transferred across the HP-IB bus to an HP dual floppy-disk drive. Each of the 5-1/4 inch disks in the HP drive were capable of storing 270k bytes of information, more than sufficient to contain a single day's worth of data.

The computer/controller hardware was also used to effect the transfer of collected load data to the Sandia National Laboratories computing system for further analysis. This transfer was accomplished through the telephone lines to Sandia's dial-up network. Once transferred to Sandia, the data were reformatted and stored on magnetic tape.

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B. DETAILED RESIDENTIAL ELECTRICAL LOAD DATA ACQUISITION SOFTWARE

The data acquisition software was written on the HP-85 and controlled all processes involved in the data acquisition. A timing flag allowed the HP-85 to query the JEM meter for electrical load data at precise 5-second intervals. Occasionally, the JEM did not respond when queried because of noise in the telephone lines. This left the program and/or the RS-232C interface waiting for a response and tended to disconnect the HP-85. After some experience with this type of failure, a timing system built into the program corrected the problem by requerying the JEM until it responded. Each time the JEM meter failed to respond, a message was printed on the thermal paper giving the time that the failure occurred. Also, an audible tone issued roughly once every 5 seconds until the problem either was corrected or the noise stopped and the communications were re-established automatically.

The JEM meter was queried by five-character ASCII strings. A typical five-character string is 11F11, which commands the JEM to read what is in its accumulating register and to store that value in a storage register. A string of 11L11 commands the JEM to transmit what is in the storage register. So, in order to read data, it is necessary first to freeze what is in the accumulating register and the storage register and then read the contents of the storage register.

C. SYSTEM OPERATION

When the HP-85 is turned on, the data-acquisition program is loaded from the built-in magnetic tape. When first executed, this program enters as the terminal emulation mode. This mode is used to establish communications through the auto-dialing intelligent modem with the JEM and to test-query the JEM. A manual check of data ensures that the computer system is receiving the data properly. Once it has been established that the data are being transmitted correctly, the program is put into the data-collection mode where the programmer is asked to calibrate

the clocks within the HP-85 with the time of day and to establish a time when data collection should begin.

The user was prompted at the end of each 24-hour period to load a disk in the appropriate drive. For example, the first drive used by the program is "Drive 0" while the second drive is labeled "Drive 1." At the program start, the user is prompted to load an even-numbered disk in "Drive 1." At the end of 24 hours, the program has completed writing data to "Drive 0" and proceeds to write data to "Drive 1" where it automatically prints a message to load an odd-numbered disk in "Drive 0."

When the character string is sent to the JEM meter, the JEM responds with an 80-character string of information. That information includes both the kVA information and the kVAR or reactive power-information. The HP-85 extracts the kVA from the 80-character string and merges it with time of day information. The accumulated kVA and time of day are merged and integrated into each element of a 12-element array. When this array is filled, once every minute, the data are dumped to the floppy disk.

D. SYSTEM CALIBRATION AND CHECKOUT

Prior to the installation of the load monitoring instrumentation at a residence, all equipment was calibrated and tested. The JEM has an analog output for kVA and a serial digital output for kVAh. Both of these outputs were calibrated using a load resistor which was turned on and off for fixed periods.

The analog output was monitored using an Esterline-Angus strip chart recorder. JEM digital readings and Esterline-Angus readings agreed to within 0.4 percent when checked against calibrated loads. The square-0 current transformers were calibrated by PNM and were found to be accurate to within 1 percent.

The instrumentation was configured as it would be used in residential load monitoring and installed in a test bed, the BDM Prototype Development Laboratory, a 6,000-square-foot research facility. The actual load of the facility was then monitored for fixed test periods.

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The readings from the JEM meter were compared to the continuous output of Esterline-Angus strip chart reporter, and the power measured by each instrument agreed to within 0.4 percent. Actual load data were taken at 4-second intervals and comparisons made of different sampling intervals from 4 seconds to 1 minute to define the correct sampling interval for residential monitoring. A problem was encountered initially with the pulse output of the JEM (15,744 pulses per hour) which produced significant round-off error when the data were plotted at a 4-second sampling interval. In order to overcome this count error, the circuit boards of the JEM were modified to quadruple the pulse output (62,976 pulses per hour), thereby greatly improving accuracy. Although 4 seconds represented the minimum sampling interval of the JEM, a 5-second interval was selected to allow for data transfer within the HP-85.

E. RESIDENTIAL LOAD MONITORING

The two Albuquerque residences were instrumented using the JEM and modem enclosure and switchgear, which was direct-mounted to the residence. In both Newark and Atlanta, the JEM (modem enclosure only) was mounted to a utility service pole. Table IV-1 summarizes the total data collection by residence. A more detailed discussion of the load data base by region, season, and weekday/weekend can be found in chapter IV.

TABLE IV-1. DATA COLLECTION BY RESIDENCE

	<u>Hours of Load Data Collection</u>			
	<u>ALB-1</u>	<u>ALB-2</u>	<u>Atlanta</u>	<u>Newark</u>
Summer	215.5	224.5	149.5	190.5
Winter	146.5	104.0	155.5	84.0
Total	362.0	328.5	305.0	274.5

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Load data were collected through local phone lines. A data collection team was on-site in Newark and Atlanta to collect summer and winter data. In Newark, the original residence selected for monitoring exhibited very small variation in the monitored load due to the use of natural gas for cooking and domestic water heating. The instrumentation package was removed and installed at a larger residence by PSE&G. The residence exhibited considerable load variability during the summer due to central air conditioning, but in the winter exhibited little activity beyond small appliance usage due to use of natural gas for cooking, heating, and domestic hot water.

F. RESIDENTIAL APPLIANCE CHARACTERIZATION

Residential appliance profiles were characterized at the two Albuquerque residences to determine the signatures of specific appliances. The characterization was conducted to provide both a means of visually examining the load data plotted by the HP-85, (to determine what appliances were on) and to calibrate the JEM against the more accurate strip chart recorder. These appliance profiles were collected using the Esterline-Angus chart recorder connected to the analog output of the JEM. During the appliance characterization, the JEM was simultaneously transmitting digital load data to the HP-85 which was used for comparison and calibration. The analog and digital appliance profiles are shown in figures IV-2 and IV-3. The digital JEM data were sampled every 5 seconds and then plotted every 15 seconds as shown in figure IV-2. The power measured by each device agreed to within 0.4 percent which verified the calibration performed in the laboratory. During the test, all appliances in the residence were disconnected, then connected and allowed to cycle so that the signature could be obtained. Both residences contained electric ovens; only one residence contained an electric dryer. Each had the normal complement of small appliances.

The Esterline-Angus sampled and plotted the load every 0.5 seconds and was able to identify motor starts which were not seen in the JEM data. These however did not prove significant in measuring the power consumed.

BDM/A-82-299-TR-R1

Figure IV-2. JEM/HP-85

BDM/A-82-299-TR-R1

Figure IV-3. Esterline-Angus

CHAPTER V
STATISTICAL MODEL DEVELOPMENT

A. INSTANTANEOUS LOAD DATA BASE

1. Data Base Development Procedures

Residential load data were collected at 5-second intervals via the JEM, modem, and HP-85 configuration in the form of integer counts (number of revolutions of the meter). These integer counts for up to 24 hours in duration were stored on floppy disks. Using the HP-85 terminal emulator capability and RS232 interface, contents of each floppy disk were transferred to the Sandia Network Operating System (NOS) computer and stored on files.

The transfer to the Sandia computer was over phone lines, and interference and noise problems occurred that caused some holes and extraneous characters to arise in the data files. These errors were detected through observation of the file listings and screenings with a text editor. Most of these errors (i.e., one missing 5-second data point) were easily corrected, with missing data items estimated by comparison with surrounding data points. Some transferred files did contain enough noise to require retransfer of the file. To complete the verification of the transferred data, the files were read via a Fortran program with a formatted read and also processed through a Biomedical Computer Program, P-Series (BMDP) Statistical Package, program which read the files alphanumerically and listed frequencies of symbol occurrences.

Once the data transfer and verification were completed, the count measurements were converted into kVA units and the data were structured into data base format. A conversion constant had been previously derived which accounted for the time interval of the count, and a kVA per count constant determined from calibration of the JEM. The processing of the data was then accomplished with a Fortran program which converted the data; broke the data out into 15-minute blocks with

associated time of day, day of week, house, and season; and calculated other descriptive information.

Eight load data base files contain the instantaneous load data collected, broken out into separate files for each of the four residences for winter and summer. An example of two continuous 15-minute intervals as they are configured in the load data base is shown in appendix A. Procedures for accessing the data base on the SNL computer under the NOS are also detailed in appendix A.

2. Data Base Description

A summary of the duration of the data sample for each residence is presented in figures V-1a, b, c, and d. The figures contain the header records from the load data base pertaining to the contiguous blocks of 15-minute intervals of collected data. Data collected in Newark and Atlanta were not as continuous as in Albuquerque, due to phone line problems. This resulted in an increased number of blocks of continuous data each with somewhat smaller continuous durations.

The load data base contains 5,080 complete, and mostly continuous (as can be seen from the figures), 15-minute intervals (1,270 hours) of 5-second sampled data. Tables V-1 and V-2 display a breakout of the sampled intervals by residence, season, and day of week. These tables indicate that during the monitoring period an adequate sampling of each region, season, and weekday/weekend was obtained. In most cases, data collection was planned to include two weekends to allow determination of whether weekdays and weekends display different instantaneous load patterns. Summer data collection in Newark resulted in data which displayed very steady, but varying, loads. Since steady loads are modeled by the 15-minute average, and preliminary winter results from Newark displayed the same steady loads, the winter data collection period in Newark was shortened.

More emphasis was given to load data collection of the Albuquerque residences since monitoring could be conducted without travel. In addition, all 96 quartiles (15-minute intervals in the day) were sampled, with an average of 53 15-minute interval samples per quartile.

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NEWARK THU 7/16/81 16:45-24:00, 29 QUARTILES, 68 - 96
NEWARK FRI 7/17/81 24:00-16:30, 66 QUARTILES, 1 - 66
NEWARK FRI 7/17/81 16:45-24:00, 29 QUARTILES, 68 - 96
NEWARK SAT 7/18/81 24:00-24:00, 96 QUARTILES, 1 - 96
NEWARK SUN 7/19/81 24:00-16:30, 66 QUARTILES, 1 - 66
NEWARK SUN 7/19/81 16:45-24:00, 29 QUARTILES, 68 - 96
NEWARK MON 7/20/81 24:00-16:30, 66 QUARTILES, 1 - 66
NEWARK MON 7/20/81 16:45-24:00, 29 QUARTILES, 68 - 96
NEWARK TUE 7/21/81 24:00-16:30, 66 QUARTILES, 1 - 66
NEWARK TUE 7/21/81 16:45-24:00, 29 QUARTILES, 68 - 96
NEWARK WED 7/22/81 24:00-24:00, 96 QUARTILES, 1 - 96
NEWARK THU 7/23/81 24:00-16:30, 66 QUARTILES, 1 - 66
NEWARK THU 7/23/81 16:45-24:00, 29 QUARTILES, 68 - 96
NEWARK FRI 7/24/81 24:00-16:30, 66 QUARTILES, 1 - 66
NEWARK THU 1/28/82 20:15-24:00, 15 QUARTILES, 82 - 96
NEWARK FRI 1/29/82 24:00- 2:00, 9 QUARTILES, 1 - 9
NEWARK SAT 1/30/82 4:30-24:00, 79 QUARTILES, 19 - 96
NEWARK SUN 1/31/82 24:00- 3:15, 13 QUARTILES, 1 - 13
NEWARK SUN 1/31/82 12:30-24:00, 46 QUARTILES, 51 - 96
NEWARK MON 1/32/82 24:00- 3:45, 15 QUARTILES, 1 - 15
NEWARK MON 2/ 1/82 9:15-18:45, 38 QUARTILES, 38 - 75
NEWARK TUE 2/ 2/82 21:45-24:00, 9 QUARTILES, 88 - 96
NEWARK WED 2/ 3/82 24:00- 5:30, 22 QUARTILES, 1 - 22
NEWARK WED 2/ 3/82 9:15-14:15, 20 QUARTILES, 38 - 57
NEWARK WED 2/ 3/82 21:30-24:00, 10 QUARTILES, 87 - 96
NEWARK THU 2/ 4/82 24:00- 2:00, 8 QUARTILES, 1 - 8
NEWARK SAT 2/13/82 12:00-24:00, 48 QUARTILES, 48 - 96
NEWARK SUN 2/14/82 24:00- 1:30, 6 QUARTILES, 1 - 6
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ATLNTA FRI 7/ 3/81 19:00-24:00, 20 QUARTILES, 77 - 96
ATLNTA SAT 7/ 4/81 24:00-18:45, 75 QUARTILES, 1 - 75
ATLNTA SAT 7/ 4/81 19:00-24:00, 20 QUARTILES, 77 - 96
ATLNTA SUN 7/ 5/81 24:00-18:45, 75 QUARTILES, 1 - 75
ATLNTA THU 7/ 9/81 17:30-24:00, 26 QUARTILES, 71 - 96
ATLNTA FRI 7/10/81 24:00-17:15, 69 QUARTILES, 1 - 69
ATLNTA FRI 7/10/81 17:30-24:00, 26 QUARTILES, 71 - 96
ATLNTA SAT 7/11/81 24:00-17:15, 69 QUARTILES, 1 - 69
ATLNTA SAT 7/11/81 17:30-24:00, 26 QUARTILES, 71 - 96
ATLNTA SUN 7/12/81 24:00- 0:30, 2 QUARTILES, 1 - 2
ATLNTA SUN 7/12/81 1:15-24:00, 91 QUARTILES, 6 - 96
ATLNTA MON 7/13/81 24:00- 1:00, 4 QUARTILES, 1 - 4
ATLNTA MON 7/13/81 1:15-24:00, 91 QUARTILES, 6 - 96
ATLNTA TUE 7/14/81 24:00- 1:00, 4 QUARTILES, 1 - 4
ATLNTA TUE 2/22/82 16:00-24:00, 32 QUARTILES, 65 - 96
ATLNTA TUE 2/23/82 24:00-15:45, 63 QUARTILES, 1 - 63
ATLNTA TUE 2/23/82 16:00-24:00, 32 QUARTILES, 65 - 96
ATLNTA WED 2/24/82 24:00-15:45, 63 QUARTILES, 1 - 63
ATLNTA WED 2/24/82 16:00-24:00, 32 QUARTILES, 65 - 96
ATLNTA THU 2/25/82 24:00-15:45, 63 QUARTILES, 1 - 63
ATLNTA THU 2/25/82 16:00-24:00, 32 QUARTILES, 65 - 96
ATLNTA FRI 2/26/82 24:00-24:00, 96 QUARTILES, 1 - 96
ATLNTA SAT 2/27/82 24:00- 0:30, 2 QUARTILES, 1 - 2
ATLNTA SAT 2/27/82 0:45- 6:00, 21 QUARTILES, 4 - 24
ATLNTA SAT 2/27/82 11:15-24:00, 51 QUARTILES, 46 - 96
ATLNTA SUN 2/28/82 24:00-24:00, 96 QUARTILES, 1 - 96
ATLNTA MON 2/29/82 24:00- 9:45, 39 QUARTILES, 1 - 39
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Figure V-1a. Newark Data Collection Summary Figure V-1b. Atlanta Data Collection Summary

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ALBU-1 THU 10/15/81 21:15-24:00, 11 QUARTILES, 86 - 96
ALBU-1 FRI 10/16/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 SAT 10/17/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 SUN 10/18/81 24:00-21:00, 84 QUARTILES, 1 - 84
ALBU-1 SUN 10/18/81 21:15-24:00, 11 QUARTILES, 86 - 96
ALBU-1 MON 10/19/81 24:00-21:00, 84 QUARTILES, 1 - 84
ALBU-1 MON 10/19/81 21:15-24:00, 11 QUARTILES, 86 - 96
ALBU-1 TUE 10/20/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 WED 10/21/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 THU 10/22/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 FRI 10/23/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 SAT 10/24/81 24:00-21:15, 85 QUARTILES, 1 - 85
ALBU-1 WED 12/30/81 21:30-24:00, 10 QUARTILES, 87 - 96
ALBU-1 THU 12/31/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 FRI 1/ 1/82 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 SAT 1/ 2/82 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 SUN 1/ 3/82 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 MON 1/ 4/82 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-1 TUE 1/ 5/82 24:00-24:00, 96 QUARTILES, 1 - 96
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ALBU-2 FRI 9/11/81 19:00-24:00, 20 QUARTILES, 77 - 96
ALBU-2 SAT 9/12/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 SUN 9/13/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 MON 9/14/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 TUE 9/15/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 WED 9/16/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 THU 9/17/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 FRI 9/18/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 SAT 9/19/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 SUN 9/20/81 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 MON 9/21/81 24:00- 3:30, 14 QUARTILES, 1 - 14
ALBU-2 FRI 1/15/82 17:45-24:00, 25 QUARTILES, 72 - 96
ALBU-2 SAT 1/16/82 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 SUN 1/17/82 24:00- 1:45, 7 QUARTILES, 1 - 7
ALBU-2 MON 1/17/82 12:00-24:00, 48 QUARTILES, 48 - 96
ALBU-2 MON 1/18/82 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 TUE 1/19/82 24:00-24:00, 96 QUARTILES, 1 - 96
ALBU-2 WED 1/20/82 24:00-12:00, 48 QUARTILES, 1 - 48
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Figure V-1c. Albuquerque #1 Data Collection Summary Figure V-1d. Albuquerque #2 Data Collection Summary

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TABLE V-1. LOAD DATA BASE SUMMARY

		NEWARK	ATLANTA	ALBU-1	ALBU-2	TOTAL
SUMMER	15-min intervals	762	598	862	898	3120
	hours	190.5	149.5	215.5	224.5	780.0
WINTER	15-min intervals	336	622	586	416	1960
	hours	84.0	155.5	146.5	104.0	490.0
TOTAL	15-min intervals	1098	1220	1448	1314	5080
	hours	274.5	305.0	362.0	328.5	1270.0

		MON	TUE	WED	THUR	FRI	SAT	SUN	TOTAL
SUMMER	15-min intervals	395	291	288	353	584	659	550	3120
	hours	98.75	72.75	72.00	88.25	146.0	164.75	137.5	780.00
WINTER	15-min intervals	316	296	205	214	225	392	312	1960
	hours	79.00	74.00	51.25	53.50	56.25	98.0	78.00	490.00
TOTAL	15-min intervals	711	587	493	567	809	1051	862	5080
	hours	177.75	146.75	123.25	141.75	202.25	262.75	215.50	1270.00

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TABLE V-2. SAMPLED INTERVALS CATEGORIZED BY HOUSE, SEASON
AND WEEKDAY/WEEKEND

			NEWARK	ATLANTA	ALBU-1	ALBU-2	TOTAL
SUMMER	WEEKDAY	15-min intervals	571	240	586	514	1911
		hours	142.75	60.00	146.50	128.50	477.75
	WEEKEND	15-min intervals	191	358	276	384	1209
		hours	47.75	89.50	69.00	96.00	302.25
WINTER	WEEKDAY	15-min intervals	145	452	394	265	1256
		hours	36.25	113.00	98.50	66.25	314.00
	WEEKEND	15-min intervals	191	170	192	151	704
		hours	47.75	42.50	48.00	37.75	176.00

B. STATISTICAL LOAD MODEL

1. Modeling Methodology

A modeling methodology involving the prediction of peaks (load spikes), peak durations, and frequencies per 15-minute interval based on the time-averaged load was initially proposed for this project. Previous analysis of 1-minute interval data (the shortest interval data available at the time) conducted for the proposal displayed a strong positive correlation of .97 between peaks and functions of the present and previous time-averaged loads. However, the 1-minute data were simulated, a fact not known at the time, and proved not to be realistic when compared to real data collected during the measurement phase of this project. In fact, preliminary findings of the direct measurement program showed that the instantaneous load profiles, or patterns, were driven by major appliances only, and that smaller appliances simply added to the base load. The peak loads, durations, and frequencies were thus based on particular appliance load profiles. Predicting which appliances were on based on the time-averaged load would have been difficult to do. In addition, instantaneous appliance load patterns other than those developed during the pilot phase were not available.

The findings redirected the development of the statistical load modeling methodology. A new approach was formulated and involved three basic stages plus the final prediction:

- (1) Instantaneous load profile characterization for each 15-minute interval
- (2) Determination of the most prevalent profile groups based on analysis of the characterization measures
- (3) Representation of the prevalent profile groups
- (4) Prediction of which profile group representation to use based on the time average.

The modeling methodology is shown in figure V-2.

Periodic regression analysis is a curve-fitting technique, similar to polynomial regression, applicable for periodic data and was

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Figure V-2. Modeling Methodology

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used to define or characterize the instantaneous profile for each 15-minute interval in the data base. This analysis uses functions of sine and cosine curves, the coefficients of which characterize the instantaneous profile. Cluster analysis and classification analysis were used to group similar profiles, based on the coefficient values. Once a precise separation of distinct profile groupings was determined, coefficient averages for each grouping were calculated. Based on several criteria, the real 15-minute intervals of 5-second load data having coefficients closest to the group averages were determined. These real profiles were used to represent the distinct profile groups in order to maintain the instantaneous nature of the data. Frequency analysis was performed on the profile groups to investigate possible relationships of the groups to particular residences (regions), season, and day of the week; and to determine probabilities of occurrence to be used for prediction of the presence of the profiles. Finally, an algorithm was developed incorporating the profile representations and prediction scheme. This algorithm was implemented into the SOLCEL photovoltaics analysis code to provide the capability for analyzing residential photovoltaic applications using predicted instantaneous load requirements.

2. Load Model Development

a. 15-Minute Load Profile Characterization

An example of the regression analysis results and the coefficient estimates for a selected 15-minute interval is shown in figure V-3. Three pairs of sine and cosine functions of the timeline variable, X , were included in the periodic regression example to form three harmonics. The high squared multiple correlation coefficient of 0.936 underlined in the figure indicates the periodic regression model fits the data quite well, with only three harmonics. Coefficients for the sine and cosine pairs define the presence and magnitude of the corresponding harmonic in the equation. The Y-intercept coefficient value is the 15-minute interval average load. Due to the orthogonality of the sine and cosine functions, individual coefficient estimates remain

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the same, no matter how many other harmonics are in the equation. The orthogonality also results in identical standard errors of the coefficients in the equation. Coefficients for each sine and cosine pair, say a and b respectively, can be combined to provide the amplitude, A, and phase angle, θ , of the sine curve harmonic by the following relations:

$$A = \sqrt{a^2 + b^2}$$

$$\tan \theta = a/b$$

MULTIPLE R	0.9676			
MULTIPLE R-SQUARE	0.9362			
STD. ERROR OF EST.	0.1754			
ANALYSIS OF VARIANCE				
	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO
REGRESSION	22.149336	6	3.691556	119.923
RESIDUAL	1.5083482	49	0.3078262E-01	
VARIABLES IN EQUATION				
	STD. ERROR	STD-REG		
VARIABLE	COEFFICIENT	OF COEFF	COEFF	F TO REMOVE
(Y-INTERCEPT 1.232)				
GOSX 5	0.256	0.033	0.279	59.626
SINX 6	0.791	0.033	0.860	569.068
GOS2X 7	0.140	0.033	0.152	17.820
SIN2X 8	0.204	0.033	0.222	37.826
GOS3X 9	0.028	0.033	0.030	0.695
SIN3X 10	0.195	0.033	0.212	34.506

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Figure V-3. Periodic Regression Example with Three Harmonics

Regression analysis was performed on the 4-second interval data collected during the initial stages of the direct measurement program.

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One of the conclusions reached was that data could be aggregated to 16-second intervals for modeling. Doing so reduced the roundoff effects in the data, adequately maintained the instantaneous profile information, and advantageously reduced the amount of data to be analyzed by periodic regression for each 15-minute interval. Each 15-minute interval contained 56 intervals 16 seconds long, with the exclusion of the last data point. This corresponds to the degrees of freedom shown in the figure.

A plot of the observed data (O) for the 15-minute interval in the example and the predicted values (P) from the periodic regression equation in the previous figure is presented in figure V-4. The plot displays the adequacy of the periodic regression characterization of the instantaneous profile.

Prior to performing periodic regression on each of the intervals in the load data base, the 5-second interval data were aggregated into 15-second interval load values, for the reasons previously stated, producing 60 measurements per 15-minute interval. Since no prior information existed on how many harmonics were necessary to adequately model the highly variable load profiles, it was decided to use eight harmonics in each periodic regression analysis. The use of eight harmonics was considered adequate for most intervals and was also an upper bound in consideration of the large volume of information which would require file storage.

Periodic regression analysis was performed on each of the 5,080 15-minute intervals in the load data base using International Mathematical and Statistical Library (IMSL) subroutines. Coefficients from each of the periodic regression equations and descriptive information relating the house, season, day, date, time, minimum, maximum, energy above average, squared multiple correlation, standard error of estimate, and standard error of coefficient were concurrently stored on file for further analysis. With 72.5 percent of the equations having squared multiple correlations (R^2) greater than 70.0 percent, the periodic regression stage was considered to have completely accomplished the goal of adequate profile characterization.

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NOTE: This plot was generated on a standard printer. A width of 50 columns was specified and 56 data points were plotted, resulting in 6 overplots.

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Figure V-4. Plot of Predicted (P) and Observed (O) Load Versus Time

Intervals having active profiles in contrast to steady, inactive load profiles which closely follow the 15-minute average were then selected. Since inactive, or steady, loads are adequately modeled by the 15-minute average load, no further modeling of these profiles was necessary. Most profiles in the load data base were considered to be inactive and occurred during the night, mid-morning, and mid-afternoon.

Three criteria were used to determine whether profiles were sufficiently active to require further modeling: time of day, energy above average, and the squared multiple correlation. The energy above average measures the energy (area) below the instantaneous profile and above the 15-minute average, and thus relates the activity of the profile. Active profiles would necessarily have high energy above average values. Squared multiple correlation measures the amount of variability accounted for by the regression equation in contrast to a horizontal line. Low correlations indicate that the time average values (Y-intercept or constant term in the equation) is adequate for modeling and that the profile is inactive.

Plots of energy above average versus quartile (15-minute time interval of the day) and squared multiple correlation for the 5,080 intervals are presented in figures V-5 and V-6 respectively. Also indicated on the plots are the cut-off levels for the three criteria used to define active profiles:

- (1) Quartiles greater than 22 (5:30 - 24:00) (figure V-5)
- (2) Energy above average greater than .06 kVA (figure V-5, V-6)
- (3) Squared multiple correlation greater than or equal to 70 percent (figure V-6)

The breakdown of the 5,080 intervals according to the three criteria is shown in table V-3 (counts from the plots do not exactly match the table due to interval roundoff on the plots). In choosing the cut-off levels for the three criteria, some consideration was given to maintaining a manageable data set for the remaining analysis. The cut-off level of 0.06 kVA for energy above average was used since the intervals appeared to split up at that point. Of the 60 intervals having energy above

Figure V-5. Plot of Energy Above Average (ABVAVE) Versus Quartile (QRTL)

V-14

Figure V-6. Plot of Energy Above Average (ABVAVE) Versus R-Squared (RSQR)

average greater than .06 kVA and between midnight and 5:30, all but one of them were traced to the Newark residence in summer, probably indicating high usage of electric air conditioning (complete demographics on the Newark and Atlanta residences were not obtained and direct communication with the homeowner was not allowed). Since these intervals were few in number and imprecisely defined, they were not included as active profiles. This decision led to choosing 5:30 as a cut-off for time since almost all profiles between midnight and 5:30 had energy above average values less than 0.5 kVA and were observed to be low, steady loads. The 58 intervals having energy above values greater than 0.6 kVA and correlation less than 70 percent were found to be extremely varying loads, primarily from one of the Albuquerque residences and possibly due to the stove burner elements, which could not be adequately characterized by the eight harmonic equation.

The three criteria were used simultaneously to classify 734 profiles (out of the total 5,080 intervals) as active profiles (see table V-3). The coefficients and descriptive information for these intervals were stored on a separate file for the next analysis stage.

b. Determination of Distinct Profile Groups

The goal of this analysis stage was to classify the active instantaneous profiles into distinct groups or categories to determine the most prevalent profiles. This goal is based on the premise that the active instantaneous load profiles are due mostly to a few major appliances and that, when a particular appliance is in use, the resulting load profiles would all be similar. Even though the base loads may be different, resulting in different 15-minute averaged load values, the load profiles due to a particular appliance should be similar. In fact, each distinct profile group developed could probably be associated with either an individual or a combination of major appliance loads.

Load profiles were grouped according to various criteria and based on the coefficients of the characteristic periodic regression equations. Cluster analysis and contingency table layouts were used to examine the groupings resulting from the various criteria. In cluster

TABLE V-3. BREAKDOWN OF INTERVALS BY CRITERIA FOR ACTIVE PROFILES

ENERGY ABOVE AVERAGE	QUARTILE	CORRELATION	
		LT 70	GE 70
LE .06	LE 22	313	801
	GT 22	1045	2069
GT .06	LE 22	0	60
	GT 22	58	734

NOTE:

GE - GREATER THAN OR EQUAL TO

GT - GREATER THAN

LE - LESS THAN OR EQUAL TO

LT - LESS THAN

analysis, the coefficient variables are recoded as belonging to specified intervals, and cases (profiles) having common codes for the coefficients are grouped together. The specification of the intervals for each coefficient and the number of coefficients included greatly affected the groupings.

Output from the $\bar{c}$ luster analysis routine (Biomedical Computer Programs, P-Series, Program P3M) is quite lengthy and is not included here. The cluster analysis effort required a large number of trial and error analyses. Initially, the coefficient values for the sine and cosine functions were used to group the intervals. Several problems were encountered involving the common scale of the variables, symmetry of

the variables about zero, and the large number of variables (up to 17) and cases (734). It was decided to transform the coefficients into the harmonic amplitude and phase angle values and to reduce the number of harmonics used to cluster the profiles. Results from these analyses displayed better grouping of the profiles. Intervals for the amplitudes were reduced to four: low, medium, high, and very high. Phase angles were not included individually, but combined to form phase angle differences between pairs of harmonics when both were in at least the medium category. The phase angle for a harmonic defines where along the time axis the sine curve lies. This location was not considered important since it is dependent upon when exactly the data collection occurred and when appliances were turned on. However, when two or more harmonics were present in the profile characterization, at the medium or higher categories, the phase angle difference between the pairs of harmonics did aid in grouping the profiles. Phase angle differences were placed in three categories: in phase, between phase, and out of phase.

Several analyses using this structure led to a good grouping of the profiles. One conclusion reached was that only the first two harmonics were needed to group the profiles. The final grouping structure is summarized in a contingency table layout shown in table V-4. Displayed in the table are the number of 15-minute interval profiles in each group and the group classification number. Thirteen different profile groups were identified, with groups 10 and 12 being a combination of two somewhat similar groups and group 13 being somewhat of a "grab bag" group. All the profiles not falling into a distinct group were placed in group 13. With the distinct profile groups defined, remaining modeling steps were to form representations of the groups and to develop a prediction or selection strategy.

c. Profile Group Representations

To construct the statistical model predicting the instantaneous load profile, precise definition of the predicted profiles (and therefore the profile groups) was necessary. Mathematical formulation of the profiles using the sine curve (harmonic) amplitude and phase angle

TABLE V-4. CLASSIFICATION TABLE DISPLAYING DISTINCT PROFILES

ATION

1ST HARMONIC AMPLITUDE											
		LE .05 LOW		LE .10 MED			LE .15 HIGH		GT .15 EX. HIGH		
		NUMBER OF PROFILES	PROFILE GROUP	NUMBER OF PROFILES	PROFILE GROUP		NUMBER OF PROFILES	PROFILE GROUP	NUMBER OF PROFILES	PROFILE GROUP	
2nd HARMONIC	LE .05 LOW	52	1	136	4		80	7	38	11	
	LE .10 MED	55	2	IN BTWN OUT	66 49 13	5 6 13	40 43 2	8 9 13	9 17 2	13 12 13	
	GT .10 HIGH	45	3	IN BTWN OUT	9 8 1	13 13 13	14 7 1	10 13 13	14 27 6	10 12 13	

TOTAL
IS 734.

IN = PHASE ANGLES IN PHASE
BTNW = PHASE ANGLES BETWEEN PHASE
OUT = PHASE ANGLES OUT OF PHASE

LE = LESS THAN OR EQUAL TO
GT = GREATER THAN

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differences was considered, but found to smooth out the profiles. In view of how the SOLCEL PV analysis code operates and with the desire to maintain the instantaneous nature of the profiles, it was decided to use the interval of real instantaneous data which was closest to the average or centroid of the profile group. That is, real data profiles were used to represent the distinct profile groups.

Mathematical averages of the first four harmonic amplitudes and the difference between the first two harmonic phase angles were calculated for each profile group. From the interval profiles in a particular group, the interval with amplitude and the phase angle difference closest to the averages for that group was determined. Closest was defined by several criteria: minimum sum of squared deviations, minimum sum of absolute deviations, and two different weighting schemes used to weight the deviations from the amplitudes more than the deviation from the phase angle difference. The representative intervals chosen matched on at least three of the above four criteria for all the groups.

Having determined the representative intervals for each of the 13 groups, the real load data for the intervals were extracted from the load data base and placed on a separate file. Plots of the 13 representative load profiles are included in appendix C. *

d. Profile Prediction

The final step of the load modeling task was to develop a rule for determining the presence of an active profile, and selecting which representative profile to use. Possible relationships to be included in the prediction of load profile were time of day, day of week, season, region (NE, SE, SW), and the 15-minute average load. These possible relationships were investigated through analysis of contingency tables and plots. If particular profiles occurred only at specific times of day, on weekdays or weekends, during a particular season, only in a particular region, or only for selective time-averaged loads, a relationship probably existed. However, since the loads are appliance-driven, an argument could be made that the differences occurred only because of the use of different kinds of appliances, each with different

efficiencies, load requirements, and usage practices. With a sample of only four households of appliances, determining precise relationships was not feasible. In addition, no clear relationships in terms of time, day, season, etc., as described above, were determined.

An example of the contingency table layouts used to explore the relationships is given in table V-5. This contingency table depicts the breakdown of all the 5,080 sampled intervals according to profile group (inactive profiles defined as profile group 0), weekday/weekend, and season.

A basic approach involving frequencies of occurrence was decided upon for the profile prediction. The frequency of occurrence of active profiles out of the total possible intervals when an active profile could occur was used to develop the probability of an active profile. Since very few active profiles occurred between midnight and 5:30, these intervals were not included as possible active profiles. Referring to the breakdown of the sampled intervals presented in table V-3, the first and third rows were excluded as being possible active profiles. The resultant probability of an active profile was calculated to be

$$(58 + 734)/(1045 + 2069 + 734 + 58) = 0.203$$

Finally, given the presence of an active profile, the selection of 1 of the 13 representative profiles was based on the frequencies of occurrence of the profile groups out of the 734 total active profiles. Individual profile group probabilities were calculated by dividing the number of intervals in each group, given in table V-5, by the total of 734.

The probabilities and decision criteria were formed into an algorithm to be inserted into the SOLCEL PV analysis code. Even though profiles are predicted by this relatively simple probabilistic prediction scheme, simulation results over an annual time period are considered to be both realistic and informative. However, matching the predicted instantaneous load profiles real data for smaller time durations, one day for example, would probably show large discrepancies.

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TABLE V-5. PROFILES BY SEASON AND WEEKDAY/WEEKEND

PROFIL S	2 DAY 2	(S)			TOTALS
P	D	I	SUMMER	WINTER	

0.0	WEEKDAY	I	1655	1049	4346
	WEEKEND	I	1027	614	

1.0	WEEKDAY	I	15	19	52
	WEEKEND	I	9	9	

2.0	WEEKDAY	I	6	29	55
	WEEKEND	I	5	15	

3.0	WEEKDAY	I	20	11	45
	WEEKEND	I	9	5	

4.0	WEEKDAY	I	29	53	136
	WEEKEND	I	31	23	

5.0	WEEKDAY	I	35	10	66
	WEEKEND	I	17	4	

6.0	WEEKDAY	I	18	17	49
	WEEKEND	I	10	4	

7.0	WEEKDAY	I	35	16	80
	WEEKEND	I	24	5	

8.0	WEEKDAY	I	23	7	40
	WEEKEND	I	11	2	

9.0	WEEKDAY	I	20	8	43
	WEEKEND	I	9	6	

10.	WEEKDAY	I	13	2	28
	WEEKEND	I	10	3	

11.	WEEKDAY	I	16	4	38
	WEEKEND	I	15	3	

12.	WEEKDAY	I	7	12	44
	WEEKEND	I	22	3	

13.	WEEKDAY	I	21	19	58
	WEEKEND	I	16	8	

					5080

3. Load Model Implementation into SOLCEL

SOLCEL is a SNL-developed computer simulation code designed specifically for the analysis of PV systems. The code currently is capable of accepting annual load data in hourly or 15-minute intervals and perform the simulation accordingly. Using the annual load data and solar/weather data, the program simulates the annual performance of specified PV and battery storage systems; computes the load requirements met by the PV system, battery storage, and the utility; and performs an economic analysis.

An algorithm incorporating the statistical load model prediction scheme and the representative profiles was implemented into the SOLCEL code. Real load data defining the profiles were included as deviations from the 15-minute time averaged load. SOLCEL still steps through the simulation at 15-minute intervals, but if an active profile is predicted, based on a random draw and comparison to the active profile probability, all computations are performed at 15-second interval steps.

Annual 15-minute interval load data are required to utilize the statistical load model. In stepping through the simulation, the 15-minute load value is used if (1) the time is between midnight and 5:30 A.M., (2) the time-averaged load is less than 500 W, or (3) the probability criterion for an active profile is not met. Otherwise, the active profiles are used. Based on another random draw, one of the 13 profiles is chosen. For active profiles, the algorithm uses the chosen profile deviations and the current time-averaged load to calculate the 15-second load values for that 15-minute interval. SOLCEL then steps through at 15-second intervals and calculates the PV provided load, battery storage provided load, and utility provided load. With the added capability of the instantaneous load statistical model, SOLCEL is capable of providing complete and realistic annual PV system performance measures. Appendix B describes how to access and execute the version of SOLCEL containing the statistical load model.

CHAPTER VI
PERFORMANCE COMPARISONS

Photovoltaic (PV) array residential performance is usually measured by the percentage of the PV output that meets the load demand compared to that sold to the utility. The load that is not met by the PV array is bought from the utility. The instantaneous output of the array and the instantaneous load are, therefore, crucial in the exact calculation of PV performance.

Simulation programs have been used to determine PV performance as a function of Typical Meteorological Year (TMY) solar/weather data. Errors in performance calculations have been known to exist when time-averaged load data are used, where time-averaged load refers to load demand averaged over a given interval (i.e., 15 minutes). These errors in performance calculations are in the estimates of PV output sold to and the energy bought from the utility. The amount sold and bought are always underestimated when the average data are used. Studies over short-time intervals have shown serious errors when comparisons are made between time-averaged and instantaneous load data. Percentage errors over short intervals in the amount sold back to the utility have been shown to be as high as 50 percent. But, the percentage error is not as important as the magnitude of the error. For example, if the true amount sold was 20,000 units and a 5 percent error (1,000 units) was made, a larger error results than if the true amount sold was 6,000 units and a 15 percent error (900 units) was made. Also, the combination of the above two data points result in only a 7 percent error. Since PV arrays operate over long time periods, the important issue is the magnitude of the error over long i.e., annual, periods of time.

To further define the problem, consider figure VI-1. Three possible situations exist for PV output and instantaneous load data:

- (1) Figure VI-1a shows the case for which the maximum load demand is below the PV array output. For this case, 100 percent of the load is met by the PV array, and no error (amount bought

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Figure VI-1. Three Possible Configurations of Load Versus PV Output

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from or sold to the utility) would be generated during time-averaged load data.

- (2) Figure VI-1b shows the case for which the minimum load demand is greater than the PV array output. Again, no error would be generated using time-averaged load data.
- (3) Figure VI-1c shows the third case for which the load demand crosses the PV output. For this case, power is being sold to and bought from the utility during the time interval. Using time-averaged load data would result in errors in the calculation of PV performance.

Assuming the normal variation expected from a residential load, these errors are maximized over a given time interval by having the time-averaged load demand equal to the time-averaged PV output. Raising or lowering the time-averaged load from the time-averaged PV output will decrease the error (i.e., the error in the amount sold will decrease as the time-averaged PV output is shifted above or below the time-averaged load). This concept can be proven mathematically by considering areas under the curve.

Using the above concept, the error generated by using a time-averaged load to predict PV array performance can be restated as follows. The error generated by using a time-averaged load is a function of the numerical difference between the time-averaged load and time-averaged PV output. Large errors will be generated when the numerical difference is small and small errors will be generated when this difference is large. For an annual PV performance, the issue becomes how often the time-averaged PV output becomes relatively equal to the time-averaged load demand.

Large errors occur only when the time-averaged load is approximately equal to the time-averaged PV output. The annual frequency of occurrence of approximately equal time-averaged load and PV output will depend on how closely matched the annual PV output is compared to the annual load demand. When these are closely matched, one would expect this approximate equality to occur more frequently. This frequency of occurrence is,

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therefore, the key issue in the relative size of error in predicting PV performance, and this frequency of occurrence is largely a function of PV array size relative to load demand.

To determine the size of a PV array that would cause a high frequency of approximately equal time-averaged loads and PV outputs, computer simulations were run. These simulations used actual 15-minute time-averaged load data measured from a residence, various array sizes, the statistical load model, and Albuquerque TMY solar/weather data.

BDM has previously obtained 1-year duration sets of 15-minute interval residential load data monitored by the Public Service Company of New Mexico for three Albuquerque residences. These residences were of the same class as those monitored in the Detailed Residential Electric Determination Load program. Data for one of the residences were selected and used as the input 15-minute load data, along with Albuquerque TMY solar/weather data, for SOLCEL/statistical-load-model simulations.

SOLCEL simulations were performed to produce and examine the sensitivity of annual and monthly performance measures to variations in the probability of the presence of an instantaneous load and to examine the effects of various array sizes. The sensitivity is a function of the frequency of occurrence of approximately equal time-averaged load and PV output. The purpose of this sensitivity analysis was to estimate the effects of the variables on PV direct fraction. If changes in the values of the probability of an active profile and/or the PV array size cause significant changes in the PV direct fraction, the PV direct fraction is sensitive to the variables. If changes in the variables have little effect on the PV direct fraction, the PV direct fraction is relatively insensitive to the variables. Also, the PV direct fraction may be sensitive only in subranges of the entire range examined for the variables. Thus, this analysis quantified the effects on PV direct fraction of given changes in array size and probability of an active profile. Thirty (30) simulation runs were completed varying the size of the PV array from 1 kW to 9 kW and the probability of an active load from 0.0 to 1.0. The probability of an active load of 0.0 implies 15-minute

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averaged load data were used. The probability of 1.0 implies an active profile was used. If the time was between 5:30 and 24:00 and the average 15-minute power was above .06 kVA, then the 15-minute average load was used. Both monthly and yearly totals of PV array performance were accumulated for each run.

The results of the simulations showed PV direct fraction was relatively insensitive to the probability of an active profile except for impractical small array sizes. This result is contrary to previous beliefs that estimation of PV direct fraction would be highly sensitive to load activity.

Initially, four SOLCEL simulations were performed to produce annual performance measures for comparison of

- (1) One-hour interval load data and time step
- (2) Fifteen-minute interval load data and time step
- (3) Fifteen-minute interval load data, using statistical load model with probability of active profile set to default (0.192)
- (4) Fifteen-minute interval load data, using statistical load model with probability of active profile set to 0.4

The last simulation, with the probability of an active profile approximately double the value determined from collected data, was performed to investigate the sensitivity of the annual performance measures to increasing the probability.

The results for the four initial simulations are displayed in table VI-1 in the form of annual percentages of load met by the 4 kW PV system. As expected, with smaller time intervals and the use of instantaneous profiles from the load model, the percent load satisfied by the PV system declines.

TABLE VI-1. RESULTS FROM SOLCEL SIMULATIONS

	MODEL	15 MIN	HOURLY	MODEL WITH TWICE PROBABILITY
PV DIRECT FRACTION	.333	.339	.346	.327

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To further determine the sensitivity of PV performance measures, additional SOLCEL simulations were run. Figure VI-2 illustrates a plot of the results of the simulation runs, varying array size and the probability of the occurrence of an active profile, and also shows annual results expressed in PV direct fraction, where PV direct fraction equals

$$\frac{\text{PV AC to LOAD}}{\text{Total PV AC}}$$

PV direct fraction is shown as a function of the probability of an active load where each line represents a different size PV array and the value of M is the slope of the line (i.e., I = 1000 is a 1000 Watt PV array and M = .134 implies a 13.4 percent reduction in the PV direct fraction when the probability of an active load is increased from 0.0 to 1.0). When the probability of an active load is 0.0, the simulation is run using 15-minute time-averaged load data. The solid vertical line represents the observed probability of an active load in the data from the four monitored residences, and the dashed line shows where the probability is greater than twice the observed value. Load activity beyond twice the observed value can be considered unrealistically active. This graph demonstrates the annual sensitivity of PV performance to array size and probability of an active load. The probability of an active load causes an increase in the frequency of the occurrence of approximately equal PV direct fraction (increase in frequency of approximately equal PV output and load demand). This increase in the frequency of occurrence is small for appropriately-sized PV arrays and larger PV arrays (4 kW or larger). Also from figure VI-2, as PV array size decreases, the effect of the probability of an active load increases. Table VI-2 depicts the reduction of PV direct fraction for given PV array size and probability of an active load. For the observed probability of an active load and a 4 kW array, only a 0.6 percent reduction is seen when compared to using 15-minute time-averaged load data. Even the 1 kW array shows an insignificant reduction of 2.7 percent.

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Figure VI-2. Annual PV Performance Versus Probability of an Active Profile for Different Array Sites

TABLE VI-2. REDUCTION IN PV DIRECT FRACTION COMPARED TO
PROBABILITY OF AN ACTIVE LOAD

ARRAY SIZE (kW)	OBSERVED (.2 prob)	TWICE OBSERVED (.4 prob)	EXTREME CASE (1.0 prob)
9	0.2	0.4	.9
6	0.3	0.7	1.7
4	0.6	1.2	3.1
3	1.0	1.9	4.8
2	1.6	3.1	7.8
1	2.7	5.4	13.4

The significance of having approximately equal average load demand and average PV output is displayed in figures VI-3 and VI-4. Figures VI-3 and VI-4 show monthly PV direct fraction as a function of probability of an active load for a 1 kW and a 4 kW array, respectively. Each line represents the value of the PV direct fraction for the months of January and April, and M is defined as in figure VI-2 ($M = .134$ implies a 13.4 percent reduction in the PV direct fraction where the probability of an active load is increased from 0.0 to 1.0). For the 1 kW array, a PV direct fraction near 1.0 for the 15-minute averaged-load data (probability of an active load is 0.0) implies the 15-minute averaged-load demands are approximately equal to the PV output. Thus, as the activity of the load is increased, errors in the PV direct fraction become larger. For the larger 4 kW array, the array output is larger than the load demand, and as the activity of the load is increased, relatively small errors occur.

When PV direct fraction is plotted versus the array size (figure VI-5), the insensitivity of the PV direct fraction to the probability of an active profile becomes apparent.

Three lines are displayed that represent the probability of an active profile of 0.0, 0.4, and 1.0. Very little change is seen in the

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Figure VI-3. Monthly PV Performance Versus Probability of an Active Profile for 1 kW Array

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Figure VI-4. Monthly PV Performance Versus Probability of an Active Profile for 4 kW Array

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PV direct fraction between the probability of an active profile of 0.0 and 0.4 which represent 15-minute time-averaged data and the extreme case of realistically active loads. Only for the 1 kW PV array is the PV direct fraction significantly affected.

The simulation results support the conclusion that for typically-sized arrays and observed probability of an active load, instantaneous load data are not significant in the calculation of annual PV direct fraction. Figure VI-5 shows graphically that for only extremely small arrays, where the load demand would approximately equal the PV output, do instantaneous loads become significant in the calculation of PV performance.

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Figure VI-5. PV Performance Versus Array Size for Various Probabilities of an Active Profile

APPENDIX A
LOAD DATA BASE ACCESS AND FORMAT

This appendix describes the procedures necessary to access the instantaneous load data base. The development and extent of this data base are discussed in chapter IV.

A. ACCESS TO LOAD DATA BASE FILES

Collected instantaneous (5-second interval) load data have been partitioned into eight files by residence and season and stored on duplicate public TFILE tapes on the Sandia NOS computer. Their Volume Serial Numbers (VSNs) are 13138 and 18409 and can be accessed by the following NOS command:

TFILE,R,13138,1fn1,1fn2, ...

where 1fnN = file name to be retrieved from the tape. The files will appear in the user's direct access permanent file space (required), with the same file names, within 30 minutes after the command is entered. Table A-1 lists the pertinent files contained on these tapes and their contents.

B. LOAD DATA BASE FILE FORMAT

For each file, the 5-second interval load data are blocked into 15-minute quartiles with 15 lines of 12 measurements, 1 minute per line. Figure A-1 illustrates the format of a load data base file. A header record precedes each quartile of data and contains the quartile time, number from 1 to 96 (midnight to 12:15 AM is number 1), 15-minute average in kVA and kVAh, and the energy above average in kVAh (the area below the instantaneous values and above the average). Contiguous blocks of quartiles per day are aggregated by header records which precede the header and data of the first quartile in the block. This header record depicts the corresponding residence, day of week, date, time duration of

TABLE A-1. LOAD DATA BASE FILE LIST

<u>FILE NAME</u>	<u>DESCRIPTION</u>
NWRKDAT	Newark, summer, 5-second interval load data
ATLDAT	Atlanta, summer, 5-second interval load data
ALB1DAT	Albuquerque No. 1, summer, 5-second interval load data
ALB2DAT	Albuquerque No. 2, summer, 5-second interval load data
NWKDATW	Newark, winter, 5-second interval load data
ATLDATW	Atlanta, winter 5-second interval load data
ALB1DTW	Albuquerque No. 1, winter, 5-second interval load data
ALB2DTW	Albuquerque No. 2, winter, 5-second interval load data

NEWARK THU 7/16/81 15:45-24:00, 29 QUANTILES, 68 - 95											
16:45-17:00 QRTL 68; AVE: 3.03 KVA OR .76 KVAH; ENERGY ABOVE AVE: .03 KVAH											
3.21	3.21	3.53	3.21	3.21	3.21	3.53	3.21	3.21	3.21	3.53	3.21
3.21	3.53	3.21	3.21	3.21	3.53	3.21	3.21	3.53	3.21	3.21	3.21
3.53	3.21	3.21	3.53	3.21	3.21	3.53	3.21	3.21	3.21	3.53	3.21
2.89	3.21	2.89	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89
3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	3.21	2.89	3.21
2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21
2.89	3.21	2.89	3.21	2.89	3.21	3.21	2.89	3.21	2.89	3.21	3.21
2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21
2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	2.89
3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	2.89	3.21	2.89	2.89
3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89	3.21	2.89
2.89	3.21	2.89	3.21	2.89	3.21	2.89	2.89	2.89	2.89	2.89	2.89
2.25	2.89	2.57	2.89	2.89	2.57	2.89	2.57	2.89	2.89	2.57	2.89
2.25	2.89	2.57	2.89	2.89	2.57	2.89	2.57	2.89	2.89	2.57	2.89
2.89	2.57	2.89	2.57	2.89	2.89	2.57	2.89	2.89	2.25	2.89	2.89
17:00-17:15 QRTL 69; AVE: 2.85 KVA OR .71 KVAH; ENERGY ABOVE AVE: .02 KVAH											
2.89	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	3.21	2.89	2.89
2.57	2.89	2.89	2.57	2.89	2.57	2.89	2.89	2.89	2.89	2.89	2.89
2.57	2.89	2.89	2.57	2.89	2.89	2.89	2.57	2.89	2.89	2.89	2.57
2.89	2.89	2.89	2.89	2.57	2.89	2.89	2.89	2.57	2.89	2.89	2.89
2.89	2.89	2.89	2.89	2.57	2.89	2.89	2.57	2.89	2.89	2.57	2.89
2.89	2.89	2.57	2.89	2.89	2.89	2.57	2.89	2.89	2.89	2.89	2.89
2.57	2.89	2.89	2.89	2.57	2.89	2.89	2.89	2.57	2.89	2.89	2.57
2.89	2.57	2.89	2.89	2.57	2.89	2.57	2.89	2.89	2.57	2.89	2.89
2.57	2.89	2.89	2.89	2.89	2.89	2.89	2.57	2.89	2.89	2.57	2.89
2.89	2.57	2.89	2.57	2.89	2.89	2.57	2.89	2.57	2.89	2.89	2.57
2.89	2.57	2.89	2.89	2.57	2.89	2.89	2.57	2.89	2.89	2.57	2.89
2.89	2.89	2.89	2.89	2.57	2.89	2.89	2.57	2.89	2.89	2.57	2.89
2.89	2.57	2.89	2.57	2.89	2.89	2.57	2.89	2.89	2.57	2.89	3.21
2.89	3.21	2.89	2.89	3.21	2.89	3.21	2.89	3.21	2.89	2.89	3.21
2.89	3.21	2.89	2.89	3.21	2.89	3.21	2.89	2.89	3.21	2.89	2.89
17:15-17:30 QRTL 70; AVE: 3.25 KVA OR .81 KVAH; ENERGY ABOVE AVE: .02 KVAH											

Figure A-1. Load Data Base Example

the block of contiguous quartiles, the number of quartiles in the block, and the block duration in terms of quartile numbers. According to the example in figure A-1, 29 quartile header records and the corresponding 15-minute durations of load data measurements would be read until the next block indicator header record would be encountered. Table A-2 describes the format for the different lines of the files comprising the load data base.

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TABLE A-2. LOAD DATA BASE FILE FORMAT DESCRIPTION

LINES*	COLUMN NUMBER	DESCRIPTION	FORMAT
1	1-6	Residence: NEWARK ATLNTA ALBU-1 ALBU-2	A6
1	8-10	Day of Week: MON, TUE, WED, THU, FRI, SAT, SUN	A3 (or A2 if necessary - the first two characters uniquely define the day)
1	12-20	Month, Day, Year	3(I2,IX)
1	21-32	Beginning and End Time (hrs., min.) of Contiguous Block of Quartiles	4(I2,IX)
1	34-35	Number of Quartiles in the Block	I2
1	48-54	Beginning and End Quartile Numbers for the Block	I2, 3X, I2
2	1-12	Beginning and End Time (hrs., min.) of Quartile	4(I2,IX)
2	18-19	Quartile Number	I2
2	27-31	15 Minute Time Average (kVA)	F5.2
2	41-44	15 Minute Time Average (kVAh)	F4.2
2	70-73	Energy Above Average (kVAh)	F4.2
3-17	1-72	180 5-Second Interval Load Measurements Comprising the 15-Minute Interval (1-Minute Duration Per Line)	14(12F6.2/), 12F6.2

Repeat lines 2-17 for the number of quartiles in the contiguous block (as read from line 1, columns 34-35), then read new header record with line 1 format and do the same.

LINE 1 (BLOCK HEADER) FORMAT: (A6,1X,A3,1X,3(I2,1X),4(I2,1X),1X,I2,12X,
I2,3X,I2)

LINE 2 (QUARTILE HEADER) FORMAT: (4(I2,1X),5X,I2,8X,F5.2,9X,F4.2,25X,F4.2)

LINES 3-17 (LOAD DATA) FORMAT: (14(12F6.2/),12F6.2)

*Description given for first 17 lines in figures A-1.

APPENDIX B
SOLCEL3 EXECUTION PROCEDURES

This appendix briefly describes the procedures necessary to access and execute the version of SOLCEL which includes the statistical load model (SOLCEL3). A more complete discussion of SOLCEL is given in references 1 and 2 below.

Files required for execution of SOLCEL3 are

- (1) SOLCEL3 source code
- (2) A year's duration of Typical Meteorological Year (TMY) weather data
- (3) A year's duration of 15-minute load data
- (4) Input data

The following NOS commands are used to access the SOLCEL3 source code: compile the source code to create the relocatable binary (SOLBIN); attach the files containing Albuquerque TMY weather data (ABQTMY), 15-minute load data for an Albuquerque residence (PNM02Q), and input data; set up a math function library (FXMATH); execute the program; and print the results file:

```
ATTACH,SOLCEL3
DEFINE,SOLBIN/CT=PU
FTN,I=SOLCEL3,L=FTNLST,R=3,OPT=0,B=SOLBIN
ATTACH,TAPE1=ABQTMY
ATTACH,TAPE2=PNM02Q
GET,TAPE5=SOLINP
LIBRARY,FXMATH
SOLBIN
PRINT,TAPE6
```

The ABQTMY, PNM02Q, and SOLINP files were used to produce the results presented in Table V-1 of chapter V. These files, along with the source code file (SOLCEL3), are stored on duplicate TFILES (VSNs 13138 and 18409) and can be accessed by the command presented in appendix A. Except for the input data file (SOLINP), all these files require direct access permanent file space. On a previous project, 15-minute load data for durations of a year or more were collected from utilities and stored

on the SNL computer system. These load data were collected on residences similar to those used for development of the statistical load model and are appropriate for use with the model. For further information and access details on these files, see reference 2.

SOLCEL3 can be executed using 15-minute time-steps with or without the statistical load model. In addition, the code can be executed using 1-hour time-steps, requiring a year's duration of hourly load data, however, the statistical model cannot be exercised using 1-hour time-steps.

Input data specifying one of these options is included in the SOLCEL3 input data file (SOLINP), which is read under the NAMELIST convention. A listing of this file is presented in Figure B-1. The TIMSTP and PROB variables, in the second to last line, control the time-step and statistical load model. The PROB variable specifies the overall probability of an active profile, for which instantaneous load profiles would be used (see chapter IV). For execution of SOLCEL3 at hourly or 15-minute time-steps, without the statistical load model, TIMSTP would be set at 1.0 or 0.25 (in hour units) and PROB should be set to 0.0. To execute the statistical load model, PROB can be set to a desired value (between 0.0 and 1.0) or to the value realized through the analysis (0.192), which is the default. The default value will be used if PROB is omitted or set to the value. Utilizing the statistical load model requires TIMSTP to be set to 0.25.

```

C DETAILED RESIDENTIAL LOAD
C 4KW ARRAY
C 60KWH BATTERY CAPACITY
C 15MIN TIME AVERAGE LOAD DATA
$BATTERY NDPMXI=0,NDPMNI=0,NBC=240,MPBC=4,MSBC=60,
  BTMPMN=-100,BTMPMX=100.$
$END $
$COSTS IECON=1$
$DCAC PYTT=4000,INVRTR=3$
$OPTM2 $
$ORIENT IORINT=2$
$PHOTO IPVEFM=4$
$PRINTS PRNTOT=.F.$
$SOLDAT ISKIP=1,TIMSTP=.25,PROB=.192$
$TEMP CL=1.219,CW=40.41$

```

Figure B-1. SOLINP File Listing

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REFERENCES

1. SOLCEL2, A USER'S MANUAL, Sandia Report SAND79-1785, 1979.
2. SOLAR ENERGY/BATTERY STORAGE FINAL REPORT, BDM/A-81-058-TR, June 12, 1981.

APPENDIX C
PROFILE PLOTS

Plots of real load data for the 15-minute intervals which were selected to represent the 13 distinct profile groups are presented in Figures C-1 through C-13. The horizontal axis is the 15-minute interval timeline, broken out into the 60 15-second intervals for which the associated electric load values, in kVA, are plotted. These plots display the actual data used in the statistical load model. See chapter IV for a complete discussion of these profile groups and the statistical load model.

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Figure C-1. Plot of Load Versus Time for Profile Group 1

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Figure C-2. Plot of Load Versus Time for Profile Group 2

Figure C-3. Plot of Load Versus Time for Profile Group 3

Figure C-4. Plot of Load Versus Time for Profile Group 4

Figure C-5. Plot of Load Versus Time for Profile Group 5

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Figure C-6. Plot of Load Versus Time for Profile Group 6

Figure C-7. Plot of Load Versus Time for Profile Group 7

Figure C-8. Plot of Load Versus Time for Profile Group 8

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Figure C-9. Plot of Load Versus Time for Profile Group 9

Figure C-10. Plot of Load Versus Time for Profile Group 10

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Figure C-11. Plot of Load Versus Time for Profile Group 11

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Figure C-12. Plot of Load Versus Time for Profile Group 12

Figure C-13. Plot of Load Versus Time for Profile Group 13

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APPENDIX D
RESIDENTIAL LOAD MONITORING SYSTEM
SCHEMATIC WIRING DIAGRAMS

Figure D-1a. Residential Load Monitoring System Schematic Wiring Diagram--House Interface Unit

NOTES:

1. ALL OUTSIDE WIRING TO BE IN LIQUID-TIGHT CONDUIT AND ALL WIRING TO BE IN ACCORDANCE WITH N.E.C. AND STATE CODES.
2. ALL WORK SHALL BE EXECUTED IN A GOOD WORKMANLIKE MANNER.
3. DEBURR ALL HOLES AT LEAST 1/32" MIN. AND USE LIQUID TAPE TO PREVENT WIRES FROM SHORTING OUT.
4. ALL WIRING MUST BE STRANDED AND TYPE TW OR EQUIVALENT.
5. USE HEAT SHRINK TUBING ON ALL SPLICES.
6. ALL WIRING WHERE POSSIBLE WILL BE IN SPIRAL WRAP TUBING, EXCEPT 200 AMP SERVICE WIRING (TWIS WILL HOLD WIRING BUNDLE TOGETHER AND HAVE LESS CHANCE OF SHORTING OUT).
7. THE JEN-NODEN ENCLOSURE WILL BE MOUNTED TO MOUNTING PLATE TO ENSURE MINIMAL DAMAGE TO HOUSE WHEN ENCLOSURE IS REMOVED.
8. WHEN THE JEN-NODEN UNIT IS USED IT WILL BE CONNECTED WITH LIQUID-TIGHT CONDUIT WITH NUTS AT BOTH ENDS (4" LONG). THE CONDUIT WILL HAVE A PLUG OF NEOPRENE RUBBER IN IT SO HEAT WILL NOT LEAK OUT. THE TUBING WILL BE APPLIED SO WIRING CAN RUN BY AND MAKE A SEAL. USE 2" CONDUIT.

9. COVER IS USED WHEN JEM AND MODEN UNIT IS NOT USED (COVER HAS NEOPRENE GASKET).
10. THE LIQUID-TIGHT CONDUIT WILL HAVE A 1/2" HOLE IN IT THROUGH ONE WALL, SO TELEPHONE CABLE CAN BE FED IN AND CONNECTED TO MODEN UNIT.
11. FOR WIRE COLOR (NOT SERVICE WIRING):

VOLTAGE MONITOR	CURRENT MONITOR
HOT 1 - BLACK	HOT 1 - BLACK
HOT 2 - BLUE	RETURN - WHITE
NEUTRAL - WHITE	HOT 2 - BLUE
	RETURN - WHITE
12. JUMPER PINS 9 AND 20 ON THE RS232 CONNECTOR MAKE CONNECTION WHERE CONNECTOR IS SOLDERED TO CIRCUIT BOARD (INSIDE OF MODEN UNIT).

12. JUMPER PINS 9 AND 20 ON THE RS232 CONNECTOR MAKE CONNECTION WHERE CONNECTOR IS SOLDERED TO CIRCUIT BOARD (INSIDE OF MODEM UNIT).

NO. REQ'D	PART NO.	MATERIAL	DESCRIPTION	ITEM NO.		
LIST OF MATERIAL						
DRAWN:	DATE:	MATERIAL:	<p>THE BDM CORPORATION 2805 YALE BLVD., S.E., ALBUQUERQUE, NM 87108</p>			
J.C. RUSSELL	3-1-81					
CHECKED:						
ENGINEER	3-13-81	FINISH:				
PROJ. ENGR.						
PROGRAM MANAGER		TOLERANCES:	TITLE: RESIDENTIAL LOAD MONITORING SYSTEM SCHEMATIC WIRING DIAGRAM			
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES CONTRACT OR COST CENTER			CODE IDENT.	SIZE	QTY. NO.	REV.
			52308	D	02D001578	
			SCALE: NONE		SHEET OF	

Figure D-1c. Residential Load Monitoring
System Schematic Wiring
Diagram--JEM/ Modem Enclosure

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