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Stand-Alone Photovoltaic
Lighting Systems
A Decision-Maker's Guide

Volume 3: Technical
Specifications and Case
Studies

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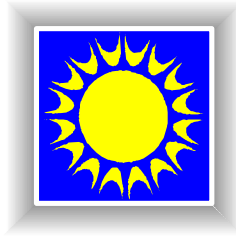
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STAND-ALONE PHOTOVOLTAIC LIGHTING SYSTEMS

A Decision-Maker's Guide

Volume 3: Technical Specifications and Case Studies



Prepared for:

Florida Energy Office / Department of Community Affairs

By:

Florida Solar Energy Center

First Edition September 1998

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Abstract

This document provides considerations for developing PV lighting system technical specifications and includes suggestions for top-level functional requirements and equipment specifications. Case studies of two PV lighting projects are also presented as an example of specific system requirements. This information is intended to help prospective buyers of PV lighting equipment establish their requirements and to help ensure that system suppliers have a clear understanding of customer expectations.

Preface

This document is one of four topical reports on stand-alone photovoltaic (PV) lighting systems. The information is based on current state-of-the-art understanding, and is intended for those individuals and organizations evaluating the potential of using PV systems for a number of lighting applications. These documents may also be useful to PV lighting system suppliers, by helping educate prospective customers in the process of identifying and implementing practical and cost-effective PV lighting solutions.

Principal target groups for this document include:

- Federal, state and local government agencies
- Transportation and navigational authorities
- Planners, developers and builders
- Electric utilities
- Consumers and homeowners
- Emergency management officials
- Development and conservation organizations
- PV lighting system manufacturers and suppliers

The information presented in this set of topical reports provides an overview of PV lighting systems from a technical perspective. The content covers considerations for evaluating the feasibility of PV lighting applications, PV lighting components and system design, developing technical project specifications, and fundamentals of lighting design and lighting equipment. At the end of each report, sources for PV lighting equipment and a reference list are provided.

The four documents in this set of topical reports are:

- Volume 1: Photovoltaic Lighting Applications
- Volume 2: PV Lighting Components and System Design
- Volume 3: Technical Specifications and Case Studies
- Volume 4: Lighting Fundamentals and Equipment

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1. INTRODUCTION

“How do we cost-effectively provide power to our lighting needs in cases where utility power is not practical or available?”

This question is asked by many public and private concerns, including facilities managers, municipal planners and developers, navigation and transportation authorities, outdoor advertisers, utilities, contractors and property owners. For many, **solar photovoltaic (PV)** lighting systems have provided a practical and cost-effective solution for powering a diversity of lighting applications.

Thousands of PV lighting systems are being installed annually throughout the world, including applications for remote area lighting, sign lighting, flashing and signaling systems, consumer devices and for home lighting systems. PV lighting systems are simple, easy to install, and if properly designed and maintained, can provide years of exceptional service.



1.1 Advance Organizer for PV Lighting Systems

Figure 1-1 shows an **“advanced organizer”** for stand-alone PV lighting systems. This simplified diagram is intended to organize the reader’s thinking about the major components and interactions in stand-alone PV lighting systems.

In typical PV lighting systems, the light source is powered by a battery, which is recharged during the day by direct-current (DC) electricity produced by the PV array. Electronic controls are used between the battery, light source and PV array to protect the battery from overcharge and overdischarge, and to control the timing and operation of the light.

In a basic way, these systems operate like a bank account. Withdrawals from the battery to power the light source must be compensated for by commensurate deposits of energy from the PV array. As long as the system is designed so that deposits exceed withdrawals on an average daily basis during the critical design period, the battery remains charged and the light source is reliably powered.

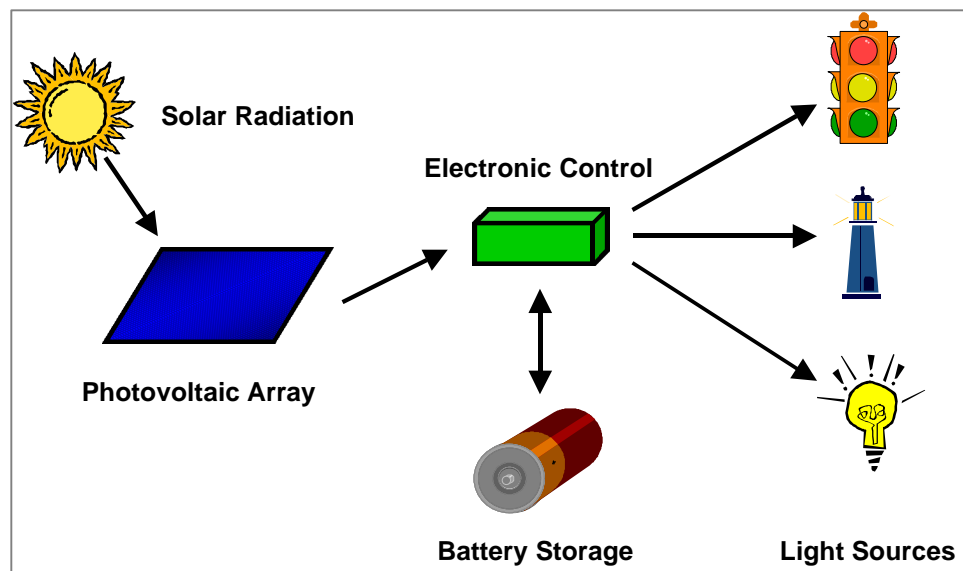


Figure 1-1. PV lighting system advance organizer.

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2. Developing Technical Specifications for PV Lighting Systems

This section presents guidelines for the specification and procurement of PV lighting systems and equipment. These guidelines are intended to help both buyers of PV lighting equipment as well as those supplying systems and equipment.

A well-written specification for a PV lighting project helps ensure the buyer purchases the equipment they need, and gives the system supplier a clear understanding of customer expectations. Depending on the lighting application, these project specifications will include a combination of design and performance-based requirements. In all cases, PV lighting specifications should include the primary functional and operational requirements for the end-use product – the quantity and quality of lighting provided by the systems. The following provides an overview of issues to consider in specifying PV lighting systems and equipment.

The Buyer Should Provide the Following Information

- Specification of system functional, operational and performance requirements
- Magnitude, duration, variation and critical nature of lighting application
- Applicable codes, standards, permits, qualifications and other requirements
- Autonomy or battery storage capacity
- Auxiliary systems, controls and backup provisions
- Site-specific information, data and other requirements.

The Buyer Should Insist on the Following

- Photometric data for lighting fixtures and overall design
- System and component warranty information
- System and component specifications (parts lists and product literature)
- Electrical and mechanical drawings
- Operation, maintenance and diagnostic procedures
- Service, repair and safety information
- User/operator training
- Acceptance tests to verify delivered system meets specified performance
- Complete documentation package including all of the above information.

2.1 What Should the Buyer Consider?

Once a decision has been made to pursue a PV lighting application, the buyer must establish project constraints and tradeoffs. The constraints establish necessary and essential criteria for the project such as budget, schedule, and performance. Tradeoffs are variables that allow flexibility in the design and performance of the systems.

2.1.1 What are the Project Constraints?

- What are the maximum initial and life cycle target costs for the lighting project?
- What is the projected schedule and what are the target dates for procurements and completing the installation?
- What are the requirements for minimum light levels, time of operation, availability or other factors?
- Are there any regulatory requirements such as product listings or approvals, contractor licensing, permitting or inspections that are required for the project?

2.1.2 Consider Key Tradeoffs

The size and costs of PV lighting equipment for a given light application are directly related to the energy required for light, in other words the amount of illumination and the time of operation required. For this reason, the buyer may want to:

- Consider automatically controlling the light operation (duty cycle) based on time of day, time of operation, time after dusk, or occupancy (presence) sensing.
- Consider alternative designs and configurations for array mounting, type, height and installation requirements for light poles, location and accessibility to battery/control enclosures.
- Consider initial versus life cycle cost tradeoffs such as the system sizing (size of battery/autonomy period, array to load ratio), and the quality, expected life, warranties and maintenance requirements for individual components.

2.1.3 Provide Site-Specific Information

The buyer should provide as many details as possible about the site and prevailing conditions, to ensure the designs offered by system suppliers meet or exceed performance and reliability expectations. Site specific information includes but is not limited to:

- Description and/or drawings of the site identifying the area to be illuminated, suggested/required lighting fixture locations, elevations, soil conditions, and the potential for flooding.
- Meteorological conditions at the site, including temperatures, wind speeds, humidity and solar radiation data.
- Solar exposure at the site and any particular shading concerns such as tall trees or nearby buildings.
- Establishing the potential risk of vandalism, theft, and personal injury.
- Any special installation concerns such as limited site access or preparation requirements.

2.1.4 Establish Proposal Requirements

Bid specifications should clearly indicate the requirements for responsive proposals. In addition to the total price, the buyer should include additional proposal requirements that help in selecting the most qualified response. Proposal requirements may include:

- Experience, qualifications and capabilities of system supplier
- Field experience and reliability of the same or similar designs
- Total price and schedule
- Electrical and mechanical drawings
- Product literature and specifications for major system components
- Lighting system layout and illuminance calculations
- System sizing and design computations.

2.2 Top-Level Functional and Operational Requirements

Top-level requirements are those specifications that deal primarily with the overall function and operational performance of the PV lighting systems. Top-level functional and operational requirements include:

- Lighting quantity and quality requirements
- Lighting time of use requirements
- System maintenance requirements
- System and component cycle life requirements.

2.2.1 Specifying the Quantity and Quality of Lighting

The quantity and quality of light should always be specified and are key to achieving the visual acuity requirements for the lighting application. Generally, these requirements are related to some established standard or recommended practice for the given lighting application. For area and sign lighting applications, the lighting requirement is usually based on minimum and average illuminance levels, not to exceed a limit of average to minimum illuminance ratio (uniformity) over a certain surface area. For flashing and signaling devices and internally illuminated signs, the lighting requirement is usually based on the luminance (brightness) of the device, as observed at a specified distance, and the contrast between the device and the background. In addition to uniformity or contrast, other light quality features such as color, luminaire distribution type and glare reduction may be specified. The buyer should request photometric information from the system supplier for individual systems as well as the overall photometrics where more than one individual system is required for the application.

2.2.2 Specifying the Light Operation Time

The required light operation time can be prescribed by the total hours per night, number of hours after dusk, or dusk to dawn operation. Other variations may include specifying a lower number of operational lamps or illumination levels after a certain time each night, or using other automatic or manual controls to operate the light. Note that the nightly hours for dusk-dawn operation vary seasonally, especially at higher latitudes. Manual control presents the greatest uncertainty about the energy requirement for the lights.

2.2.3 Specifying System Maintenance and Life Cycle Requirements

In general, PV lighting systems should require little maintenance except for simple replacement of lamps, ballasts and batteries at projected intervals. Any required maintenance and replacements should be specified or requested from the system supplier. With the exception of batteries, a complete inventory of spare parts may be specified for expected or required replacements. In the absence of qualified, on-site personnel, a service contract may also be established between the system supplier, installer or a local contractor. The buyer will also want to ensure that the specified light output is maintained over time and under the range of operating conditions experienced at the site, such as high or low temperature, factoring in lamp lumen depreciation and dirt accumulation in and on the fixture.

2.3 Equipment Specifications

2.3.1 Request System and Component Warranties

To help ensure long-term reliability, the buyer should insist on both system and component warranty information from the supplier. The methods for implementing a warranty provision should be clearly established and handled by the system supplier (or local designee) as the single point-of-contact for warranty service. The buyer may also specify certain warranty requirements beyond the typical conditions offered by the system supplier. These issues may be negotiated in the contract for purchase.

System-level warranties include assurances for the specified performance and operation of the overall system. Complete system-level warranties are usually for a shorter period (one to three years) than individual component warranties. Warranties for individual components (PV modules, batteries and lights) are generally based on maintaining a certain percentage of initial rated performance. For example, performance warranties on PV modules may be for no more than twenty percent power output degradation over twenty-five years. Battery performance warranties will be tied closely to the operating regimes, temperatures and maintenance, and may be expressed in terms of maintaining a certain percentage of initial rated capacity over a period of years.

PV lighting system warranties should consider:

- Complete system-level warranty for the no-cost replacement of defective components for a nominal period.
- Individual warranties for major system components such as PV modules, batteries, lamps, ballasts, and controls.
- Extended warranty or service contract beyond baseline warranties offered by the system supplier.

2.3.2 Specifying Luminaires (Lamps, Ballasts and Fixtures)

Issues to consider when specifying luminaires include:

- Proper candlepower distribution for the intended application
- Efficiency of converting electrical power to light output
- Equipment listing and outdoor rating
- Mechanical design, construction and use of materials
- Ease of lamp and ballast replacement
- Aesthetic appearance
- Cost and reliability.

2.3.3 Specifying Photovoltaic Modules and Array

Any type of PV module is generally acceptable for PV lighting systems. However, for many applications, array surface area must be limited due to mechanical and wind load constraints, especially if the arrays are mounted to light poles. In these cases, higher efficiency modules may be desirable to minimize array area requirements. The PV module/array may be integrated in the light fixture for small systems, installed on a pole mount for area lighting applications, or mounted to the ground, a roof or independent structure for larger systems.

Issues to consider when specifying modules and arrays for PV lighting systems include:

- Preferred cell technology (e.g., crystalline, thin-film, etc.)
- Electrical performance (rated, guaranteed output)
- Physical properties (e.g., size, weight)
- Mechanical properties (construction materials, mounting attachment, etc.)
- Reliability (qualification tests, UL listing)
- Efficiency and surface area requirements for the array
- Cost, lifetime and warranty.

2.3.4 Specifying Batteries

Certain battery designs are more suitable for the operating conditions found in PV lighting systems. However, the ultimate selection of batteries involves many application-specific tradeoffs including:

- Preferred battery technology (e.g., flooded lead-acid, gelled, AGM, etc.)
- Performance (capacity, voltage)
- Lifetime (cycles, years to certain average daily depth of discharge)
- Physical characteristics (size, weight, case)
- Electrical configuration (series, parallel arrangement)
- Maintenance requirements (testing, cleaning, water additions)
- Costs (initial and replacements)
- Availability.

2.3.5 Specifying System Control Requirements

The following control requirements should be considered in specifying or selecting controllers for PV lighting applications:

- Nominal system operating voltage (12, 24 or 48 volts DC)
- Maximum PV array and lighting load currents
- Battery characteristics (charging requirements, allowable depth of discharge)
- Regulation and load disconnect set point requirements
- Charge algorithms and switching element
- Lighting load control strategies and thresholds
- Battery charge voltage temperature compensation (on board or external probe)
- Expected environmental operating conditions and appropriate mechanical packaging
- Availability of system status indicators
- Availability of battery overcurrent and disconnect provisions
- Overall compatibility with system functional requirements and other components
- Cost and warranty.

2.3.6 Specifying Spare Parts Requirements

Spare parts may be requested with system procurement, or sources for the equipment should be identified. Examples of spare components that may be provided with the system include lamps, ballasts, fuses, and spare PV modules. Batteries are not suitable items for spare parts inventories.

2.4 Specifying Electrical Design Requirements

Safe and reliable electrical practices should be adhered to in the design and installation of any PV lighting system. For most applications, the National Electrical Code (NEC) establishes the minimum electrical design and safety requirements for PV lighting systems. A good system electrical design not only ensures safety but can also improve the reliability of the system performance.

Examples of electrical design requirements include:

- Specifications requiring the use of approved or listed equipment for the intended application.
- Specifications for the types, sizes and ratings of conductors based on location, temperature, ampacity and voltage drop.
- Specifications and appropriate ratings for required disconnect and overcurrent protection devices such as switches, fuses and circuit breakers. In all cases, some means of isolating the battery should be provided.
- Specifications for electrical system grounding and surge suppression. All PV systems, regardless of operating voltage, must have an equipment ground connecting the exposed metal frames and enclosures to earth. For systems operating above 50 volts, the NEC requires that a current carrying conductor in the electrical circuit be grounded. Surge suppression may be specified to provide some level of lightning protection for ballasts, controllers and other sensitive system components.

2.5 Specifying Mechanical Design Requirements

Mechanical design specifications for stand-alone PV lighting systems should typically require:

- Calculation of structural loads
- Compliance with applicable standards and building/structural codes
- Use of appropriate and compatible materials to avoid degradation
- Use of appropriate enclosures for batteries, controls and lighting equipment to protect from the elements and to minimize temperature high/low temperatures
- Ease of installation and access for maintenance
- Optimum array mounting design and orientation to improve thermal performance, to gain maximum solar exposure and to avoid shading of the array
- Aesthetics and architectural compatibility of the complete installation
- System design that offers low risk for vandalism, theft and personal injury
- Tradeoffs to reduce first and life-cycle costs.

2.6 Specifying System Documentation Requirements

To ensure long-term system performance and reliability of PV systems, it is essential that the system supplier provide a complete documentation package to the buyer. As a new technology, maintenance personnel are often not as familiar with PV lighting systems as they are with common, conventional equipment.

At a minimum, the following items should be required as part of the system documentation package.

- Component and system specifications, part lists
- Electrical and mechanical drawings
- Description and requirements for operation, maintenance, diagnostics and safety
- Acceptance test procedures.

3. PV Lighting Project Case Studies

This section presents case studies of two PV lighting projects. The first case study is for PV area lighting systems installed at the Martin Luther King, Jr. National Historic Site in Atlanta, Georgia. The second case study is a PV-powered overhead highway guide sign lighting system operated by the Florida Department of Transportation near Orlando, Florida. These case studies are intended to provide an example of the specifications and design considerations for two popular PV lighting applications.

3.1 PV Area Lighting for the Martin Luther King, Jr. National Historic Site

This case study presents an example of specifications used in the procurement of 65 PV lighting systems that were installed at the Martin Luther King, Jr. National Historic Site in Atlanta, Georgia in June 1996 (Figure 3-1). The specific application was to provide PV-powered lighting for a six-acre parking area, meeting certain illumination levels with an aesthetically pleasing and architecturally compatible design. This section provides an overview of the project requirements, specifications and resulting hardware.



Figure 3-1. PV lighting at MLK, Jr. National Historic Site.

3.1.1 Project Requirements

- Design and size photovoltaic-powered outdoor lighting systems
- Specify layout of the systems in parking area
- Deliver, assemble and install the systems
- Provide appropriate documentation
- Provide on-site technical assistance and user training during acceptance testing
- Meet or exceed the lighting requirements
- Require no regular maintenance except for periodic replacement of lamps and batteries
- Reduce the risk of vandalism, theft and personal injury
- Make the design and layout aesthetically pleasing.

3.1.1.1 Hardware and Documentation Required

- Complete photovoltaic-powered outdoor lighting systems
- Spare parts: 1 module, 2 controllers, 2 lamps and ballasts and 1 luminaire (per 20 systems):
- Parts, materials, and source lists
- Assembly, installation and checkout instructions
- Operation and maintenance manual
- Electrical and mechanical drawings
- Product literature and specifications for major components.

3.1.1.2 Illumination Requirements

- A minimum illuminance of 0.4 footcandle is required
- A uniformity ratio (average to minimum illuminance) of 4:1 should not be exceeded.

3.1.1.3 Site Conditions

- The total area to be illuminated is approximately six acres
- Solar access is good except near buildings in the southeast corner of the parking area
- No shading from trees or vegetation is expected above 20 feet
- December should be used as the design month for all array tilt angles
- NREL solar radiation data for Atlanta, Georgia should be used for sizing the systems
- Risk of vandalism, theft and personal injury in a high crime area.

3.1.1.4 Schedule

- Installation and operation must be complete before the summer Olympics.
- Contractor must coordinate schedule with the National Park Service.

3.1.1.5 Warranties Required

- Three-year limited warranty on systems
- Spare parts supply replenished at end of warranty period
- Two-year, no-cost replacement warranty on batteries
- Ten-year unlimited manufacturer's warranty on modules.

3.1.2 *Equipment Specifications*

3.1.2.1 Fixture, Pole and Lamp

- Olympic design and architectural requirements require pre-approved design. Bidders should factor these special design requirements in their proposals.
- Lighting fixtures and PV arrays should be mechanically integrated on the pole, at a height no lower than 20 feet above grade.
- Fluorescent, high-pressure sodium and metal halide lamps are acceptable.
- Polarized connections on ballasts required.

3.1.2.2 Photovoltaic Modules and Array

- Photovoltaic modules must be UL-listed or meet or exceed the latest draft qualifications standard.
- Crystalline or polycrystalline silicon cells are preferred but not required.
- Flat-plate arrays are required.
- No restrictions are placed on the array tilt angle.

3.1.3 Batteries and Charge Control

- Sealed, maintenance-free batteries are required.
- Batteries must be properly matched with charge controllers.
- All batteries (and lamps) will typically be replaced at the same time.
- Battery subsystems are required to provide five days of autonomous operation.
- Battery enclosures should be designed to minimize large internal temperature swings.
- Battery subsystem design and location should minimize the risk of vandalism, theft and personal injury.
- The preferred location for the battery subsystem is either high on the pole or below ground level.
- Charge controllers are required and must be properly matched with batteries.
- Proposals must include manufacturer, model number, charging algorithm and set points.
- Proposals which do not clearly indicate proper matching of charge controllers and batteries will be rejected.

3.1.4 Lighting Operation and Control Requirements

- Systems should be adequately sized to operate the lights for a minimum of eight hours after dusk year round.
- The on-off lighting control algorithm must be specified, and a procedure for changing the duty cycle must be provided.
- Provision for turning the lights on during the day must be provided for maintenance and check out.

3.1.5 System Sizing, Lighting Design and Photometric Calculations

- PV system sizing computations and methodology must be provided. These computations will be reviewed and verified to help ensure that the systems are properly sized.
- Proposals must specify the entire lighting system layout, including the locations and number of fixtures (systems), and fixture mounting height.
- Illuminance predictions must be provided for a single fixture as well as the entire lighting system design.
- Some bidders may be asked to verify photometric data. The costs for performance verification via testing should be included in the project budget.

3.1.6 Electrical and Mechanical Design

- Designs must comply with all applicable sections of the National Electrical Code.
- Voltage drops between array, battery and ballasts should be less than four percent.
- Provision for isolating the battery subsystem must be provided.
- Electrical components must be dc-rated, labeled and accessible.
- Metal module frames, poles, supports and enclosures must be properly grounded.
- Mechanical loads due to the weight of the array, wind forces on the array, the array attachment to the poles and the footings for the poles should be computed using ANSI/ASCE 7-93.
- Direct contact between dissimilar metals must be avoided.
- Untreated wood, common steel and corrosion/weather susceptible materials will not be accepted.

3.1.7 Acceptance Testing, Performance Monitoring and User Training

- A third-party agent (to be selected by buyer) will conduct acceptance testing to ensure that project specifications have been met.
- Measurements will include array performance, verification of proper charge control operation and light control function, and ground-level illuminance.
- Selected systems will be monitored for at least one year to document performance.
- The contractor is required to provide eight hours of training to National Park Service.
- Topics will include component descriptions and specifications, theory of operation, maintenance requirements and schedule, instrumentation and test points, diagnostics and troubleshooting, safety precautions and record keeping.

3.1.8 Proposal Requirements and Award Criteria

At a minimum, each proposal shall include:

- Total price
- Complete design and system sizing calculations
- Electrical and mechanical drawings
- Product literature and specifications for major system components
- Illuminance calculations for single fixture and entire layout
- Bidder capability information - experience and qualifications, field experience and references
- Proposed schedule for complete design, installation and training.

Evaluation criteria for proposals shall be weighted according to:

- Quality of the design in meeting the performance requirements and in reducing the risk of vandalism, theft, and personal injury (20%)
- Prospects for minimizing maintenance and maximizing reliability (20%)
- Total price (20%)
- Capability of the bidder to satisfactorily implement the project (20%)
- Aesthetics (20%).

3.1.9 Design Summary

Table 1 on the following page summarizes the system sizing and components delivered for the PV lighting systems at Martin Luther King, Jr. National Historic Site.

Table 1. Design Summary for MLK PV Lighting System.

MLK PV Lighting System Summary	
Location	Atlanta, Georgia 33° N
Design Month	December
Design Insolation	3.7 kWh/m ² /day, south-facing 45° tilt surface
LOAD	
System, Load Voltage	24-volts DC
Lighting Load	36-watt compact fluorescent fixtures, 2 per system, 1.5 amps each, 3 amps total load
Time of Operation	8 hours after dusk each night, year round
Average Daily Load	24 amp-hours at 24-volts DC
BATTERY	
Battery Bank	Deka Gel-Tech gelled lead-acid: 6-volt, 190 amp-hour (4 in series)
Rated Battery Capacity	190 amp-hours at 24 volts, C/20 rate, 25 °C
Average Daily DOD	12.6 percent
Maximum DOD	80 percent
Maximum Charge/Discharge Rates	Discharge rate C/60, maximum charge rate C/22
Autonomy Period	5 days
PV	
PV Module and Array	ASE-50-AL/16: Imp = 2.8 amps @ STC (2 series x 3 parallel)
Array Rating	8.4 Imp @ STC
Array Design Month Output	31 amp-hours per day
Minimum PV to Load Ah Ratio	1.3 (December)

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3.2 PV-Powered Highway Guide Sign Lighting System

In 1987, the Florida Solar Energy Center and the Florida Department of Transportation designed and installed a PV-powered lighting system for an overhead highway guide sign, shown in Figure 3-2. Located on a remote stretch of highway, this site is located several miles from the nearest utility service, making the cost of grid extension cost-prohibitive. One of the first few systems of this type to be installed in the U.S., this project illustrates many of the considerations in the specification and design of PV lighting systems.



Figure 3-2. PV-powered highway guide sign lighting system.

The following presents an overview of the project, including the selection of a light source, system sizing, and electrical and mechanical design considerations.

3.2.1 Characterization of Light Sources and Load Assessment

The first objective in the design process was to select the most efficient lighting system meeting the overall sign illumination requirements. Recommended levels of luminance and illuminance for overhead highway guide signs are given below in Table 2 for low, medium and high ambient light area [ref]. To achieve acceptable contrast with the surrounding background, higher lighting levels are required for signs located in high ambient light areas. For this application, the low ambient light requirements apply.

Table 2. Recommended Luminance and Illuminance Levels for Highway Signs.

Ambient Light	Low	Medium	High
Luminance (fl)	7-14	14-28	28-56
Illuminance (fc)	10-20	20-40	40-80

Further lighting design guidelines include maintaining a uniformity of illuminance of no higher than 6:1 over the sign face, with a ratio of 4:1 desirable. The selected light source should adequately illuminate and preserve the colors on the sign, and should not shadow or obstruct the motorist's view of the sign message. Spill light should be minimized to reduce glare and luminaires should be installed with maintenance considerations in mind.

Photometrics and electrical power consumption were measured at several guide sign locations in the field, as well as for a number of representative luminaires in the laboratory to characterize the light sources being considered. A number of high-pressure sodium, fluorescent and mercury-vapor lighting systems were evaluated. The final choice was a 32-watt T-8 fluorescent lamp based on energy efficiency, availability, ballast requirements, lifetime and cost. Six of these light fixtures were required to meet the minimum required illumination and uniformity levels.



Figure 3-3. Photometric measurements.

3.2.2 Sizing and Load Analysis

After the light source had been selected, the second objective was to develop the load profile and size the battery and PV array accordingly. Since the light was required to operate all night, December was defined as the critical design period. Using the equations presented earlier, the nightly light operation time was determined to be 13.4 hours. Using the peak load of 9 amps (at 24 volts DC) for all six luminaires, the total daily load during the critical design period was calculated to be 120 amp-hours per day. The battery selected for this application was a deep-cycle design, so we used 80 percent as the allowable maximum depth of discharge limit. The desired autonomy period was seven days.

Table 3 on the following page shows the results of the system sizing process and component requirements for the PV-powered highway sign lighting system.

Table 3. Sizing Example for PV Highway Sign Lighting System

PV Guide Sign Lighting System Sizing Worksheet	
Application: Highway Guide Sign Lighting System	
Location: Orlando, Florida	
Latitude: 28.5° N	
Electrical Load Estimation	
A1: Total Load DC Current Requirement (amps)	9
A2: Average Daily Load Usage, Design Month (hours)	13.4
A3: Average Daily Load Energy Requirement, Design Month = A1 x A2 (amp-hours)	120
A4: Nominal Load (System) DC Voltage (volts)	24
A5: Maximum Load DC Current (amps)	9
Battery Sizing	
B1: Autonomy Period, Days of Storage (days)	7
B2: Allowable Maximum Depth of Discharge (decimal)	0.8
B3: Minimum Battery Operating Temperature (°C)	0
B4: Battery Capacity Temperature Derating Factor (decimal)	0.8
B5: Required Battery Capacity = (A3 x B1) / (B2 x B4) (amp-hours)	1312
B6: Nominal Capacity of Selected Battery (amp-hours)	1350
B7: Nominal Voltage of Selected Battery (volts)	2
B8: Number of Batteries Required in Series = A4 / B7 (#)	12
B9: Number of Batteries Required in Parallel = B5 / B6 rounded up to next integer (#)	(0.97) 1
B10: Total Number of Batteries Required = B8 x B9 (#)	12
B11: Total Battery Capacity = B9 x B6 (amp-hours)	1350
B12: Battery Average Daily Depth of Discharge = (A3 *100) / B11 (%)	8.9
B13: Battery Maximum Discharge Rate = B11 / A5 (hours)	150
PV Array Sizing	
C1: Design Month	December
C2: Design Month Insolation (kWh/m ² /day)	4.03
C3: Optimal Array Tilt Angle to Maximize Insolation to Load Ratio during Design Month (degrees)	45
C4: Design Month Average Daily Load Requirement (amp-hours)	120
C5: Load Adjustment Factor for System Inefficiencies (decimal)	0.85
C6: Adjusted Design Month Average Daily Load = C4 / C5 (amp-hours)	141
C7: Selected Module Maximum Power Current Output at STC, Imp (amps)	3.5
C8: Module Output Derating Factor (decimal)	0.9
C9: Adjusted Module Maximum Power Current Output = C7 x C8 (amps)	3.15
C10: Selected Module Maximum Power Voltage at STC, Vmp (volts)	17.4
C11: Module Voltage Temperature Derating Factor (decimal)	0.85
C12: Temperature Derated Module Maximum Power Voltage = C10 x C11 (volts)	14.8
C10: Module Daily Output = C2 x C9 (amp-hours)	12.7
C11: Number of Parallel Modules Required = C6 / C10 rounded up to next integer (#)	(11.1) 12
C12: Number of Series Modules Required = A4 / C12 rounded up to next integer (#)	(1.62) 2
C13: Total Number of PV Modules Required = C11 x C12 (#)	24
C14: Nominal Rated PV Module Output (watts)	60
C15: Nominal Array Rated Output = C14 x C13 (watts)	1440
Sizing Summary	
Lighting Load (Ah/day)	120
Design Autonomy Period (days)	7
Selected Battery Series/Parallel Configuration (S x P)	1 x 12
Total Number of Selected Batteries (#)	12
Battery Storage Capacity (Ah)	1350
Allowable Depth of Discharge Limit (%)	80
Average Daily Depth of Discharge (%)	8.9
Selected Module Series/Parallel Configuration (S x P)	2 x 12
Total Number of Selected Modules (#)	24
Estimated PV to Load Ah Ratio for Design Month = (C7 x C11 x C2) / C4	1.41

3.2.3 Electrical Design

The electrical design of the PV lighting system included selection of appropriate wire types and sizes, and selection and location of overcurrent protection, disconnect devices, surge protection and grounding.

Due to the long wire runs from the array to the battery and from the battery to the lights, special attention was given to select wire sizes to limit the overall voltage drop to less than four percent. Each of the 12 two module series strings and each of the six luminaires were wired separately to minimize the wire sizes required and to allow for easier troubleshooting. Each two-module sub-array was terminated at a junction box through a fuse and blocking diode and connected in parallel with the other sub-arrays. Fused disconnect switches were installed at the system controller connections to the PV array, battery and lighting load. Figure 3-5 shows the control room housing the batteries, combiner boxes, disconnects and system controller.

The control design for the system includes battery overcharge and over discharge protection, and dusk to dawn lighting control. System status indicators on the controller provide active operational mode, and a digital display reads battery voltage, and battery, PV array and load currents.

3.2.4 Mechanical Design

The battery bank, combiner box and control components were located in a monolithic concrete equipment enclosure at the south base of the sign structure. Existing techniques employed for luminaire mounting were used to facilitate lamp and ballast replacements.

In order to reduce the potential for vandalism and shading, the array was mounted on top of the sign structure. This required special considerations for wind loading effects on the structure. To minimize this load, it was desirable to locate the arrays as close to the ends of the structure as possible without introducing any shading problems between arrays. With the given dimensions and tilt angle of the array mounting assemblies, a spacing of 80 inches was required between sub-arrays to prevent shading in the winter months. Figure 3-4 shows the array mounting design.



Figure 3-5. Guide sign lighting battery and control room.



Figure 3-4. Array mounting design.

3.2.5 Economic Analysis

During the initial phases of the project, the cost of utility service extension was explored. In general, if the utility can expect a 15 percent rate of return on their investment in extending utility service, the extension is done at no charge to the customer. For this site, a budgetary estimate was obtained for overhead 7,620-volt service at \$9,000 per mile, or a total of \$45,000 for five miles. The alternatives were to use a generator or design a PV system to light the signs.

To compare the economics of the PV system, utility service extension and generator, a simple economic procedure was used assuming a 30-year PV system lifetime and expected replacement intervals for the battery and luminaires. The initial cost for the PV system was approximately \$20,000, including the PV array, batteries, system controller, luminaires, mechanical components and labor. Nominal costs and replacement intervals were obtained for typical 300-watt gasoline-fueled generators. Table 4 summarizes the results of the economic analysis.

Table 4. PV guide sign economic comparisons.

Power Option	Present Life Cycle Cost	Present Cost per kWh	Initial Cost
PV	\$ 20,590	\$ 0.60	\$ 20,000
Generator	\$ 20,340	\$ 0.60	\$ 300
Utility	\$ 47,927	\$ 1.40	\$ 45,000

While the PV and generator systems appear competitive based on the assumptions made for this analysis, in application it is expected the PV system will require less attention and have higher reliability than a generator system. Utility extension costs are obviously prohibitive when compared with the PV and generator options.

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4. Sources for PV Lighting Systems and Equipment

The following lists suppliers of PV lighting systems and equipment. This list is not comprehensive, and appearance of any company on this list does not imply endorsement or approval by the author nor by the Florida Solar Energy Center.

Effective September 1998

Advanced Energy Systems, Inc.
9 Cardinal Dr.
Longwood, FL 32779 USA
Phone: (407) 333-3325
Fax: (407) 333-4341
magicpwr@magicnet.net
<http://www.advancednrg.com/>

ALTEN srl
Via della Tecnica 57/B4
40068 S. Lazzaro di Savena
Bologna, Italy
Tel: 39 51 6258396
Fax: 39 51 6258398
alten@mbox.vol.it
<http://www.bo.cna.it/cermac/alti.htm>

Alternative Energy Engineering
1155 Redway Drive - Box 339
Redway, CA 95560, USA
Tel: (707) 923-2277
Fax: (707) 923-3009
energy@alt-energy.com
<http://www.alt-energy.com/>

Applied Power Corporation
1210 Homann Drive SE
Lacey, WA 98503, USA
Tel: (360) 438-2110
Fax: (360) 438-2115
info@appliedpower.com
<http://www.appliedpower.com/>

Ascension Technology
235 Bear Hill Road
Waltham, MA 02451 USA
Tel: (781) 890-8844
Fax: (781) 890-2050
info@ascensiontech.com
<http://www.ascensiontech.com/>

Atlantic Solar Products, Inc.
P.O. Box 70060
Baltimore, MD 21237 USA
Tel: (410) 686-2500
Fax: (410) 686-6221
mail@atlanticsolar.com
<http://www.atlanticsolar.com/>

BP Solar, Inc.
2300 N. Watney Way
Fairfield, CA 94533 USA
Tel: (707) 428-7800
Fax: (707) 428-7878
solarusa@bp.com
<http://www.bp.com/bpsolar/>

C-RAN Corp.
699 4th Street, N.W.
Largo, FL 34640-2439 USA
Tel: (813) 585-3850
Fax: (813) 586-1777
<http://www.scild.com/web/cran/>

Cornette and Co.
P.O. Box 3443
Tampa, FL 33601-3443 USA
Tel: (813) 251-5915

Eco-Wise
110 W. Elizabeth
Austin, TX 78704
Tel: (512) 326-4474
eco@ecowise.com
<http://www.ecowise.com/>

Energy Conservation Services of
North Florida
6120 SW 13th Street
Gainesville, FL 32608 USA
Tel: (352) 377-8866
Fax: (352) 338-0056

Electro Solar Products, Inc.
502 Ives Place
Pensacola, FL 32514 USA
Tel: (850) 479-2191
Fax: (850) 857-0070
espsolar@cheney.net
<http://scooby.cheney.net/~espsolar/>

Golden Genesis (Photocomm)
7812 Acoma Drive
Scottsdale, AZ 85260 USA
Tel: (602) 948-8003
Fax: (602) 951-4381
info@goldengenesi.com
<http://www.photocomm.com/>

GeoSolar Energy Systems, Inc.
P.O. Box 812467
Boca Raton, FL 33481 USA
Tel: (561) 218-3007
Fax: (561) 487-0821
abtahi@geosolar.com
<http://www.geosolar.com/>

Hutton Communications, Inc.
1775 McLeod Drive
Lawrenceville, GA 30043 USA
Tel: (800) 741-3811
Tel: (770) 963-1380
Fax: (770) 963-7796
locker@huttoncom.com
<http://www.huttoncom.com/>

IOTA Engineering
1301 E. Wieding Road
Tucson, AZ 85706 USA
Tel: (520) 294-3292
Fax: (520) 741-2837
iotaeng@iotaengineering.com
<http://www.iotaengineering.com/>

Jade Mountain Inc.
P.O. Box 4616
Boulder, CO 80306 USA
Tel: (800) 442-1972
Fax: (303) 449-8266
jade-mtn@indra.com
<http://www.jademountain.com/>

Morningstar Corporation
1098 Washington Crossing Road
Washington Crossing, PA 18977
USA
Tel: (215) 321-4457
Fax: (215) 321-4458
<http://www.morningstarcorp.com/>

Neste Advanced Power Systems
PL 3, 02151
Espoo, Finland
Tel: 358 204 501
Fax: 358 204 50 4447
jaana.sirkia@neste.com
<http://www.neste.com>

Precision Solar Controls
2915 National Court
Garland, TX 75041 USA
Tel: (972) 278-0553
Fax: (972) 271-9853

Real Goods Trading Co.
555 Leslie St.
Ukiah, CA 95482-5576 USA
Tel: (800) 762-7325
<http://www.realgoods.com/>

Quasar Solar Electric Co.
001 Tullamore
Offaly, Ireland
Tel: 353 882 706 775
Fax: 353 506 41650
quasar@tinet.ie
<http://homepage.tinet.ie/~quasar>

Trace Engineering
5916 195th St. NE
Arlington, WA 98223
Tel: (360) 435-8826
Fax: (360) 435-2229
inverters@traceengineering.com
<http://www.traceengineering.com/>

Siemens Solar Industries
P.O. Box 6032, Dept. FL
Camarillo, CA 93011 USA
Tel: (800) 947-6527
Fax: (805) 388-6395
<http://www.solarpv.com/>

Simpler Solar Systems
3118 W. Tharpe St.
Tallahassee, FL 32303 USA
Tel: (850) 576-5271
Fax: (850) 576-5274
simpler@simplersolar.com
<http://www.simplersolar.com/>

Solar Depot
8605 Folsom Blvd.
Sacramento, CA 95826 USA
Tel: (916) 381-0235
Fax: (916) 381-2603
solrdpo@calweb.com
<http://www.solardepot.com>

Solar Electric Light Co.
35 Wisconsin Circle Suite 510
Chevy Chase, MD 20815 USA
Tel: (301) 657-1161
Fax: (301) 657-1165
bcook@selco-intl.com
<http://www.selco-intl.com>

Solar Electric Light Fund
1734 20th Street, NW
Washington, DC 20009 USA
Tel: (202) 234-7265
Fax: (202) 328-9512
solarlite@self.org
<http://www.self.org/>

Solar Electric Power Co.
7984 Jack James Drive
Stuart, FL 34997 USA
Tel: (561) 220-6615
Fax: (561) 220-8616
sepco@tcol.net
<http://www.sepco-solarlighting.com/new/>

Solar Electric Specialties Co.
101 North Main St.
Mail: PO Box 537
Willits, CA 95490 USA
Tel: (707) 459-9496
Fax: (707) 459-5132
ses@solarelectric.com
<http://www.solarelectric.com/>

Solar Electric Systems of Kansas
City
13700 W. 108th Street
Lenexa, KS 66215 USA
Tel: (913) 338-1939
Fax: (913) 469-5522
solarelectric@compuserve.com
solarbeacon@msn.com

Solar Outdoor Lighting, Inc.
3131 S.E. Waaler Street
Stuart, FL 34997, USA
Tel: (800) 959-1329
Tel: (561) 286-9461
Fax: (561) 286-9616
info@solarlighting.com
<http://www.solarlighting.com/>

Solarex Corp.
630 Solarex Court
Frederick, Maryland 21703 USA
Tel: (301) 698-4200
Fax: (301) 698-4201
info@solarex.com
<http://www.solarex.com/>

Sollatek
Unit 4/5, Trident Industrial Estate
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Poyle Slough, SL3 0AX
United Kingdom
Tel: 44 1753 688-3000
Fax: 44 1753 685306
sales@sollatek.com
<http://www.sollatek.com/>

Sunelco
PO Box 1499
Hamilton, MT 59840, USA
Tel: (406) 363-6924
Fax: (406) 363-6046
info@sunelco.com
<http://www.sunelco.com>

Sunalex Corp.
5955-T N.W. 31st Avenue
Ft. Lauderdale, FL 33309 USA
Tel: (954) 973-3230
Fax: (954) 971-3647

SunWize Technologies, Inc.
90 Boices Lane
Kingston, NY 12401 USA
Tel: (914) 336-0146
Tel: (800) 817-6527
Fax: (914) 336-0457
sunwize@besicorp.com
<http://www.sunwize.com/>

The Bodine Company
236 Mount Pleasant Road
Collierville, TN 38017 USA
Tel: (800) 223-5728
Tel: (901) 853-7211
Fax: (901) 853-5009
ldailey@bodine.com
<http://www.bodine.com/>
<http://www.tran-bal.com/>

Tideland Signal Corp.
P.O. Box 52430-2430
Houston, TX 77052 USA
Tel: (713) 681-6101
Fax: (713) 681-6233
hq@tidelandsignal.com
<http://www.tidelandsignal.com>

Traffic Control Devices, Inc.
P.O. Box 418
Altamonte Springs, FL 32715-0418
USA
Tel: (407) 869-5300

Work Area Protection Corp.
2500-T Production Dr.
P.O. Box 87
St. Charles, IL 60174 -0087 USA
Tel: (630) 377-9100
Fax: (630) 377-9270

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