Case Studies of Grid-Connected Photovoltaic Systems, Vol. 2

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Technical Report

Case Studies of Grid-Connected Photovoltaic Systems, Vol. 2

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PRODUCT DESCRIPTION

The photovoltaics (PV) industry is growing rapidly, and PV power is likely to become an increasingly significant source of distributed generation as its cost declines over the next ten years. This report documents a number of grid-connected photovoltaics case studies covering a broad range of system configurations and project types. The report provides field experience useful to improve the design of future PV systems and identifies problems that need to be addressed to promote the integration of PV power into utility systems.

Results & Findings

- The capital cost of the studied projects ranged from about $7/W(ac) to over $12/W(ac) installed. These costs are still too high to be competitive with grid power at sites with grid access unless subsidies are involved, but the trend is favorable. The industry is heading towards the threshold of $3/W(ac) where many industry experts feel that PV becomes competitive.
- Although none of the studied projects are cost-effective without tax credits and other incentives, the non-energy benefits of PV projects can be significant, especially where PV applications are integrated in building designs to provide insulation, shading, hot water, and extended roof life.
- Performance results from systems located throughout the United States show that PV is suitable, not only in high-sunlight areas such as Hawaii and New Mexico, but also can work in less-sunny areas such as New York and Wisconsin.
- The systems generally performed well, but lower output from solar modules and reliability problems with inverters resulted in worse than predicted performance in a few cases. The cases highlight the particular importance of improvements in inverter reliability and protection in future installations.
- The interconnection of these PV systems to the utility system was a smooth process in most cases. The most common interconnection-related issue was time delay in resolving the utility requirements and permitting. The most recent installations had the most streamlined interconnection process, indicating substantial recent progress in this area.

Challenges & Objectives

This report will be useful to PV system integrators, utility system planners, and engineers that are involved in distributed-generation and/or PV issues. The PV system case studies provide information that is useful for the planning, technical design, capacity rating and performance prediction of PV systems. More generally, the report can provide utility managers with insight into the current state of the PV industry and its prospects for further development.

Applications, Values & Use

The results provide detailed guidance on problem areas such as inverter susceptibility to surges and reliability issues. The information will help system designers improve lightning protection and equipment hardening in PV system design and ultimately develop lower cost, better performing PV installations.

EPRI Perspective

The PV industry has grown at over 20% annually since the 1970s and will probably continue such growth, or even accelerate, in the next few decades as the cost of PV generation declines. EPRI is promoting the profitable and timely integration of PV technology into utility systems by providing up-to-date information on the state of the art, by identifying technical issues that remain to be addressed, and by promoting standardized test plans and interconnection agreements that make it simpler for commercial and residential customers to use PV systems.

Approach

In order to gain insight into the current status of grid-connected photovoltaics, the project team selected six systems that provide a representative cross section of systems in operation in terms of system size, type, location, and installation date. Working closely with system owners and operators, the team developed a case history and performance evaluation for each project. Basing their observations on the lessons learned in the cases, the team summarized the status of grid-connected PV and made recommendations for additional research and other practical steps to advance the field.

Keywords

Photovoltaics
Grid-Connected
Solar Energy
Renewable Energy
Distributed Generation
Green Power

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1 INTRODUCTION

The photovoltaics (PV) industry is growing rapidly, and PV power is likely to become an increasingly significant source of distributed generation as its cost declines over the next ten years. Many experts expect PV systems to become cost competitive with conventional power by about 2010, and PV is already an attractive option in many settings. This is especially true in building-integrated PV systems where ancillary benefits such as insulation, shading, hot water, and extended roof life improve cost-effectiveness. Beyond projected future declines in the basic cost of PV installations, standardization, simple improvements in design, better power electronics, and simplified procedures for grid integration are already improving the economics of PV systems.

This report documents the field experience of six grid-tied photovoltaic (PV) installations. It is the second volume of a series of reports on PV projects—see EPRI Report 1004037 for the first volume. The case studies in the report discuss projects in New York, New Mexico, Hawaii, and Wisconsin that range in size from 2 to 100 kW and provide a cross section of the most common installation environments and system types. The aim of the studies is to capture field experience relevant to improving the performance and economics of future PV system designs.

Objectives and Data Collected

Each of the six case studies of PV systems provides the following information:

- Background information describing why the system was installed, the design configuration, planned modes of operation, and its year of its commissioning
- Actual PV system performance compared to predicted performance
- Specific problems or issues related to each installation, including utility system interconnection issues, inverter reliability issues, and other factors that are relevant to the system performance and operation
- The cost of each system
- Lessons learned

A chapter is devoted to each case study, and the report concludes with an overall recommendation section based upon the findings of all case studies.

Rationale for Case Selection

In order to cover a broad assortment of grid-tied PV installations, researchers selected systems in a range of sizes and locations. To decide which cases to include in the study, they considered the following system characteristics including:

- Size
- Type
- Location
- Technology employed
- Installation date and length of operation

The selected cases cover systems ranging in size from 2-kW to100-kW and spanning a variety of climates and solar resource profiles to provide a cross section of typical PV installations. Installations include building-integrated photovoltaic (BIPV) systems using PV glazing, a PV parking shade project, and several more conventional roof mounted or ground mounted PV array systems.

Cases Studied

Table 1-1 shows the range of sizes, locations, and installation dates of the studied projects.

Table 1-1
Grid-Connected PV Case Studies

Case	Size	Location	Installation Date
Tuckahoe Library and Community Center – NYPA	18-kW	Tuckahoe, NY	1995
Yonkers Wastewater Treatment Facility – NYPA	100-kW	Yonkers, NY	1996
Cofrin Hall on the University of Wisconsin - Green Bay Campus	24-kW	Green Bay, WI	2001
Parking Structure Photovoltaic System – PNM	5-kW	Albuquerque, NM	2002
PVUSA System on Ulapalakua Ranch in Kihei, Maui, Hawaii – HECO	18.5-kW	Kihei, Maui, Hawaii	1989 with renovations in 1997
Building-integrated PV System at Ford Island, Hawaii – HECO	2-kW	Oahu, Hawaii	1999

Approach

The system owners and operators supplied most of the data used for the case studies. Once the cases were chosen, researchers began the data collection process by sending a questionnaire to the owner of each system. Many of the cases draw on information that was already compiled in system progress reports and maintenance logs. A good working relationship with each system owner/operator was crucial to the data collection process. Since most of the information exchange process took place over the phone or by e-mail, the system owners reviewed the final case write-ups to determine if any additional information had been overlooked in the data collection process.

2 BACKGROUND

Compared to other forms of electricity generation, photovoltaic systems are relatively simple. In fact, other than cooling fans on some power electronics components, PV systems do not contain any moving parts. The heart of a PV system is the photovoltaic module. The PV module absorbs sunlight and converts its energy to direct current (dc) electricity. The dc electricity produced by the PV system can be stored in batteries, ultra capacitors, flywheels, or other devices but storage is not mandatory. While some loads can use dc electricity, it is common for PV systems to use an inverter, a solid-state power-conditioning device, to convert the dc electricity to alternating current (ac). The inverter output can be connected directly to a load, directly to the utility distribution grid, or connected to both the load and the utility distribution grid. Today, all PV system components are typically UL listed and designed to meet the National Electric Code (NEC) as well as several emerging standards for system safety.

Grid-tied PV systems interact dynamically with the utility distribution grid. Some utility-scale PV systems are used solely for feeding into the power grid. In these situations, the PV system feeds into the power grid during the daylight hours and remains idle during the night although energy storage can be incorporated into the system to help the grid ride through power-quality events. It is much more common, however, for grid-tied PV systems to supply power to local loads, exporting power to the utility only when an excess of generation occurs. Such systems can incorporate energy storage to maximize the utilization of PV-produced energy but most often the power grid will supply the local loads when the PV system cannot meet the demand. The ability to export to the power grid allows customers to reduce their power bill by spinning their meter backward during periods of high generation and low demand.

Issues Associated with PV Installations

The case studies in this report focus more on how the PV system characteristics and application environment impact PV system performance and cost than on details about equipment types and site configurations. The aim is to provide information relevant to feasibility studies or performance evaluation studies. The following list details the issues most relevant to utility planners and strategists.

- *Project size.* For most power generating types, large systems are more cost-effective per unit. However, economies of scale have a much smaller effect on PV system cost than on the cost of conventional power plants such as combustion turbines. Comparing the relative costs of the large and small PV projects can provide valuable insight into economies of scale as they relate to PV.
- *Demonstration versus production systems.* Demonstration projects are more expensive per unit of capacity than production systems and, because they are research oriented and employ

new or untested equipment, can have lower reliability as well. To gauge the true state of the art in PV, demonstration projects must be compared with successful projects where PV use is routine. Several of the projects in this case study report could be considered as operational PV as opposed to research demonstrations.

- *Location*. It is sometimes assumed that PV only works well in sunny regions such as the southwestern United States. However, PV systems have worked well in other areas of the country that do not have as high a level of solar resources. The case studies in this report include systems in areas with capacity factors ranging from under 0.15 up to about 0.25.
- *Type of installation (ground-mounted, roof-mounted or building-integrated PV systems).* Ground-mounted systems may benefit from economies of scale because they can be larger and heavier than roof-mounted systems. However, roof-mounted systems or building-integrated PV may benefit from savings in land costs or provide ancillary benefits such as shade or insulation.
- *PV and inverter technology:* Inverters have proven to be an area of reliability concern and may be the weakest link in battery-less grid-tied PV systems. It is desirable to compare alternative technologies to evaluate which technologies currently best suit the system needs and which technologies hold the most promise for future use. Inverter performance was studied closely in these six cases so that operational anomalies could be identified and, if possible, explained.
- *Use of storage:* PV is an intermittent resource. Storage technologies can be used to produce dispatchable or "firm" solar power but they add cost to the system. None of the grid-tied systems studied employed storage.
- *Interconnection and inspection requirements:* Some critics contend that utility distribution companies and some jurisdictions create barriers to PV by imposing unnecessarily stringent interconnection and inspection requirements. For each case study in this report, system owners/operators were asked about issues related to interconnection.
- *System Age:* Newer systems may be more cost-effective and/or reliable. For these case studies, some older systems were selected for evaluation to determine how they are holding up over time and how much maintenance they require.
- *Type of Developer*: PV projects are designed and installed by electric utilities, energy service companies, solar companies, and private individuals. In many of the projects discussed in this report, the background and experience of the system developer had a significant effect on the success of the project. For example, an experienced system integrator using high-quality components, proper protection, and installation practices can improve the likelihood that a project will be trouble free.
- *Ownership and advocacy*: PV has a variety of champions. It makes a difference who initiated the project under consideration and who are the project owners and team members. Several of the cases in this report discuss the role of ownership and its influence on the system design and operation.
- *Non-energy benefits (ancillary benefits):* Beyond power, PV can provide additional value in some applications. Building-integrated photovoltaics can provide insulation, shading, hot water, and extended roof life among other benefits. These ancillary benefits are discussed in several case studies.

- *Distribution system issues:* Utility distribution companies have concerns about the safety and power-quality effect of connecting PV to distribution feeders. These interconnection questions involve such issues as islanding protection, fault contributions, and voltage regulation. For most small PV systems, recent IEEE and State utility commission standards have made interconnection more straightforward.
- *Cost-effective applications:* PV is recognized as cost-effective for many off-grid energy applications that are remote from a distribution line. The technology has advanced to the point where some on-grid applications may also prove cost-effective in high-price utility locations when coupled with various tax incentives. None of the studied projects are cost-effective without tax credits and other incentives.
- *Financial Assumptions*: It is important to look at how projects are funded and the assumptions associated with cost analysis. PV system energy cost is impacted by issues involving insurance, taxes, incentives, rebates, green pricing, return on investment, O&M, and capital costs. For example, depending on the lifespan assumptions, maintenance assumption, and the discount rate used in an analysis, PV energy costs can vary by as much as a factor of 2 for the same basic system design at the same location. Costs must be compared on an equivalent basis. In this report, only capital costs are compared and no attempt was made to compare life cycle energy costs of the systems.

3 TUCKAHOE LIBRARY AND COMMUNITY CENTER AND THE YONKERS WASTEWATER TREATMENT FACILITY – NEW YORK POWER AUTHORITY (NYPA)

Background

The New York Power Authority (NYPA) is the nation's largest State-owned power organization. Providing more than a quarter of New York's electricity, NYPA generates over 5,000 megawatts of power and operates about 1,400 circuit miles of transmission lines. Additionally, NYPA has been active in renewable energy technologies for several years. In 1994 NYPA decided to expand its solar program with the aim of increasing the deployment and manufacture of PV systems in New York State. Two key projects in that expansion were the Tuckahoe Library and Community Center project and the Yonkers Wastewater Treatment Facility project, both of which were undertaken as part of the TEAM-UP program.

TEAM-UP (Technology Experience to Accelerate Markets in Utility Photovoltaics) was created in 1994 by The Utility Photovoltaic Group (UPVG) with funding from the U.S. Department of Energy—UPVG was renamed the Solar Electric Power Association (SEPA) in 2000. TEAM-UP is intended to increase the experience of energy service providers and their customers with PV and stimulate growth in demand for solar power. Through three rounds of funding initiated in 1995, '96, and '98, the TEAM-UP program funded a total of 35 PV ventures resulting in over 1,100 PV system installations at a cost of more than $75 million.

Project Goals

NYPA participated in the Tuckahoe and Yonkers PV projects to achieve the following objectives:

- Expand staff experience with PV technology
- Respond to energy preferences expressed by New York State's governor and citizens
- Gain experience with PV systems in distributed-generation applications
- Establish a standard 100-kW system design for deployment in future projects

NYPA performed the design and construction management portions of the Yonkers project to better achieve some of these goals. The project team for the Yonkers system design and procurement was comprised of personnel from NYPA's Research and Technology Development group and Project Management group. The R&TD group provided overall project management and electrical engineering analysis while the Project Management group provided constriction management support and civil structural analysis of the proposed installation site. As a result of these in-house design and construction management activities, NYPA developed a great deal of internal expertise.

System Descriptions

Village of Tuckahoe Library and Community Center

The Tuckahoe system, shown in Figure 3-1 and Figure 3-2, was constructed through a turnkey project with the PowerLight Corporation and began operation in November 1995. The project was a commercial prototype for the PowerLight Corporation and was one of the first installations of its kind. The 18-kW array used in the system consists of 120 PowerLight brand PowerGuard tiles. Each tile utilizes a 187-watt single crystal silicon module manufactured by Atlantis. The tiles are connected in 24 strings and wired in a bi-polar fashion. Each string is comprised of 5 modules connected in series to create a string voltage of 197 Volts.

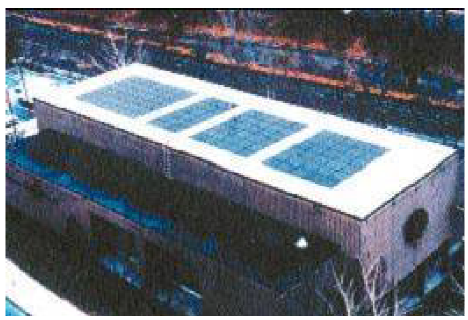

Figure 3-1
Roof Mounted PV Installation on the Village of Tuckahoe Library and Community Center

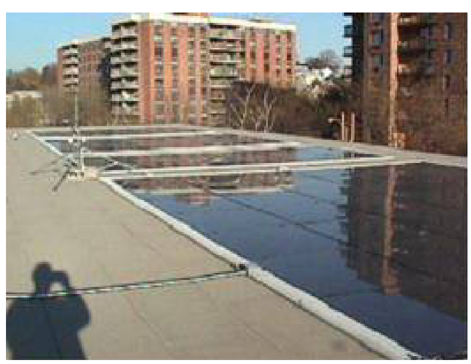

Figure 3-2
Alternate View of the Roof Mounted PV System on the Tuckahoe Library and Community Center

PowerGuard tiles are formed by bonding a PV module to a sheet of polystyrene insulation as shown in Figure 3-3. The tiles are interlocked with each other through grooves along the edges and lay flat on the roof (tilt angle of 0 degrees) to form the array. The tiles typically have insulation values greater than R-10 and therefore provide protection and additional insulation to the roof. The additional insulation of the PowerLight tiles helps increase the overall energy efficiency of the building by minimizing heat loss or gain depending on the season. The PowerGuard tiles are laid directly onto new and existing rooftops without mechanical fastening. They are self-ballasting and remain stable in wind speeds up to 140 mph.

Power conditioning is accomplished through 3 single-phase Omnion inverters similar to that shown in Figure 3-4. Each 120-Volt, 6kW inverter is fed by 40 modules. The output of each inverter is connected between one phase and neutral in the building's three-phase, 208-Volt service panel. Figure 3-5 and Figure 3-6 illustrate the array connections and wiring scheme.

Figure 3-3
PowerGuard® Insulating Rooftop Solar Panels from the PowerLight Corporation

Figure 3-4
Typical Omnion Power Inverter

Tuckahoe Library and Community Center and the Yonkers Wastewater Treatment Facility – New York Power Authority (NYPA)

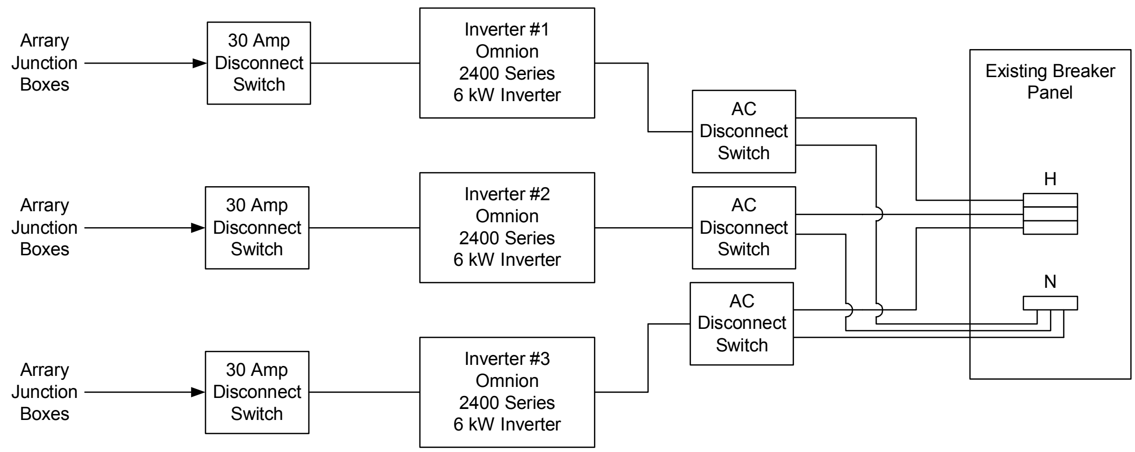

Figure 3-5
One-Line Diagram of the PV System at the Tuckahoe Library

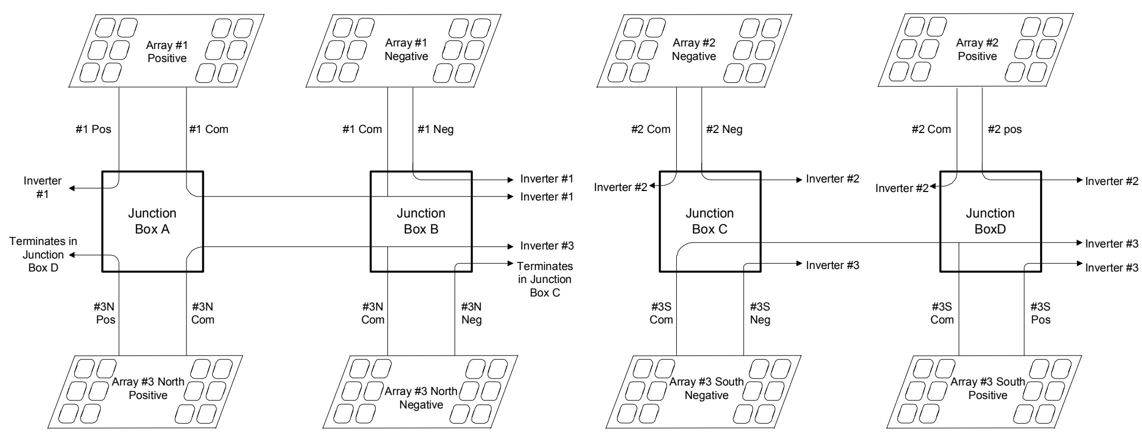

Figure 3-6
Bipolar Array Wiring of the Tuckahoe Library PV System

Yonkers Wastewater Treatment Facility

The Yonkers (New York) Wastewater Treatment Facility operates a 100-kW PV system installed by NYPA. The array, shown in Figure 3-7, consists of 924 Solarex MSX-120, 120-watt polycrystalline silicon modules connected in 77 strings and wired in a mono-polar fashion. Each string is comprised of 12 modules connected in series to create a string voltage of 420 Volts. Six strings are wired in parallel in each of 13 combiner boxes. The one-line electrical diagram for the PV system at the Yonkers Wastewater Treatment Facility is shown in Figure 3-9.

The modules are bonded in pairs to two aluminum angle beams bolted to a ballast tray and supported at a tilt angle of 19 degrees from horizontal facing due south. The array supplies a 100-kW Kennetech inverter.

This installation began operation in December of 1996. The facility owners, Westchester County, New York, handled permitting for this project.

An interesting note on this project is that it was originally intended to be part of a larger PV system at another location. The initial design was to be a 400 kW array installed at a NYPA site called Gun Hill. Late in the design process it became evident that the roof of the Gun Hill facility would not be able to support the lateral forces caused by wind loading on the array. Consequently, 100 kW of the installation was moved to the Yonkers wastewater treatment facility and the remaining array modules were mounted at nearly 0º tilt on the Gun Hill facility.

In addition to the 100 kW PV system, a 200 kW phosphoric acid fuel cell manufactured by UTC is also operated at the Yonkers wastewater treatment facility. The fuel cell is supplied with anaerobic digester gas (ADG), which is a by-product of the wastewater treatment process. ADG is approximately 60% methane and 34% carbon dioxide.

Figure 3-7
Roof Mounted PV Installation at the Yonkers Wastewater Treatment Facility

Figure 3-8
BP Solar (formerly Solarex) MSX-120, 120 Watt Polycrystalline PV Module

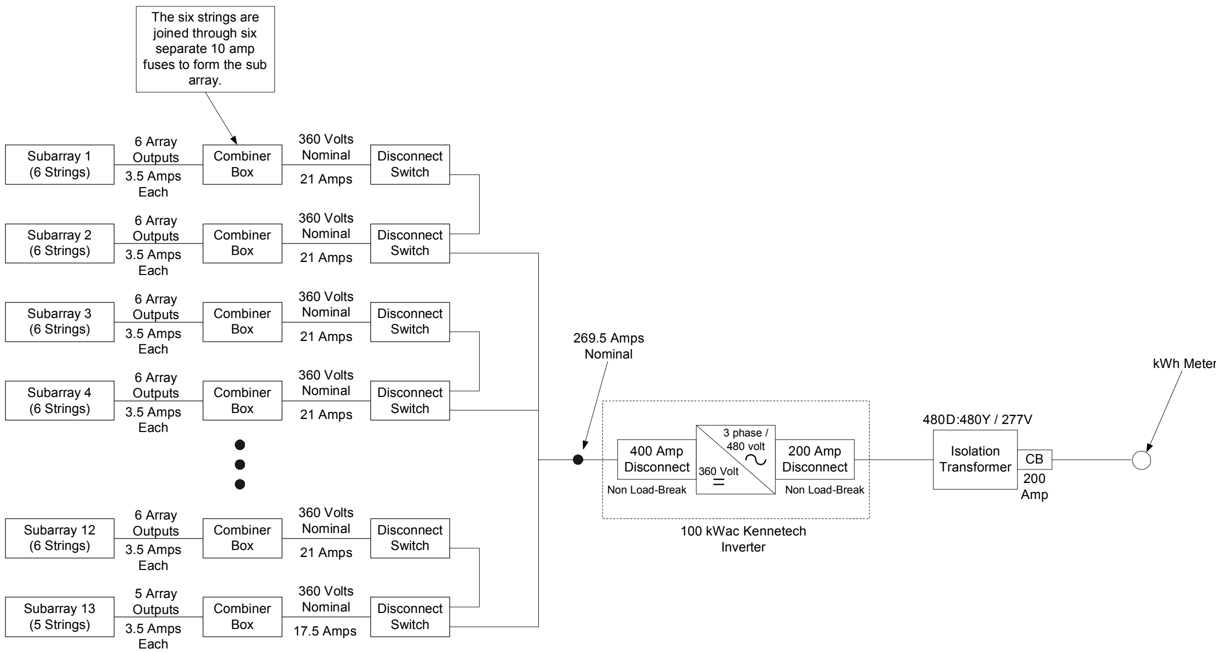

Figure 3-9
One-Line Diagram of the PV System at the Yonkers Wastewater Treatment Facility

Predicted Performance

Village of Tuckahoe Library and Community Center

The 30-year average irradiance for a horizontal flat plate collector reported for the New York City area as reported by the National Renewable Energy Laboratory (WBAN No. 94728, 40.78º North latitude, 88.13º West longitude) is 4.0 kWh/m^2 per day. Tuckahoe is approximately 15 miles north of the monitoring station. The expected annual production of the Tuckahoe PV system is calculated to be 24,179 kWh as shown in Table 3-1.

Table 3-1
Predicted Annual Production of the Tuckahoe PV Facility

Array rating at STC: (120 modules x 187 watts/module)	22,440 Watts
Expected loss due to module mismatch	3% (673 Watts)
Expected loss due to soiling	5% (1,122 Watts)
Expected loss due to temperature in excess of 25º C	10% (2,244 Watts)
Total losses from dc array	18% (4,039 Watts)
Expected dc output per 1 kW/m^2 of irradiance	18,400 Watts
Inverter efficiency	90%
Expected ac output per 1 kW/m^2 of irradiance	16,560 Watts
Predicted annual production (16.56 kW per 1 kW/m^2 x 4.0 kWh/m^2 per day x 365 days)	**24,179 kWh**
Predicted Capacity Factor 100 * (24,179 kWh) / (16,500 Watts)*(8760 hrs.)	**16.7%**
Note: The predicted performance calculation does not take into account snow or other environmental media covering the solar array for extended periods of time. Additionally, the predicted annual production assumes no outages.	

Yonkers Wastewater Treatment Facility

The 30-year average solar irradiation for a flat plate collector facing south at latitude-15º for the New York City area as reported by the National Renewable Energy Laboratory (WBAN No. 94728, 40.78º North latitude, 88.13º West longitude) is 4.5 kWh/m^2 per day. The expected annual production of the Yonkers PV system is therefore calculated to be 137,392 kWh as shown in Table 3-2.

Table 3-2
Predicted Annual Production of the Yonkers PV Facility

Array rating at STC: (924 x 120 Watts)	110,880 Watts
Expected loss due to module mismatch	3% (3,326 Watts)
Expected loss due to soiling	5% (5,544 Watts)
Expected loss due to temperature in excess of 25° C	10% (11,088 Watts)
Total losses from dc array	(19,958) Watts
Expected dc output per 1 kW/m^2 of irradiance	90,922 Watts
Inverter efficiency	92%
Expected ac output per 1 kW/m^2 of irradiance	83,648 Watts
Predicted annual production (83.6 kW per 1 kW/m^2 x 4.5 kWh/m^2 per day x 365 days)	**137,392 kWh**
Predicted Capacity Factor 100 * (137,392 kWh) / (83,648 Watts)*(8760 hrs.)	**18.8%**
Note: The predicted performance calculation does not take into account snow or other environmental media covering the solar array for extended periods of time. Additionally, the predicted annual production assumes no outages.	

Actual Performance

Village of Tuckahoe Library and Community Center

Initial System Performance

The Village of Tuckahoe system began operation in November 1995. Due to poor solar insolation values during the winter months, it was not noticed that the configuration of the module strings did not meet the low voltage threshold of the power-conditioning unit. As a result, the inverter spent a significant amount of time in the off state. Once this condition was diagnosed in the spring, PowerLight personnel re-wired the system. The module strings were reconfigured to produce a higher voltage, which matched the required window, and the overall system performance improved. Generation data for first year of operation of the Tuckahoe system is shown in Table 3-3.

Table 3-3
Early Performance of the Tuckahoe PV System

Month	Generation (kWh)	Capacity Factor	Month	Generation (kWh)	Capacity Factor
January-96	NA	NA	July-96	2766	22.5 %
February-96	566	5.1%	August-96	1438	11.7 %
March-96	1229	10.0 %	September-96	1303	10.9 %
April-96	1723	14.5 %	October-96	NA	NA
May-96	1407	11.4 %	November-96	NA	NA
June-96	1612	13.5 %	December-96	394	3.2 %
Capacity Factor = (kWh Generated) / (Rated Capacity x Total Hours)					

Long-Term Performance

The most recently available long-term performance data for the Tuckahoe PV Facility is presented in Table 3-4.

Table 3-4
Long Term Output Statistics for the Tuckahoe PV System

Parameter	Low	Average	High
Monthly Capacity Factor (%)	4.44	14.6	24.79
Monthly Performance Index	0.63	0.82	0.92
Monthly Energy Production (kWh)	436	1,409	2,356
Monthly Performance (kWh/kW)	33.03	106.7	178.48

The peak matching ability of the Tuckahoe PV system was also examined. Unfortunately, as shown in Figure 3-10, the peak load at the Village of Tuckahoe Library occurs in the mid evening, near 8pm. This is a reasonable usage pattern for a public library because most patrons are at work during the day but have free time after dinner. Since the peak output of the PV system occurs in the mid afternoon, effective peak matching did not occur.

Predicted versus Actual Performance

Table 3-1 shows that the predicted yearly generation of the Tuckahoe system was 24,179 kWh with a capacity factor of 16.7%. These predicted values are somewhat more than the actual performance values of 16,908 kWh and 14.6% reported in Table 3-4. Comparison shows that the system produced 30% less energy on average than predicted. While the exact cause of the lowered energy production is not known, it may be due to underestimating the system de-rating caused by soiling. The predicted energy production did not take into account snow or other environmental media covering the solar array for extended periods. Since this site is in an area prone to winter snowfall and was mounted in a horizontal manner, the array may have been covered by snow for several months of the year.

Another factor may be in play. As Figure 3-2 shows, the Tuckahoe Library is a relatively short building with some tall neighboring structures. The taller buildings surrounding the Library may have created some degree of shading that was not accounted for in the initial energy generation prediction.

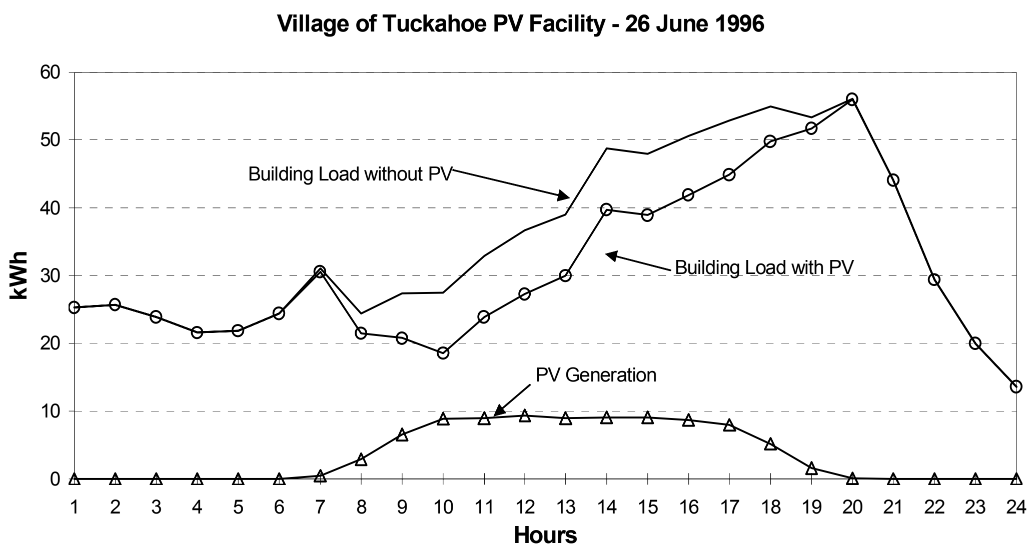

Figure 3-10
PV System Output Compared to Building Load at the Library

Yonkers Wastewater Treatment Facility

Initial Performance

The first full month of operation of the Yonkers PV facility occurred in January of 1997. Table 3-5 shows the monthly energy production by the site from January 1997 through June 1997.

Table 3-5
Early Performance Data for Yonkers PV Facility

Month	Generation	Capacity Factor
January-97	5,693	9.1%
February-97	6,632	11.8%
March-97	7,048	11.3%
April-97	7,149	11.9%
May-97	7,954	12.8%
June-97	7,954	13.2%
Capacity Factor = (kWh Generated) / (Rated Capacity x Total Hours)		

Long Term Performance

The most recently available long-term performance data for the Yonkers PV Facility is presented in Table 3-6.

Table 3-6
Long Term Performance Data for Yonkers PV Facility (April 1998 – June 1999)

Parameter	Low	Average	High
Monthly Capacity Factor (%)	8.08	16.98	23.39
Monthly Performance Index	0.88	0.94	0.97
Monthly Energy Production (kWh)	4,881	10,069	13,677
Monthly Performance (kWh/kW)	60.11	124	168.44

While it is believed that the peak system output occurred during times of peak electrical demand at the facility, no data is available for this case study. It is also important to note that while the peak system output occurred during peak billing hours, the local utility did not permit the wastewater treatment facility to offset their demand charge. The reason stated by the local utility is that the PV system is not dispatchable or "firm" capacity.

Predicted versus Actual Performance

Table 3-2 shows that the predicted yearly generation of the Yonkers system was 137,392 with a capacity factor 18.8%. A comparison of the predicted values to the actual generation shown in Table 3-6 shows that the system generated slightly less energy than expected at a total of 120,828 kWh produced with an average capacity factor of 16.89%. Part of the explanation for this 12%-below-expected production lies in the manner in which the expected production was calculated. The prediction relied upon solar irradiation values recorded at an array angle of 25.78º, which results in maximum solar exposure at the site. In actuality, the array is mounted at an angle of 19º from the horizontal and receives about 10% less annual irradiation than if it were mounted at 25.78º.

Periodic maintenance problems also caused reductions in output. The windward row closest to the edge of the roof was particularly susceptible to blown gravel and debris and suffered occasional damage. One solution to this problem would be the use of other array orientations or the construction of a wind block to shield the array.

Equipment Failure and Maintenance Issues

Village of Tuckahoe Library and Community Center

The Tuckahoe PV facility performed well over the study period. Few component failures were observed. There were **three** operational issues stemming from faulty installations. Each was quickly remedied once they were diagnosed.

- The PV array at the Tuckahoe installation operated outside the allowable voltage window of the power-conditioning unit (PCU) leading to frequent system shutdown. The PCUs were reconfigured and have been operating well.
- A wiring fault in the original conduit installation was found to produce a short and was repaired.
- Several metal oxide varistors (MOVs) used to protect the array from lightning damage have burned out. It is not known whether there were lightning strikes or whether failures were due to other causes such as thermal runaway of the MOV during periods of high PV module voltage.

Yonkers Wastewater Treatment Facility

One problem experienced at the Yonkers installation may have stemmed from the strength of the bonding between the module and the array support. Currently, the unframed modules are glued to the array structure. Under severe wind conditions several of the modules de-laminated from the array. Additionally, several panels broke due to wind force and flying roof gravel. Most of the damage occurred in the windward row. The panels in this row are mounted within 8 feet of the edge of a flat roof with no parapet on a building that is approximately 30 feet high.

In a separate problem, several panels exhibited failure in the early stages of operation due to excessive heat buildup at the wire junction. This problem was quickly remedied by Solarex and has not been observed since.

Project Economics

Tuckahoe Library and Community Center

NYPA's original expectation was that participation with the Sacramento Municipal Utility District (SMUD) in the collaborative utility photovoltaics (CUPV) proposal would result in lower module prices. As it turned out, NYPA did not purchase equipment jointly with SMUD; rather it designed and procured components for its systems independently and attained no financial benefit from CUPV. The major benefit to its participation with SMUD was shared experience and knowledge.

Estimated and Actual Costs

Table 3-7 shows the estimated and actual costs for the Tuckahoe Library PV system.

Table 3-7
Estimated and Actual Costs of the Tuckahoe PV Installation

Item	Estimated Cost	Final Cost
Hardware	$168,976	$159,421
Installation	$59,500	$59,778
O&M	n/a	$15,000
Total Cost		**$234,199**

Incentives and Reimbursements

Under phase one of the UPVG TEAM-UP program, NYPA was to be reimbursed $885 per kW of PV power installed at the Tuckahoe library. The total system installation was designed to be 18 kW, resulting in an expected payment of $15,930. Final project payment, however, was based on ac power ratings as calculated from a regression analysis of actual operating data collected through a remote data acquisition system (DAS). The result of this analysis, as performed by Ascension Technology, was a 13 kW rating of the Tuckahoe system. This rating should have yielded a reimbursement of $11,505. However, NYPA was reimbursed in advance for a large portion of the project and was therefore compensated at a slightly higher level.

Yonkers Wastewater Treatment Facility

Estimated and Actual Costs

Table 3-8 shows the estimated and actual costs for the combined projects of the Gun Hill bus depot and the Yonkers wastewater treatment facility. The exact allocations for each project are unknown but can be estimated as 75% Gun Hill and 25% Yonkers. As mentioned in the background section, the materials used in the Yonkers facility were originally intended to be installed as part of the Gun Hill facility.

Table 3-8
Estimated and Actual Costs for the Gun Hill and Yonkers PV Facilities

Site	Item cost	Estimated costs	Final costs
Gun Hill & Yonkers	Module	$2,727,828	$2,720,054
	PCU	$575,984	$568,208
	Installation	n/a	$224,784
	O&M	n/a	$37,000
	Total		**$3,550,046**

Incentives and Reimbursements

Under phase one of the UPVG TEAM-UP program, NYPA was to be reimbursed $885 per kW of PV power installed at the Gun Hill and Yonkers facilities. The total system designed capacity, actual capacity, and reimbursements are shown in Table 3-9. Final project payment was based on ac power ratings as calculated from a regression analysis of actual operating data collected from each site through a remote DAS. The result of this analysis, as performed by Ascension Technology, was a rating of 81 kW for the Yonkers system. This rating should have yielded a reimbursement of $71,685. However, NYPA was reimbursed in advance for a large portion of the project and was therefore compensated at a slightly higher level.

Table 3-9
TEAM-UP Participation Reimbursements

Site	Designed Capacity	Intended Reimbursement ($885 / kW)	Actual Capacity	Adjusted Reimbursement ($885 / kW)
Yonkers	100 kW	$85,000	81 kW	$71,685*
Gun Hill	300 kW	$265,500	236 kW	$208,860*
*NYPA was reimbursed in advance for a large portion of the project and was therefore compensated at a slightly higher level.				

In addition to the TEAM-UP funding, NYPA also applied for and received funds from the federal Department of Energy Renewable Energy Production Incentive program on an annual basis since 1998. This program provides an incentive of $0.0165 per kWh that NYPA generates with renewable resources. NYPA received approximately $6,000 per year for the electricity generated from the TEAM-UP Phase One projects.

Lessons Learned

NYPA's involvement in the TEAM-UP program allowed them to gain valuable experience in solar energy projects. Furthermore, since the NYPA projects are some of the earliest discussed in this report, they provide a snapshot of PV conditions and issues, as they existed in the mid-1990s. Some of the lessons learned through this work are:

- *Interconnection agreements with local utilities need to be standardized.* NYPA identified the length and stringency of the interconnection permitting process as a possible barrier to the widespread use of grid-connected PV. Experience gained during this project suggested that more standardized interconnection agreements would help streamline the process, and the process has indeed become more streamlined since these projects were commissioned. New York State now has standardized interconnection requirements for small distributed-generation (DG) and PV systems. There are also several new and/or updated interconnection standards since 1994-95. These include IEEE 1547 and IEEE-929-2000.
- *Adoption of an industry standard test plan*. O&M costs were minimal once start-up and design flaws were remedied. In hindsight, it was felt that a standard system test plan designed by the PV industry would have been helpful in identifying design flaws and manufacturer defects during the construction phase of the project.
- *The monitoring and data acquisition system should be kept as simple as possible*. NYPA attempted to design and build a database capable of capturing all the required data using an in-house system based on daily modem call schedules. They were not able to provide the time and effort to troubleshoot and maintain this type of system. Data acquisition system are best purchased as "off the shelf" systems.

4
COFRIN HALL ON THE GREEN BAY CAMPUS OF THE UNIVERSITY OF WISCONSIN – WISCONSIN PUBLIC SERVICE CORPORATION

Background

Mary Ann Cofrin Hall (Figure 4-1) is the newest addition to the University of Wisconsin-Green Bay campus. The building owners, the Wisconsin Department of Administration – Division of Facilities Development (DFD), wanted to continue Wisconsin's tradition of environmentally friendly policies with the construction of Cofrin Hall. Therefore, the DFD contacted Wisconsin Public Service to assist in evaluating photovoltaic technologies for use in Cofrin Hall early in the design process. The goal expressed by the DFD was to construct a classroom building that used 50% less energy than a traditional building but cost the same to construct. It was determined that building-integrated photovoltaic technologies (BIPV) would be incorporated into the design but would not be the driving force behind the design. While many BIPV technologies were considered, it was decided that a combination of PV standing seam metal roofing and PV vision glass would be used to provide Cofrin Hall with a total PV capacity of 23.8 kW.

Upon completion in September 2001, the Cofrin Hall PV installation was the largest in Wisconsin as well as the largest BIPV installation in the Midwestern United States. It was the first building in Wisconsin to employ the PV standing seam metal roof and the first installation of a PV vision glass system anywhere in the United States.

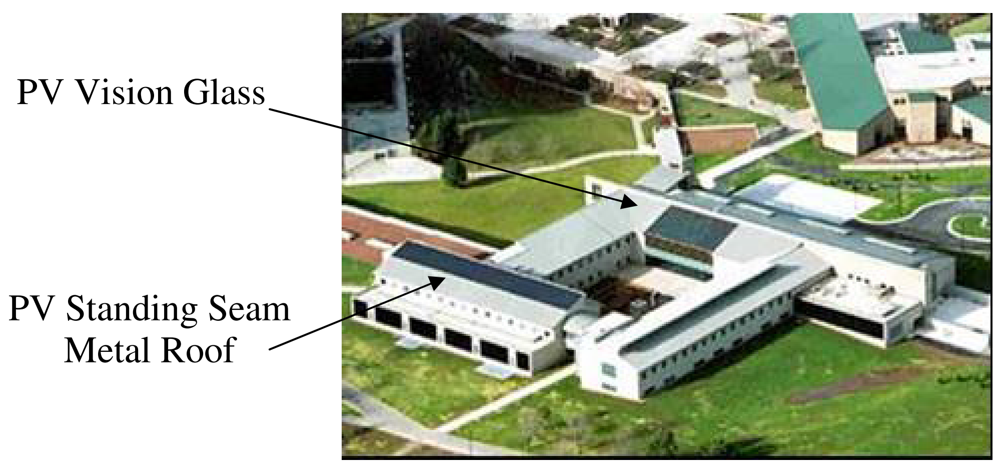

Figure 4-1
Mary Ann Cofrin Hall on the University of Wisconsin – Green Bay Campus

Project Goals

The construction of Mary Ann Cofrin Hall on the University of Wisconsin-Green Bay campus is a research effort designed to evaluate Building-integrated Photovoltaics. Cofrin Hall also acts as a showcase for BIPV technology to demonstrate the viability and aesthetic qualities of the BIPV systems employed. As a showcase, it is intended to increase the use of both PV standing seam metal roof systems and PV vision glass systems in the United States as well as to further the concept of environmentally friendly buildings

System Description

Photovoltaic System

A 12.8-kW PV array is incorporated into the standing seam metal (SSM) roof of the south-facing wing of Mary Ann Cofrin Hall. Both traditional and BIPV standing seam metal roofing systems use vertically sloping metal trays that snap together along raised edges to form the roof. The BIPV metal roofing from the United Solar Systems Corporation goes one step further by gluing or laminating thin-film amorphous-silicon triple-junction photovoltaic modules to the metal trays. The BIPV metal roofing provides the same protective functions as tradition SSM but presents the added benefit of producing electricity. The installation of the United Solar Systems Corporation standing seam metal roofing product is shown in Figure 4-2 and Figure 4-3. The array is composed of 100 of the 128-watt panels (SSR-120) covering 2,300 square feet of roof space. The SSM roof array feeds one Trace Engineering PV15208 inverter.

Figure 4-2
Installation of PV Standing Seam Metal Roof on Mary Ann Cofrin Hall

Figure 4-3
Completed Installation of PV Standing Seam Metal Roof on Mary Ann Cofrin Hall

In addition to the BIPV standing seam metal roof, a 10.8-kW array of photovoltaic vision glass is used in the Wintergarden of Mary Ann Cofrin Hall as shown in Figure 4-4 and Figure 4-5. Vision glass is manufactured by replacing the exterior glass panel of a double-pane glass window with a thin-film, semi-transparent photovoltaic module. Each window or module is then wired together in the same manner as any other PV array. BP Solar laser etched their MST-43LV 43-watt modules to create the required transmittance. The semi-transparent solar modules were incorporated into architectural glass panels by Viracon Inc. Finally, a total of 252 vision glass modules were installed in a standard Kawneer Company PowerWall™ 1600 to create an array that spans 2,000 square feet. Each vision glass module uses 13 layers of thin film with a total film thickness less than a sheet of paper. The array feeds a total of four Trace Engineering 2500 Watt ST-XR inverters.

Figure 4-4
Exterior View of the Vision Glass Wintergarden at Mary Ann Cofrin Hall

Figure 4-5
Interior View of the Vision Glass Wintergarden at Mary Ann Cofrin Hall

Data Acquisition System

The PV systems installed in Mary Ann Cofrin Hall are fully instrumented in order to monitor and evaluate system performance. The monitored system parameters are shown in Table 4-1. A separate data acquisition computer monitors each PV system operating at Cofrin Hall. The data acquisition computers run a National Instruments LabView executable file that is tailored for the particular PV system being monitored. The computer collects data from each PV system and then transfers the data to the University of Wisconsin – Green Bay server. The server then distributes the data to the website and information kiosk. Historical data is also saved in CSV format. The historical data file is composed of 15 minute averaged data points stored at 0, 15, 30, and 45 minutes of each hour.

Table 4-1
Parameters Monitored by the Mary Ann Cofrin Hall Data Acquisition System

PV Systems and Building Demand		Weather Conditions
Module Temperature	Inverter Temperature	Ambient Temperature
String Current	Building kW	Irradiance
Array Voltage	Inverter Voltage	Wind Speed
Array Current	Inverter Current	--
Phase Voltage	Inverter kW	--
Phase Current	Inverter kVAR	--

Additional Energy Enhancements

Photovoltaics are not the only design feature of Mary Ann Cofrin Hall intended to reduce the amount of grid-supplied electricity and natural gas required to operate the building. In addition to the PV arrays, Cofrin Hall also utilizes extensive day lighting and SolarWall technology.

Daylighting is used to reduce the daytime lighting load within the building by creating passageways for sunlight to enter interior rooms. This was accomplished by incorporating skylights, clerestories, borrowed lighting, daylight diffusers, and direct sun lighting into the building design. To achieve these goals, five different types of window glazing were used with transmittances ranging from 15% to 25%.

SolarWall technology is used to pre-heat the HVAC intake air during the winter months. The SolarWall is an unglazed porous solar collector that absorbs heat energy from the sunlight shining on it. In the case of Cofrin Hall, one south-facing wall is a 2,256 square foot transpired solar collector or SolarWall as shown in Figure 4-6. The HVAC intake air enters the wall at vents near the ground and exits the wall to the air handlers through vents at the top. While passing through, the air is warmed by the collected solar heat.

Figure 4-6
The South Facing Wall of Mary Ann Cofrin Hall Incorporates Solar Wall Heating Technology

In addition to these many energy conservation technologies, the construction of Cofrin Hall incorporates the following recycled and biodegradable building materials:

- Cork Flooring
- Low Volatile Organic Compound (VOC) Carpeting
- Wool Carpeting (Classroom Walls)
- Porcelain Tile Flooring
- Recycled Rubber Flooring
- Linoleum Flooring
- Bamboo Flooring

Predicted Performance

The 30-year average solar irradiation for a flat plate collector facing south at latitude-15° for the Green Bay area as reported by the National Renewable Energy Laboratory (WBAN No. 14898, 44.48° North latitude, 88.13° West longitude) is 3.8 kWh/m^2 per day. The expected annual production of the PV standing seam metal roof and PV vision glass systems is calculated as shown in Table 4-2 and Table 4-3.

Table 4-2
Predicted Performance of the PV Standing Seam Metal Roof System

Array rating at STC: (100 x 128W)	12,800 Watts
Expected loss due to module mismatch	3% (384 Watts)
Expected loss due to soiling	5% (640 Watts)
Expected loss due to temperature in excess of 25° C	10% (1,280 Watts)
Total losses from dc array	18% (2,304 Watts)
Expected dc output per 1 kW/m^2 of irradiance	10,496 Watts
Inverter efficiency	94%
Expected ac output per 1 kW/m^2 of irradiance	9,866 Watts
Predicted annual production (9.86 kW per 1 kW/m^2 x 3.8 kWh/m^2 per day x 365 days)	**13,684 kWh**
Predicted Capacity Factor 100 * (13,684 kWh) / (10,496 Watts)*(8760 hrs.)	**14.9%**
Note: The predicted performance calculation does not take into account snow or other environmental media covering the solar array for extended periods of time. Additionally, the predicted annual production assumes no outages.	

Table 4-3
Predicted Performance of the PV Vision Glass System

Array rating at STC: (252 x 43W)	10,836 Watts
Expected loss due to module mismatch	3% (325 Watts)
Expected loss due to soiling	5% (542 Watts)
Expected loss due to temperature in excess of 25° C	10% (1,084 Watts)
Total losses from dc array	18% (1,950 Watts)
Expected dc output per 1 kW/m^2 of irradiance	8,886 Watts
Inverter efficiency	94%
Expected ac output per 1 kW/m^2 of irradiance	8,352 Watts
Predicted annual production (8.35 kW per 1 kW/m^2 x 3.8 kWh/m^2 per day x 365 days)	**11,585 kWh**
Predicted Capacity Factor 100 * (11,585 kWh) / (8,352 Watts)*(8760 hrs.)	**15.8%**
Note: The predicted performance calculation does not take into account snow or other environmental media covering the solar array for extended periods of time. Additionally, the predicted annual production assumes no outages.	

Table 4-4
Total Predicted Output of PV Systems on Mary Ann Cofrin Hall

PV Standing Seam Metal Roof	13,684 kWh
PV Vision Glass	11,585 kWh
Total	**25,269 kWh**

Actual Performance

Figure 4-7 and Table 4-5 show the outputs of both the roof and vision glass systems from October 2001 until October 2002. Unfortunately, the vision glass system was plagued by inverter failures during much of its first year of operation. The inverter failures are discussed in more detail in the Equipment Failures and Maintenance Issues Section of this chapter.

The output for the standing seam metal roof system shown in Figure 4-7 exhibited a downturn in June 2002. At the time of writing of this report, December 2002, it is unclear whether the system output was actually reduced for the month or if there was a data acquisition error.

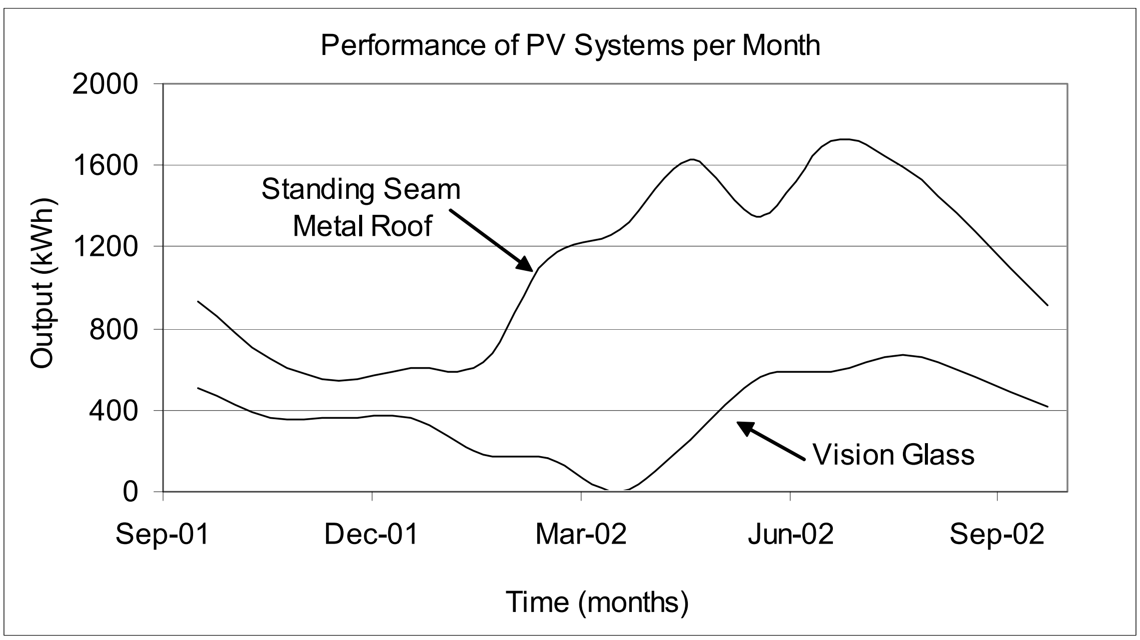

Figure 4-7
PV System Performance from October 2001 through October 2002

Table 4-5
Output and Capacity Factor of the Mary Ann Cofrin Hall PV Systems by Month

Month	Standing Seam Metal Roof		Vision Glass	
	Output (kWh)	**Capacity Factor**	**Output (kWh)**	**Capacity Factor**
October-01	939	12.7 %	510	8.2 %
November-01	665	9.4 %	366	6.1 %
December-01	557	7.6 %	360	5.8 %
January-02	620	8.4 %	363	5.8 %
February-02	639	9.6 %	180	3.2 %
March-02	1149	15.7 %	165	2.7 %
April-02	1289	18.1 %	3.6	0.06 %
May-02	1638	22.3 %	250	4.0 %
June-02	962	13.5 %	599	10.0 %
July-02	1727	23.5 %	593	9.5 %
August-02	1597	21.8 %	671	10.8 %
September-02	1288	18.1 %	558	9.3 %
Total	**13,070**	**15.1 % avg.**	**4,619**	**6.3 % avg.**
Capacity Factor = (kWh Generated) / (Rated Capacity x Total Hours)				

The ability of the PV systems to load match the power demand of Mary Ann Cofrin Hall is illustrated in Figure 4-8. The peak output of the PV systems, equaling approximately 10% of the building load, did occur during a time of peak building demand. However, because of the type of use Cofrin Hall experiences it exhibits a rather long period of peak use. The building power demand jumps up around seven o'clock in the morning and remains at an elevated level until nearly 10 o'clock in the evening. This load shape is reasonable for a university building because of its varied class schedule, many computer facilities, and the propensity of college students to work at odd hours of the day.

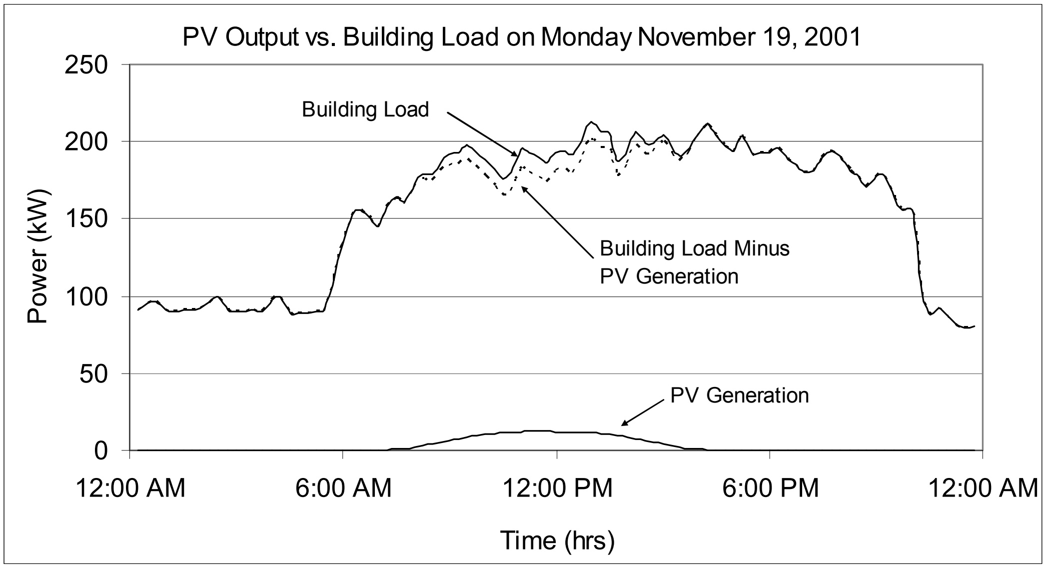

Figure 4-8
Typical Daily Building Load and PV System Output

Predicted versus Actual Performance

The output of the standing seam metal roof PV system was very close to its predicted output for the first year of operation (Table 4-6). There is some confusion about the SSM roof system's performance during the month of June 2002. The recorded inverter output for that month shows that it reduced by approximately 50% for a portion of the month resulting in approximately 15% less generation than expected. At the time of writing it is still unclear whether the output was actually reduced or if there was a data acquisition error.

The PV vision glass system did not fair as well as the SSM roof system and was plagued by inverter failures that hurt the system's overall performance. The lengthy downtime associated with the failures greatly reduced the system's energy production. Further information on the inverter failures is available in the Equipment Failures and Maintenance Issues section of this chapter.

Table 4-6
Comparison of Predicted and Actual Energy Production for the Mary Ann Cofrin Hall PV Systems

	Standing Seam Metal Roof		Vision Glass	
Predicted Power Production and Capacity Factor	13,684 kWh/year	14.9%	11,585 kWh/year	15.8%
Actual Power Produced and Capacity Factor 10/01-10/02	13,363 kWh	15.1%	4,619 kWh	6.3%
Percent Deviation	-2.3% (-321 kWh)	NA	-43.5% (-6548 kWh)	NA

Equipment Failures and Maintenance Issues

The four inverters associated with the Wintergarden system experienced simultaneous failure on March 8, 2002 from what was believed to be a lightning induced surge. The inverters were returned to the factory for repair and also received a software upgrade and were re-installed on May 8, 2002. Another failure was exhibited on a single Wintergarden inverter on June 24, 2002 possibly due to an ac surge. That unit was returned to service on August 16, 2002. In a separate problem, one other inverter exhibits poor performance during periods of high irradiance shifts. The manufacturer is aware of this issue and plans to upgrade the software on all of the inverters to solve the problem. There have also been two failures of PV modules in the Wintergarden system. The cracked modules have been replaced, but the cause of the failures is unknown.

Project Economics

The BIPV portion of the total cost of Mary Ann Cofrin Hall was approximately $258,029. Wisconsin Public Service also donated approximately 1,500 hours of time for project management. The value of this time is not reflected in the BIPV costs.

State of Wisconsin buildings are required to install energy-saving devices that have a five-year payback or less. Since the BIPV system did not meet these criteria, it was not covered under the State of Wisconsin's scope of work and other funding sources had to be secured. Financial support for Cofrin Hall was greatly influenced by Wisconsin Public Service's interest in testing the relatively new photovoltaic technologies, and Wisconsin Public Service provided 60% of the necessary funding. The University of Wisconsin – Green Bay and the DFD received $45,000 co-funding from the State of Wisconsin's Focus on Energy program. An additional $10,000 grant was received from the Energy Center of Wisconsin's WisconSUN program.

The estimated cost structure in Table 4-7 was derived from written and verbal quotes from manufacturers, suppliers, and developers.

Table 4-7
Costs Associated with the BIPV Portion of the Construction of Mary Ann Cofrin Hall

Photovoltaic Modules		
Standing Seam Metal Roof	$57,753.70	
Vision Glass	$50,929.30	
		$108,683
Inverters		
Standing Seam Metal Roof	$16,669.00	
Vision Glass	$14,773.00	
		$31,442
Electricians & Installers		
Standing Seam Metal Roof	$6,328.44	
Vision Glass	$5,580.56	
		$11,909
Miscellaneous		
Standing Seam Metal Roof	$860.32	
Vision Glass	$758.68	
		$1,619
BIPV Subtotal (Equipment and Installation)		***$153,653***
BIPV Consultant		$15,536
BIPV Net Cost Study		$21,000
Data Acquisition System		$9,712
Education & Outreach Activities		$33,128
Internet Site Development		$25,000
Total		**$258,029**

Education and Outreach

One of the primary goals of the BIPV demonstration at Mary Ann Cofrin Hall was to educate the public, engineers, architects, and the construction trade about the viability of BIPV technology. It was also the intent of the project funders that the familiarity gained in the construction and operation of Cofrin Hall would spur further BIPV use in new construction. Besides providing a high profile BIPV application, public education about BIPV technology is accomplished through:

- *The Mary Ann Cofrin Hall Website***.** The website describes the BIPV technology employed and details the installation process. The website also contains a variety of other information including a project history and timeline, key stakeholders, and links to performance analysis data. (http://www.buildingsolar.com)
- *Facility Tours***.** Representatives of the University of Wisconsin – Green Bay and Wisconsin Public Service, lead Building tours.
- *The Electronic Information Kiosk***,** Located inside Mary Ann Cofrin Hall, the kiosk terminals are user driven via interactive touch screens or configured for tours and group presentations. The information available through the kiosk includes the building's real-time solar performance, a solar quiz, and information on other aspects of the building's environmentally friendly design and construction

Lessons Learned

The Wisconsin Public Service staff learned a great deal about BIPV systems through work on the Cofrin Hall project. Some of the lessons gained from this experience include:

- *Inverter surge protection is critical.* The system inverters suffered multiple failures that have been attributed to voltage surges. The inverter failures resulted in several months of system downtime and may have been prevented by applying more stringent surge protection.
- *PV is a viable energy source outside of the southwestern United States.* The photovoltaic systems in use at Mary Ann Cofrin Hall have proven to be a viable source of energy for the building. This shows that while the southwestern U.S. may have optimal solar resources, photovoltaic installations can be successful in other parts of the country as well.

5
PARKING STRUCTURE PHOTOVOTAIC SYSTEM – PUBLIC SERVICE COMPANY OF NEW MEXICO (PNM)

Background

Public Service Company of New Mexico (PNM) is New Mexico's largest utility, providing electricity to more than 360,000 customers and natural gas to more than 420,000 customers. In total, PNM serves 1.3 million people in more than 100 communities in New Mexico. The company employs about 2,700 people – making it the eighth-largest private employer in New Mexico [1].

In 2001, PNM carried out several initiatives to implement demonstration projects that provided information about the reliability, capital costs, operating costs, and performance of alternative energy systems. Included among these initiatives was the addition of a 5-kW photovoltaic system to a pre-designed parking lot shading structure at one of PNM's facilities.

Project Goals

The PNM PV parking structure project was undertaken with two main goals: (1) to provide PNM with information on the reliability, performance, and economics of current PV technology and (2) to showcase viable and aesthetically pleasing alternative energy technologies. As a technology showcase, emphasis was placed on creating a PV system that exhibited the following characteristics:

- Little or no problems with the installation
- Correct operation right from the initial system start-up
- Little impact on the overall renovation project
- An aesthetically pleasing design

System Description

Photovoltaic System

PNM was well into the design process for renovations to the parking area at one of their Albuquerque, New Mexico facilities when they decided to install a PV system at the facility. A parking lot shading structure that was already planned for in the renovation proved to be ideal for mounting the PV array and required only minor design revisions. The size of the columns and footings for the proposed parking structure was increased to ensure that additional wind loading due to the PV array would not cause the structure to fail.

The 5-kW photovoltaic array consists of two sub-arrays of PV modules mounted on top of the parking structure at a fixed tilt angle of 30º (Figure 5-1). Each subarray is comprised of 48 BP Solar BP 270F 70-watt monocrystalline modules divided to form two strings of 24 modules. Each subarray feeds a SMA Sunny Boy 2500 inverter shown in Figure 5-2. Figure 5-3 is a one-line electrical diagram of the whole system.

The system began operation in April 2002 with data collection beginning in May 2002. The PV system is grid-tied through the building electrical system and operates without batteries or other storage medium. For safety reasons, the PV system ceases to produce power when either the PNM power grid goes off-line or the PV system is disconnected from the grid.

Figure 5-1
Parking Structure Photovoltaic System at the PNM Facility in Albuquerque, New Mexico

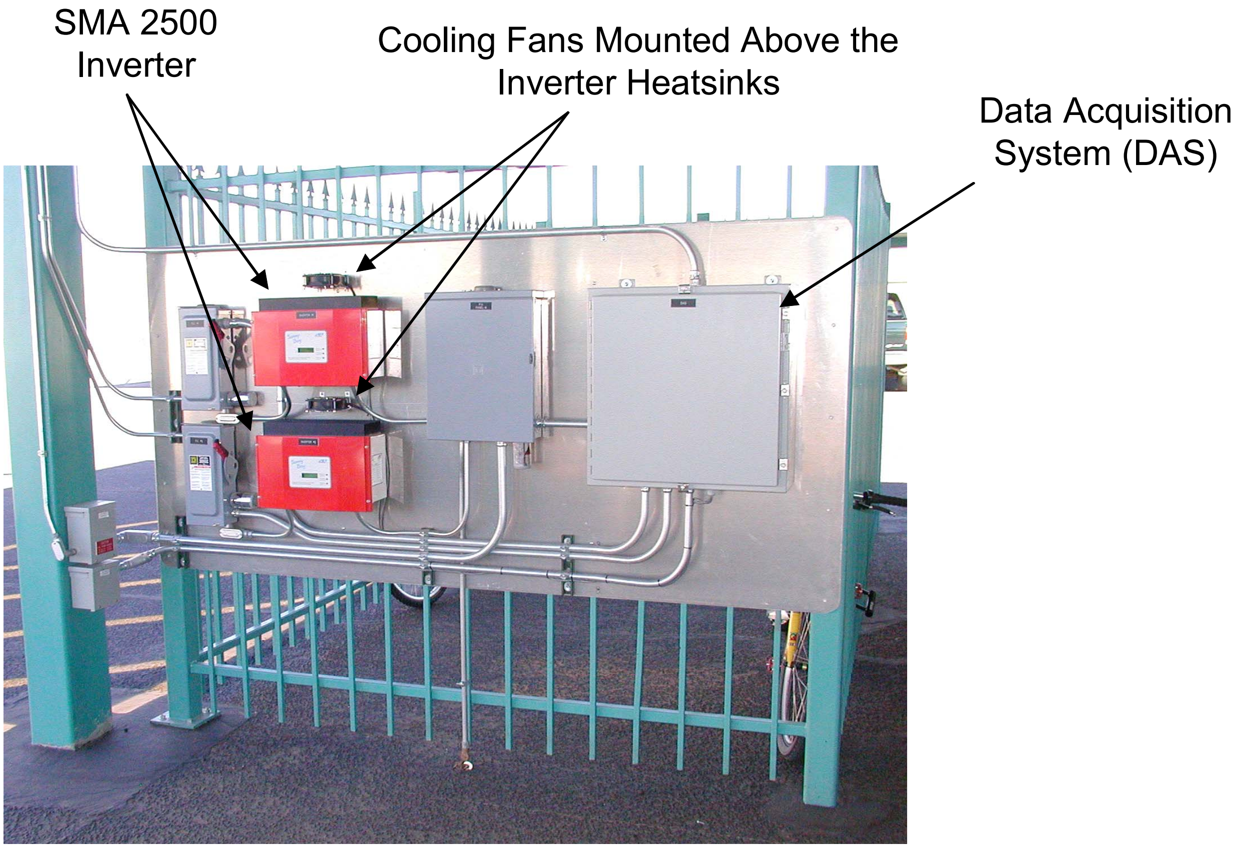

Figure 5-2
SMA Sunny Boy 2500 Inverters Installed at the PNM Photovoltaic Parking Structure

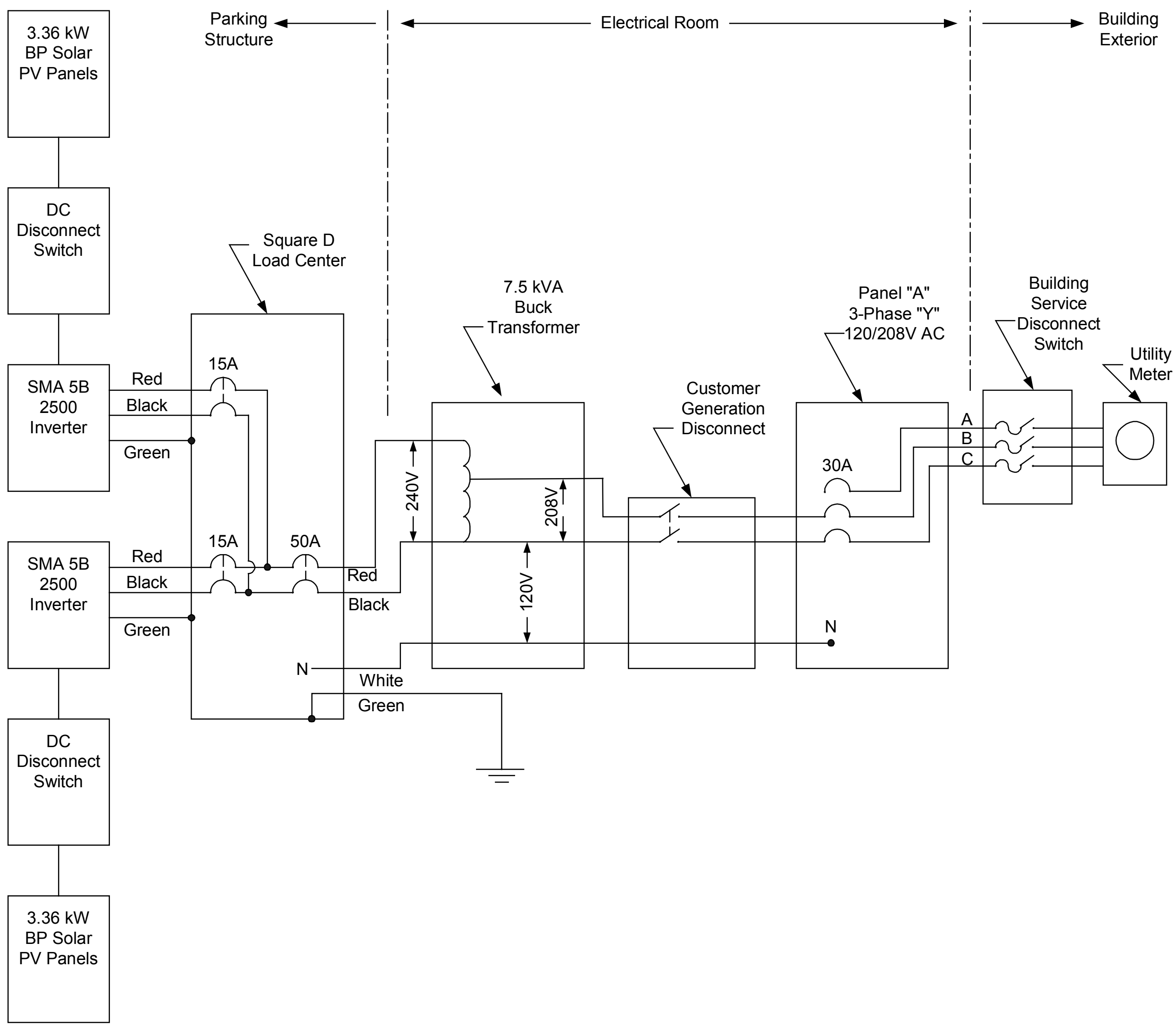

Figure 5-3
One-Line Diagram of the PNM Parking Structure PV System

Data Acquisition System

The data acquisition system (DAS) was designed and installed by the Southwest Technology Development Institute at New Mexico State University. The data collected by the DAS can be accessed from remote locations by telephone line or viewed on a touch-screen kiosk in the building lobby (Figure 5-4). The parameters measured by the DAS are shown in Table 5-1.

Table 5-1
Parameters Monitored by the PNM Parking Structure Photovoltaic System DAS

PV System and Building Demand		Weather Conditions
dc kW & kWh	Module Temperature	Irradiance
ac kW & kWh	Net Building kW & kWh	Ambient Temperature
Inverter Spreader Bar Temperature		Wind Speed

Figure 5-4
Touch-Screen of the Information Kiosk for the PNM Parking Structure Photovoltaic System

Predicted Performance

The 30-year average solar irradiation for a flat plate collector facing south at latitude for the Albuquerque area is reported by National Renewable Energy Laboratory (WBAN No. 23050, 35.05° North latitude, 106.62° West longitude) as 6.4 kWh/m^2 per day. The expected annual production of the parking structure photovoltaic system is shown in Table 5-2.

Table 5-2
Predicted Performance of the PNM Parking Structure Photovoltaic System

Array rating at STC: (96 x 70W)	6,720 Watts
Expected loss due to module mismatch	3% (202 Watts)
Expected loss due to soiling	5% (336 Watts)
Expected loss due to temperature in excess of 25° C	12% (806 Watts)
Total losses from dc array	20% (1344 Watts)
Expected dc output per 1 kW/m^2 of irradiance	5,376 Watts
Inverter efficiency	93%
Expected ac output per 1 kW/m^2 of irradiance	5,000 Watts
Predicted annual production (5.0 kW per 1 kW/m^2 x 6.4 kWh/m^2 per day x 365 days)	**11,680 kWh**
Predicted Capacity Factor 100 * (11,680 kWh) / (5,000 Watts)*(8760 hrs.)	**26.7%**
Note: The predicted performance calculation does not take into account heavy layers of environmental media covering the solar array for extended periods of time. Additionally, the predicted annual production assumes no outages.	

Actual Performance

PNM's parking structure photovoltaic system has performed well since its commissioning in April 2002. System data acquisition began in May 2002 with the recorded system output shown in Table 5-3 along with the calculated monthly capacity factor.

Table 5-3
PNM Parking Structure Photovoltaic System Output (May 2002 – Present)

Month (2002)	System Output (kWh ac)			Capacity Factor
	Inverter 1	Inverter 2	Total	
May*	285*	270*	555*	14.9 %*
June	482	454	936	26.0%
July	458	432	890	23.9 %
August	498	468	966	25.9 %
September	445	423	868	24.1 %
October	463	446	909	24.4 %
Average*	469	445	914	24.8 %
*Data acquisition began in mid-May and average values exclude May data. Capacity Factor = (kWh Generated) / (Rated Capacity x Total Hours)				

The load matching ability of the PV system is somewhat hindered by the building usage pattern. As Figure 5-5 shows, the period of peak building load occurs during the evening hours – usually between 3pmand 9pm. However, the peak PV system output occurs in the afternoon between 12pm and 3pm**.** Fortunately, the PV system is well sized for the facility. Building demand exceeds the PV production at all times resulting in good utilization of the PV energy.

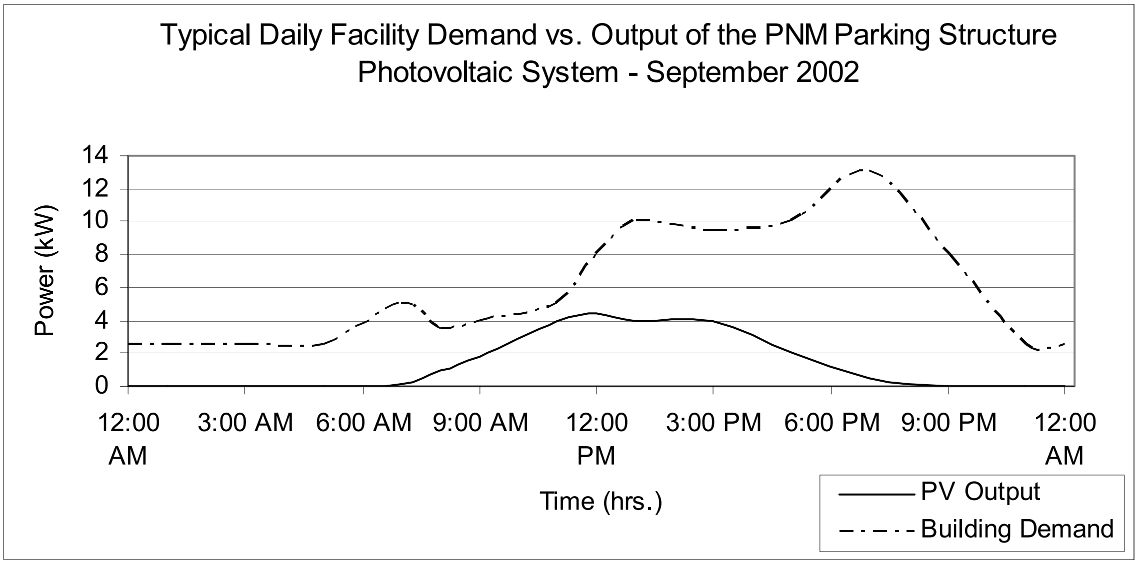

Figure 5-5
Typical Daily Facility Demand vs. Parking Structure Photovoltaic System Output

Predicted versus Actual Performance

The parking structure photovoltaic system has performing very close to its predicted level. The system owners are very happy with its performance thus far. Barring any unforeseen failures, the system should continue to perform as predicted.

Equipment Failures and Maintenance Issues

System maintenance is expected to be limited to annual visual inspections with further maintenance required only upon equipment failure. The PV modules come with a 25-year warranty but are expected to operate for 40-50 years at reduced output due to aging. The inverter comes with a 2-year warranty and is expected to last 5-10 years before replacement. For planning purposes, the full system life is estimated at 20 years.

No equipment failures have been observed since the system began operation in May 2002. However, it was found that the inverters reached their UL temperature limit on hot, windless days this past summer, which reduced the expected power output. This issue was addressed by installing small ventilation fans above each inverter's heat sink as recommended by the manufacturer (Figure 5-2). The fans were installed on October 17, 2002, and they appear to have solved the problem. However, the ambient temperature is decreasing due to seasonal changes and the performance of the fans can't be fully evaluated until June 2003.

Project Economics

PNM funded the full cost the of the parking structure photovoltaic system without utilizing any incentive plans. The final installed cost of the system was $50,000 or $10/watt. The chosen system was a "cookie-cutter" system with a proven track record for installation and operational success. Standardization helped to eliminate the first-time installation costs that many PV projects suffer from.

Lessons Learned

Using experienced PV designers and proven system architectures can help ensure project success . PNM utilized experienced PV designers and high-quality contractors in order to achieve the project goals of trouble-free installation and operation. High-quality equipment and proven system architecture were employed to ensure that the system operated properly with little or no maintenance right from the beginning. The installation went very well and PNM recommends this approach to anyone who may be installing a PV system.

6
PVUSA SYSTEM ON ULAPALAKUA RANCH IN KIHEI, MAUI, HAWAII (HECO)

Project Description

The 20-kW PVUSA (Photovoltaics for Utility-Scale Applications) system is located on a parcel of land within the Ulapalakua Ranch in Kihei, Maui. This ground-mounted, grid-connected system is owned by the State of Hawaii under the Department of Business, Economic Development and Tourism (DBEDT). Maui Electric Company, Ltd (MECO) operates and maintains the facility. MECO is a subsidiary electric utility of Hawaiian Electric Company, Inc. (HECO) that serves the islands of Maui, Molokai, and Lanai, The Kihei PV facility is shown in Figure 6-1.

Figure 6-1
PVUSA 20-kW Facility in Kihei, Maui

System Description

The Kihei PVUSA facility provides electrical energy to MECO's grid. System characteristics are provided below:

Table 6-1
Characteristics of the PVUSA Maui System

Location Latitude Longitude	Kihei, Maui, Hawaii Latitude 20.8° N Longitude 156° W
Orientation	Fixed, south-facing, 22° array tilt
Modules	1,200 Sovonics P23S tandem junction amorphous silicon, 497 m^2 module area
Inverters	Original: 1 DECC/Helionetics #61635 (25-kW) New: 3 Omnion Series 2400 (6-kW)
Installation Dates	Original: October 1989 New: November 1997 (new inverters only)
Rated Capacity	18.5 kW dc

Operational History

The Kihei PV facility was installed in late 1989, which made it the first PVUSA host site and the largest PV system in Hawaii at that time. Along with an identical installation in Davis, California, the facility was among the first systems to pioneer the use of tandem-junction amorphous silicon modules. The facility served as a key PVUSA installation to assess the performance of similar PV systems in varying geographic locations. Today, the Kihei facility continues to provide operational experience and performance data for MECO.

In late 1996, the original DECC/Helionetics 25-kW inverter failed after having generated a cumulative total of over 200,000 kWh at an average capacity factor of 19%. The DECC/Helionetics inverter had burnt components on a circuit board and could not be re-started. Because the manufacturer was no longer in business and no service team or spare parts were available, it was concluded that it was not feasible to repair the inverter. A service contractor who had access to a DECC/Helionetics inverter manual and some design drawings offered to fix the circuit board; however, no warranty was offered on the work.

Given the good condition of the PV array and its favorable performance history, HECO, PVUSA, and Sacramento Municipal Utility District (SMUD), which had become the owner and operator of the system during this period, agreed to renovate the system. A cost-share arrangement among PVUSA, HECO, and SMUD was executed to replace the failed inverter with three off-the-shelf Omnion Series 2400 6-kW inverters and reconfigure the sub-arrays and balance of system. The renovation was completed in November 1997.

System Performance

Since the PVUSA Maui site underwent major renovations in late 1997 this case study will primarily focus on system performance in the post-renovation time period. The main component of the renovation was the replacement of the original DECC/Helionetics inverter that had failed after seven years of service. A failure of a replacement inverter occurred in early 2001 and is discussed further in the next section- Equipment Failures and Maintenance Issues.

The system was initially rated at 18.5 kW dc but has exhibited an average decline of 2.3% per year based on its first eight years of operation. The 1998 PVUSA Progress Report rated the Maui system at 15.4 kW dc and 13.9 KW ac and indicated that the rate of decline may be slowing. It is common for amorphous silicon PV system performance and system rating to decline over time due to declining module efficiency. Although there is not a consensus on the exact rate that photovoltaic systems degrade in the field, the literature suggests that a 0.5-5.0% per year decline in system rating is reasonable given field observations

Unfortunately, PVUSA analysis of the Maui system ended during mid-1999, and post-renovation data is limited to 1998 and part of 1999. Table 6-2 shows the energy production and system capacity factors during this time period. The monthly energy production of the PVUSA Maui system during 1998 is shown in Figure 6-2. The system output is visibly reduced in the month of July due to four failed junction-box connections.Excluding the month of July, the system performance was in line with its revised rating of 13.9 kW ac and the renovations were considered to be a success.

Table 6-2
Energy Production and Capacity Factor for the PVUSA Maui System

Quarter	Output (kWh)	Capacity Factor
1st qtr. 1998	7,728	20%
2nd qtr. 1998	6,327	16%
3rd qtr. 1998	6,430	17%
4th qtr. 1998	6,608	17%
1st qtr. 1999	7,477	20%
Total	**34,570**	**18% avg.**

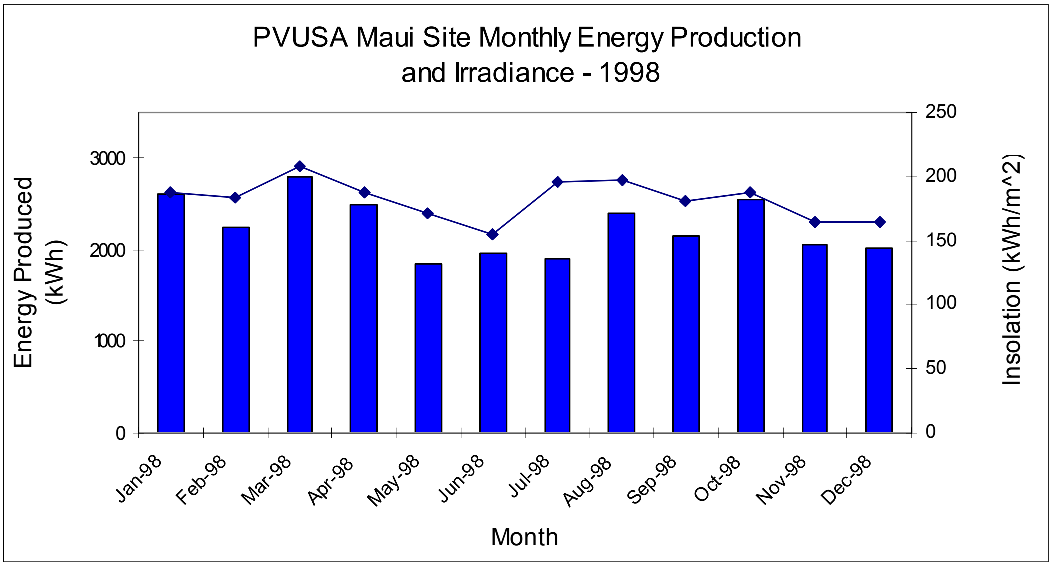

Figure 6-2
PVUSA Maui Site Monthly Energy Production and Irradiance - 1998

Equipment Failures and Maintained Issues

In early March 2001, MECO personnel discovered evidence of a fire involving one of the Omnion inverters during a routine inspection of the facility. As MECO personnel opened a dc-side junction box, a fire erupted inside the junction box and was quickly extinguished by MECO personnel. Fire damage was observed in one of the Omnion inverters, the dc-side junction box, and a connector in the transducer box. Photographs of the damage are shown in Figure 6-3, Figure 6-4, and Figure 6-5. The fire damage is described below:

- A portion of the power board within the Omnion inverter was burned, including the dc neutral connection. Several capacitors were damaged with ruptured casings and/or separation from the board and insulation was burned off much of the main wiring within the inverter. Refer to Figure 6-3.
- Fire damage was contained primarily within the inverter with some blackening present on the board to which the damaged inverter was mounted. Refer to Figure 6-4. According to S&C Electric Company —S&C acquired Omnion Power Engineering Corporation in 1999— the temperature inside the enclosure was estimated to be at least 125˚C (257˚F) based on the condition of the capacitors.
- The fire inside the dc-side junction box damaged the connectors, metal oxide veristors (MOVs), and fuses for the circuits supplying negative dc power to the damaged inverter and one of the other two inverters. The diodes on the negative dc circuits supplying the damaged inverter were found to be open and the remaining inverters were found to be closed. Refer to Figure 6-5.

- A wire on the dc circuit supplying negative power to the damaged inverter was loose and had significant charring at the connector.

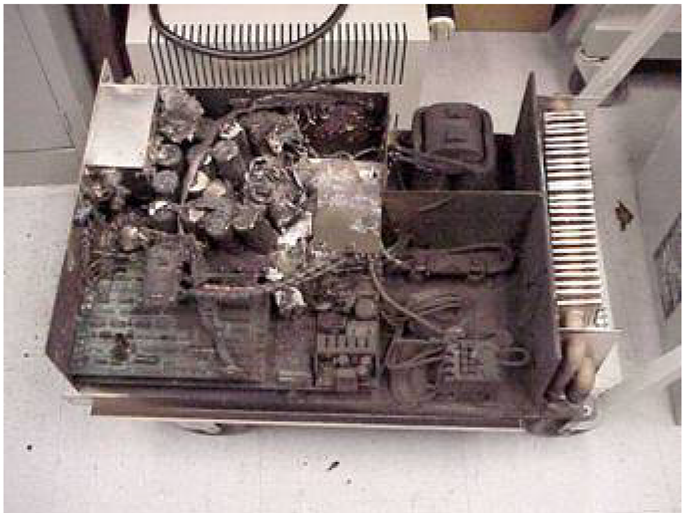

Figure 6-3
Photograph of Damaged Omnion Inverter

Figure 6-4
Photograph of the Board to Which the Damaged Omnion Inverter was Mounted (Note the two Burn Marks at the Top of the Board)

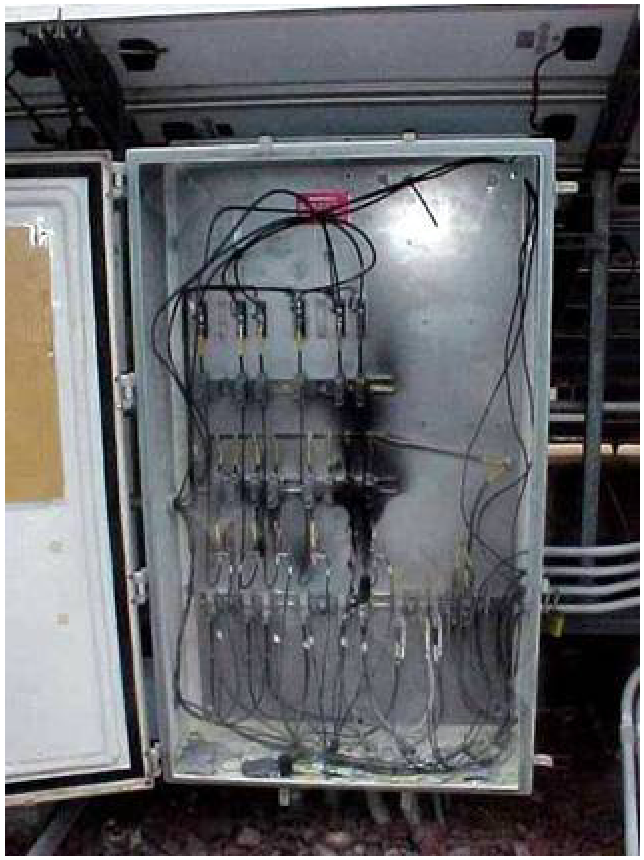

Figure 6-5
Photograph of the Damaged DC-Side Junction Box

The damaged inverter and information on the PVUSA system were sent to S&C for evaluation for investigation, but the investigation was inconclusive as to the cause of the fire. Inspections of the PVUSA system did not uncover any suspicious array or wiring arrangements and the occurrence of lightning around the time of the fire was highly unlikely as there was no storm activity in the vicinity during the period of time within which the inverter fire occurred. Based upon the investigation, the inverter itself cannot be ruled out as the cause of the inverter fire at the Kihei PVUSA facility.

Following the investigation, MECO modified the PVUSA facility to run on the remaining two Omnion inverters and the system has been re-energized. The PVUSA facility is arranged so that damage would be limited to a few PV panels if a fire were to occur in the remaining inverters because the PVUSA facility is unmanned and not located near inhabited structures. The system continues to provide PV performance information and operational experience.

Lessons Learned

- *Well-planned design and layout can help to limit system damage during component failures* . Due to the remote nature of this installation, undesirable system conditions could exist for a period of time without being noticed. Proper electrical design and system layout can help limit the damage caused during component failure events. While these design features may not keep the system online, they will help to reduce recovery time and cost.
- *Inverter issues continue to be a focus of concern*. As in many of the other projects discussed in this report, the weak link in the PV system seems to be the inverter. Inverters have shorter life spans and are more vulnerable to damage than PV modules.

7
BUILDING INTEGRATED PV SYSTEM AT FORD ISLAND, HAWAII (HECO)

Project Description

A 2-kW building-integrated photovoltaic (BIPV) system was installed on Building 44 of the U.S. Navy's Ford Island Boat House in Pearl Harbor (Oahu, Hawaii). The Ford Island BIPV facility is shown in Figure 7-1. The system was installed under a collaborative project between the Commander Navy Region Hawaii, Hawaiian Electric Company, Inc. (HECO), University of Hawaii at Manoa School of Architecture (UHSOA), and the National Renewable Energy Laboratory (NREL).

Figure 7-1
Ford Island 2-kW BIPV System – Boat House (top photo) and Standing Seam PV Panels on the Roof (bottom photo)

The PV installation at Ford Island serves as a showcase of BIPV technology for future development on the island. In addition, the project supports Executive Order No. 13123, which mandates the examination of renewable energy and reduced energy usage, and the federal Million Solar Roofs Initiative. The project partners benefit by gaining experience with BIPV technology and evaluating the potential of using PV systems mounted on buildings to help meet peak electric demand and energy requirements as an air pollution mitigation strategy.

System Description

The Ford Island BIPV system provides electrical energy to the Navy's distribution system at Pearl Harbor. System characteristics are provided below:

Table 7-1
Characteristics of the Ford Island BIPV System

Location	Building 44 – Boat House, Ford Island, Pearl Harbor, Oahu, Hawaii
Orientation	Fixed, south-facing
Modules	24 Uni-Solar SSR 120 standing seam PV panels (18 feet by 18 inches); thin-film amorphous silicon cells laminated on roofing material; PV panels integrated with 77 MacElroy non-PV standing seam panels (28 feet by 18 inches).
Inverter	Trace Technologies SW4048 4-kW inverter
Installation Date	September 1999
Size	2-kW

The goal of the project was to examine the use of PV systems as structures that are integrated with existing buildings. Installations that utilize BIPV technology have the potential to reduce overall construction costs due to the sharing or displacement of conventional building materials and structures.

Operational History

In August 1997, a grant was awarded by HECO and NREL to the UHSOA to design, procure, and contract the installation of the BIPV system. HECO initiated the facilities use agreement, assisted in project coordination, and provided funds to UHSOA. The Commander of Navy Region Hawaii selected candidate buildings in September 1997 and system design and engineering were completed in January 1998. The BIPV system was installed and began to generate electricity in September 1999.

The PV-generated electricity is provided to the Commander Navy Region Hawaii free of charge. The energy output is roughly 3,150 kWh per year. The equivalent annual emissions reductions are estimated at 6,130 pounds of carbon dioxide and 20 pounds of nitrogen oxides. Approximately 6 barrels of oil equivalent are saved annually.

Project Economics

The costs and funding structure associated with the design and construction of the Ford Island system were as follows:

Table 7-2
Costs and Funding Sources Associated with the Ford Island BIPV System

Project Cost		Funding Sources	
Materials	$23,000	HECO	$77,000
Design, Removal, and Installation	$69,000	NREL	$10,000
		United States Navy	$5,000
Total	**$92,000**	**Total**	**$92,000**

Lessons Learned

- *System integration of BIPV components is not always straightforward*. Integrating the new metal roofing with the existing roof posed design and construction challenges. Uni-Solar could not provide panels long enough to cover the required run of over 26 feet. As a result, overlapped joints on the ends of the panels were needed and additional purlines had to be welded for support. Full-length standing seam panels and non-PV panels were installed in an alternating pattern with the PV panels. In addition, the color of the roofing material needed to match the color of the existing structure, but MacElroy required a minimum order to custom-paint the new roof panels. As a result, about one-third more non-PV roofing panels had to be purchased than were needed. This increased the overall project cost.

8 OVERALL CONCLUSIONS AND RECOMMENDATIONS

The operational experience of the six PV systems studied in this report provides valuable knowledge that can be applied to improve future PV systems. This section of the report focuses on the practical implications of these results and provides recommendations for future PV system applications.

Technical Performance of PV Systems

The system owners were generally happy with the performance of their systems for all the cases studied. While some technical problems were encountered, most of the problems were easily fixed once diagnosed, for example:

- In one case faulty wiring installation resulted in the system string voltage being insufficient for operating the inverter. The issue was remedied by re-wiring the array.
- Some component damage was observed on arrays mounted in windy areas. Gravel roofing seems to be particularly damaging since it can be blown into the PV modules.
- One case demonstrated that system inverters can become overheated. Once diagnosed, this problem was easily remedied by installing external inverter cooling fans to increase airflow over the inverter heat sink. Overheating problems will be more prevalent for components mounted in direct sunlight. System electronics should be mounted in shaded locations or indoors whenever possible.
- Several inverter failures and/or damage in various projects point to the fact that inverters are the weakest link in current PV system technology. In particular, it is important to recognize that the life spans of inverters are shorter than typical PV module life spans.

A more general finding is that the output of most of the PV systems is lower than what was predicted from PV system ratings, even when the obvious effects of inverter problems are taken into account. The lower than predicted output is attributed to effects such as snow cover on some of the systems, unaccounted-for temperature effects on PV module efficiency and system wiring, and inverter losses not factored into the predicted power output calculations. PV system designers need to include additional 5-10% margin 5-10% in PV array capacity to account for these non-ideal conditions.

In general, the systems perform well and the primary barriers to the expansion of use of the grid-connected PV are not technical but cost related. However, there is still room for substantial improvement in the life span and reliability of inverters. In particular, PV system designers should be aiming for inverters that have 20-year life spans.

Economic Performance

The projects considered in this report ranged in capital costs from $7000/kW to $12,000/kW, but $3,000/kW is commonly regarded as an "ignition point" for photovoltaic markets, the point at which PV becomes cost competitive with conventional power in certain higher-value applications. Although there are many incentive and rebate programs available for PV projects, they often aren't enough to lower the system costs to a point where they become competitive strictly on a cents per kilowatt-hour basis. Why, then, are PV systems being installed if they are not cost competitive? The answer lies in a combination of factors that that often work together to make new PV projects attractive.

- *Utility / Public Service Initiated Projects*. The Sacramento Municipal Utility District (SMUD) program in California has been the most visible project initiated by a utility, but many other utilities are actively pursuing the addition of photovoltaic systems in their territories. In fact, most of the cases considered in this report were either initiated or greatly influenced by the local utilities or public service organizations: Hawaiian Electric Company (HECO), Wisconsin Public Service (WPS), Public Service Company of New Mexico (PNM), and the New York Power Authority (NYPA). Direct participation in grid-connected PV projects benefits utilities by building in-house expertise.
- *Government Incentives*. The Solar Electric Power Association (SEPA) sponsored their TEAM-UP projects using Department of Energy funds to subsidize the capital costs of the projects. This project is just one example of the many ways in which the State and federal governments are encouraging the use of photovoltaics. Additional funding comes in the form of rebate incentives based on PV system size, grant programs, tax incentives, and low-interest loans.
- *Ancillary Benefits*. Several of the case studies show that PV systems do more than just generate electricity, particularly when used in a building-integrated approach. For example, the PowerLight tiles used on the Tuckahoe Library not only provide additional insulation to the building but protect the building's roof membrane, thereby extending roof life by a factor of 2 or 3. The PNM photovoltaic parking structure is another example. In that project, the PV array replaces other building materials to provide shade. A similar approach has been used in other projects where PV arrays mounted on buildings reduce air conditioning loads. When combined, the ancillary benefits of a properly designed PV system can equate to a credit of up to 15¢/kWh, which can partially offset the currently high cost of PV.
- *Green Pricing Programs*. These programs demonstrate the some customers are willing to pay a premium to support clean energy sources, and PV is usually their preferred choice. Indeed, PV-based green-pricing programs typically have a waiting list of people who want to join them but cannot because the available capacity has been filled.
- *The Desire to Produce Clean Power*. Small-scale residential PV systems are not usually economically competitive with conventional grid power. However, many residential customers feel that as long as PV for their home is affordable, it is worth the extra expense to produce their own clean power by using photovoltaics.

Many of the projects considered in this report capitalized on a combination of these factors. As an example, consider Cofrin Hall on the University of Wisconsin – Green Bay campus. The BIPV portion of the construction costs were partially funded by Wisconsin Public Service, the

State of Wisconsin's Focus on Energy Program, and the Energy Center of Wisconsin's WisconSUN program. An additional cost offset was achieved by using PV equipment that replaced building materials as when the traditional standing seam metal (SSM) roof was replaced with SSM roofing that incorporated PV. One final factor in the decision to install the PV systems was the Wisconsin Department of Administration – Division of Facilities Development's desire to continue their tradition of environmentally friendly policies by supplying a portion of the building's electrical load with green power.

Impact of Solar Resource on PV Economics

Where the sun provides less light, PV power can be expected to cost more. The capacity factor of a PV system, a measure of solar input, has an inverse impact on the cost of electricity produced by the PV. For similar system designs, PV energy at a location like the Wisconsin case study with a capacity factor of about 12% should cost about 2 times as much as a location like New Mexico where the capacity factor is about 24%. For this reason, it is no surprise that installations in New Mexico and Hawaii with good solar resource profiles are regarded as very successful. What may be surprising is that installations in New York and Wisconsin, areas not known for their solar resources, have also proven successful.

The southwest section of the United States exhibits the best solar profile in the country but that does not mean that other areas are unsuitable for PV use. The northeastern United States generally has higher conventional electricity rates, which partly compensate for the lower capacity factor in that region. As a result, the economics of deploying PV are not necessarily worse in New York than in New Mexico or Arizona. Perhaps, the best combination of high electricity rates and solar resource is found in Hawaii where PV is most likely to be economical before locations in the contiguous 48 states.

Cost of PV Energy

The capital cost of the systems studied were in the range of $7,000-12,000 per kW-ac of capacity —about 2-4 times more expensive than what is needed to be competitive on a direct cost basis in grid-tied situations. Considering the capacity factors of the studied systems and the cost of money and maintenance, PV energy from a $7,000/ kW system would cost at least 33 cents per kilowatt-hour without subsidies. The initial capital cost of PV systems must get to about $3,000 per kW-ac of capacity for energy to be produced at competitive prices. Of course, with subsidies and ancillary benefits from BIPV applications and environmental factors taken into account, PV may be justified at a somewhat higher cost of energy even before it achieves price parity with delivered powered. In the longer term, many PV technology experts predict, and price performance data show, that PV system prices will reach $3,000 per kW-ac by about 2015. Some predict this will happen sooner due to the rapidly advancing PV market.

Utility Interconnection Issues

Relatively few interconnection issues arose in the cases considered for this report. However, it should be noted that many of these PV projects were either utility sponsored or had a significant degree of utility involvement beyond simply permitting of the installation. The most common interconnection related issue expressed by the participants were time delays associated with the application process for placing distributed generation from PV on the local utility's distribution system. This process took longer in the two NYPA cases probably because these were installed in 1995 and 1996, prior to recent developments in interconnection such as the New York State DG interconnection requirements for 300 kW or less generators, the IEEE 929-2000 standard, and the IEEE 1547 standard. With standards like these now in place, the permitting process is now more streamlined in many locations around the country. The two most recent case studies (Cofrin Hall in Wisconsin and the PNM Parking Structure in New Mexico) appeared to have the most streamlined process.

In general, these case studies suggest that utilities are getting more familiar with PV as time goes on and that standardization of the interconnection and improvements in the PV equipment will allow increasingly easier interconnections.

Inverter Concerns

The reliability of the inverters is the primary concern in the design of grid-tied PV systems. Both the Cofrin Hall (WPS) and Maui (HECO) systems exhibited inverter failures, with the Maui failure resulting in a small fire. This is not to say that PV systems are not safe or highly reliable, but the inverters need to be sufficiently sized and protected.

Every connection port to an inverter except fiber optic lines is a potential route of entry for an electrical surge. Inverters are also susceptible to extreme voltage differentials between their various input ports. For these reasons, surge-protection schemes for PV inverters should incorporate the following:

- *Surge suppression on ALL of the inverter ports*. The ac, dc, and communication ports must all have separate surge protection.
- *Protection for voltage differentials between ports*. In addition to providing surge protection for the individual ports, designers must ensure that voltage differentials between the ports are equalized.
- *Metal Oxide Varistor (MOV) protection technology*. Spark gaps are often used to provide lightning protection, but their response characteristics may not be fast enough to protect the inverter from damage during a lightning strike.
- *Lead lengths must be kept as short as possible.* Induction in the leads to the MOV units can create very high voltages due to the fast current rise time associated with most lightning strikes. For this reason, lead lengths should be as short as possible. Lead lengths of several inches are sufficient but lengths approaching a foot or more are unacceptable.

These measures must be viewed objectively. While they add to initial system cost, they will also increase system reliability and save money by preventing costly inverter failures.

Overall Recommendations

The PV industry has grown over 30% per year recently and will most likely exhibit similar growth in the near future. While there is no question that PV is gaining popularity, more can still be done to educate people on the benefits of PV. At the same time, costs can be lowered to make grid-connected photovoltaic systems more affordable.

- *Continue educational efforts.* Projects such as Cofrin Hall (WPS) and the photovoltaic parking structure (PNM) that incorporate information kiosks are crucial to educating the public on the benefits of grid-tied PV. These projects give grid-tied PV systems a high profile and allow the public to see PV in action while also helping to dispel some of the myths about the reliability or complexity of PV systems.
- *Utilize "cookie cutter" designs and large volume purchases*. PNM had great success using a mature standardized system with a proven design. Coupling the strong track record of these types of systems with the economic benefits of large volume purchasing can be an effective tool for lowering system costs.
- *Capitalize on the advances in BIPV technology*. Products are now available that allow PV systems to be integrated into a building's structure as never before. The combination of PV performance, ancillary benefits, and aesthetics associated with these new products imparts some system cost savings while still using very high-quality components.
- *Pay close attention to inverter protection*. Inverters remain one of the most vulnerable and least reliable components of PV systems. Close attention to inverter protection will add reliability to the system.
- *Continue working towards standard test plans and interconnection agreements.* The amount of time and effort required to gain utility approval for interconnection remains a stumbling block for both commercial and residential customers who wish to utilize PV systems. Streamlining the interconnection process and adopting standard test plans will help to increase the number of PV systems in operation. A nation-wide set of interconnection criteria and test standards would be ideal. IEEE P1547 makes a good first step towards this goal, but there is still more work to be done.

Target:

Renewable Technology Options & Green Power Marketing

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