

LEARNING MADE EASY



Photovoltaic Design & Installation

for
dummies[®]
A Wiley Brand



Design and install
photovoltaic systems

Follow processes for permitting,
commissioning, inspection

Expand your skill set for
“green collar” jobs

Ryan Mayfield

President, Renewable
Energy Associates



Photovoltaic Design & Installation

by Ryan Mayfield

for
dummies[®]
A Wiley Brand

Photovoltaic Design & Installation For Dummies®

Published by

John Wiley & Sons, Inc.,

111 River St.

Hoboken, NJ 07030-5774

www.wiley.com

Copyright © 2019 by John Wiley & Sons, Inc., Hoboken, New Jersey

Published simultaneously in Canada

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 646-8600. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permissions>.

Trademarks: Wiley, the Wiley Publishing logo, For Dummies, the Dummies Man logo, A Reference for the Rest of Us!, The Dummies Way, Dummies Daily, The Fun and Easy Way, Dummies.com, Making Everything Easier, and related trade dress are trademarks or registered trademarks of John Wiley & Sons, Inc. and/or its affiliates in the United States and other countries, and may not be used without written permission. NFPA 70®, *National Electrical Code*®, and NEC® are registered trademarks of the National Fire Protection Association, Quincy, MA. All other trademarks are the property of their respective owners. John Wiley & Sons, Inc., is not associated with any product or vendor mentioned in this book.

LIMIT OF LIABILITY/DISCLAIMER OF WARRANTY: THE PUBLISHER AND THE AUTHOR MAKE NO REPRESENTATIONS OR WARRANTIES WITH RESPECT TO THE ACCURACY OR COMPLETENESS OF THE CONTENTS OF THIS WORK AND SPECIFICALLY DISCLAIM ALL WARRANTIES, INCLUDING WITHOUT LIMITATION WARRANTIES OF FITNESS FOR A PARTICULAR PURPOSE. NO WARRANTY MAY BE CREATED OR EXTENDED BY SALES OR PROMOTIONAL MATERIALS. THE ADVICE AND STRATEGIES CONTAINED HEREIN MAY NOT BE SUITABLE FOR EVERY SITUATION. THIS WORK IS SOLD WITH THE UNDERSTANDING THAT THE PUBLISHER IS NOT ENGAGED IN RENDERING LEGAL, ACCOUNTING, OR OTHER PROFESSIONAL SERVICES. IF PROFESSIONAL ASSISTANCE IS REQUIRED, THE SERVICES OF A COMPETENT PROFESSIONAL PERSON SHOULD BE SOUGHT. NEITHER THE PUBLISHER NOR THE AUTHOR SHALL BE LIABLE FOR DAMAGES ARISING HEREFROM. THE FACT THAT AN ORGANIZATION OR WEBSITE IS REFERRED TO IN THIS WORK AS A CITATION AND/OR A POTENTIAL SOURCE OF FURTHER INFORMATION DOES NOT MEAN THAT THE AUTHOR OR THE PUBLISHER ENDORSES THE INFORMATION THE ORGANIZATION OR WEBSITE MAY PROVIDE OR RECOMMENDATIONS IT MAY MAKE. FURTHER, READERS SHOULD BE AWARE THAT INTERNET WEBSITES LISTED IN THIS WORK MAY HAVE CHANGED OR DISAPPEARED BETWEEN WHEN THIS WORK WAS WRITTEN AND WHEN IT IS READ.

For general information on our other products and services, please contact our Customer Care Department within the U.S. at 877-762-2974, outside the U.S. at 317-572-3993, or fax 317-572-4002. For technical support, please visit <https://hub.wiley.com/community/support/dummies>.

Wiley publishes in a variety of print and electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at <http://booksupport.wiley.com>. For more information about Wiley products, visit www.wiley.com.

Library of Congress Control Number: 2019932064

ISBN 978-1-119-54435-7 (pbk); ISBN 978-1-119-54433-3 (ebk); ISBN 978-1-119-54437-1 (ebk)

Manufactured in the United States of America

10 9 8 7 6 5 4 3 2 1

Table of Contents

INTRODUCTION	1
About This Book	1
Conventions Used in This Book	2
What You're Not to Read	3
Foolish Assumptions	3
How This Book Is Organized	3
Part 1: Here Comes the Sun: Shedding Some Light on PV Systems	4
Part 2: Digging into Complete System Details	4
Part 3: Sizing a PV System	4
Part 4: Installing a PV System	4
Part 5: The Part of Tens	5
Icons Used in This Book	5
Where to Go from Here	5
 PART 1: HERE COMES THE SUN: SHEDDING SOME LIGHT ON PV SYSTEMS	 7
CHAPTER 1: The Photovoltaic Revolution	9
Peeking into the Past, Present, and Future of PV Installations	9
Acquainting yourself with typical PV applications	10
Checking out PV pros and cons	10
Looking into the future of PV	11
Introducing PV Components and Systems	11
Knowing Your Electricity A-B-Cs	12
Solar Resource 101	13
Surveying a PV System Site	13
Delving into PV System Details	14
PV modules	14
Batteries	14
Charge controllers	15
Inverters	15
Wiring and safety devices	15
Sizing a PV System	16
Grid-direct systems	16
Battery-based systems	16
Conductors and safety devices	17
Bringing a PV System to Life	17
Permitting	17
Staying safe	17
Putting together the mechanical parts	18

	Adding the electrical parts	18
	Commissioning, inspecting, and maintaining a system.	19
	Introducing the Sections of Code You Need to Know	20
CHAPTER 2:	Checking Out Common Components and Systems	21
	Introducing the Components That Make Up PV Systems	21
	PV modules and racking.	22
	Battery bank.	23
	Charge controller.	24
	Inverter	24
	Loads.	25
	Load centers.	26
	Disconnects and overcurrent protection.	27
	Utility interconnection	27
	Differentiating between PV System Types.	29
	Grid-direct systems	29
	Battery-based systems	31
	Figuring Out the Right System Type for Any Situation.	34
	The customer is connected to the grid.	34
	The customer isn't connected to the grid	35
CHAPTER 3:	Powering through Electricity Basics.	37
	Going with the Flow: Current.	38
	Understanding amps	38
	Distinguishing between direct current and alternating current.	39
	Measuring current with a meter	40
	May the (Electromotive) Force Be with You: Voltage	43
	Grasping the concept of voltage	43
	Getting a grip on nominal voltage and operating voltage.	43
	Measuring voltage	44
	Making a Stop: Resistance	46
	Introducing ohms	47
	Measuring resistance	47
	Connecting Current, Voltage, and Resistance with Ohm's Law	49
	Pondering Power and Energy	50
	Recognizing the differences between power and energy	50
	Relating power to current, voltage, and resistance with the power equation.	51
	Calculating energy in terms of watt-hours.	53
	Introducing amp-hours, a companion to watt-hours.	53
	Wrapping Together Current, Voltage, Resistance, Power, and Energy	54

Another Electricity Concept: Circuit Configurations	55
Series	56
Parallel	57
Series-parallel	58
CHAPTER 4: Warming Up to the Solar Resource	59
High (Or Low) Energy: Solar Radiation	60
Distinguishing between direct radiation and diffuse radiation . .	60
Determining the intensity of solar radiation: Irradiance	61
Calculating solar radiation energy: Irradiation	65
Just for a day: Peak sun hours	66
Examining the Effects of the Sun's Path on the Earth	69
Getting a grip on seasonal effects.	70
Understanding the sun's relationship to your location:	
Altitude and azimuth.	72
Ticking off solar time.	74
Interpreting sun charts.	74
Opening up to the solar window.	76
Positioning PV Modules to Make the Most of the Solar Resource . .	77
Introducing tilt angle.	77
Orienting your array to the azimuth.	79
CHAPTER 5: Properly Selecting a Site for a PV System	81
Setting the Stage for a Site Survey	82
Putting aside enough time	82
Creating a standard site-survey form.	83
Toting a site-survey bag	83
Picture This: Documenting Your Entire Site Survey	
with Digital Photos	84
Collecting Basic Information during a Site Survey	86
General site information	86
Structural and mechanical information	87
Electrical information	89
Measuring Information in Degrees.	90
Understanding magnetic declination	91
Calculating the array's tilt angle and azimuth	93
Exploring Shading-Analysis Tools	95
Interpreting the Data and Bringing It All Together.	97
Analyzing reports from your shading-analysis tool	98
Considering the total solar resource factor.	98
Using other collected information to plan out	
the design and installation.	100

PART 2: DIGGING INTO COMPLETE SYSTEM DETAILS 103

CHAPTER 6: PV Modules: From Sand to Electricity	105
Creating Solar Electricity: It All Starts with a Cell.	106
Getting a grip on cell construction and manufacturing.	106
Connecting cell construction to the photovoltaic effect	108
Reviewing Common Types of PV Modules.	108
Checking out crystalline modules	109
Looking at thin film modules.	111
Pointing Out Electrical Specifications on PV Modules	113
Current specifications.	114
Voltage specifications	115
Maximum power point.	116
Voltage temperature coefficient	117
Power tolerance.	118
Series fuse rating.	118
Surveying Test Conditions for PV Modules	118
Standard test conditions	119
Environmental effects on standard test conditions	120
Relating Current and Voltage in IV Curves.	122
An IV curve with varying temperature	123
An IV curve with varying irradiance.	124
 CHAPTER 7: The Basics of Batteries	 127
The Fundamentals of Battery Anatomy and Operation	128
Constructing a battery, from cell to bank	128
Discovering how batteries charge and discharge.	130
Comparing Different Types of Batteries	133
Lead-acid batteries	133
Lead-calcium batteries	136
Nickel-cadmium batteries	136
Comprehending Battery Capacity.	137
Considering the C rate for capacity.	137
Recognizing factors that affect capacity.	138
Specifying Batteries.	141
Specifying the type of battery to use	141
Specifying the battery bank size	142
 CHAPTER 8: Keeping Current and Voltage in Check: Charge Controllers	 147
The Essentials of Charge Controllers	148
Seeing how a charge controller works in stages.	148
Surveying special effects provided by some charge controllers	151

Maximum Power Point Tracking Technology	153
How MPPT works.	153
The pros and cons of MPPT controllers	154
Pulse-Width Modulation Technology	155
How PWM works	155
The pros and cons of PWM controllers	156
Specifying a Charge Controller	156
CHAPTER 9: Inverters: AC (From) DC.....	157
Getting the Goods on Grid-Direct Inverters	158
Basic operation	158
Standard features	159
Power output sizes	162
The importance of transformers.	162
Investigating Battery-Based Inverters	164
Utility-interactive inverter operation	165
Stand-alone inverter operation.	166
Standard features for all battery-based inverters	167
Sizes of battery-based inverters	168
Low-frequency transformer technology	168
Specifying Any Inverter.	168
Grid-direct.	169
Battery-based.	170
CHAPTER 10: Staying Secure: Wiring and Safety Components	173
Defining the Circuits in a PV System.	174
Checking Out Types of Conductors	175
USE-2	176
PV wire	176
Building wiring.	177
Battery wiring.	178
Ground wiring	178
Considering Kinds of Conduit	179
Metallic conduit	179
Nonmetallic conduit	180
Delving into Disconnects	181
Perusing Overcurrent Protection Devices	182
Circuit breakers	183
Fuses	183
Focusing on Ground Fault Protection.	184
Looking at the Basics of Labels	185

PART 3: SIZING A PV SYSTEM	187
CHAPTER 11: Sizing a Grid-Direct System	189
First Things First: Evaluating the Budget and the Available Array Area	190
Estimating the Site's Annual Energy Production	191
Sizing the Array to Meet Your Client's Energy Consumption	193
Determining annual energy consumption	193
Looking at contract options with the utility	194
Using consumption and contract options to select an array's needed power value	195
Getting Ready to Match an Inverter to an Array	196
Matching Power Values for an Array and an Inverter	197
Coming Up with the Right Voltage Values for Your Array and Inverter	199
Establishing the inverter's AC voltage	200
Defining the inverter's DC voltage window	200
Calculating the modules' maximum DC voltage contribution	201
Figuring out the modules' minimum DC voltage contribution	208
Bringing It All Together: Combining Your Power and Voltage Information	213
One Last Check: The Inverter's Maximum Current Input	214
CHAPTER 12: Sizing a Battery-Based System	215
Get Loaded: Looking at Loads in a Battery-Based System	216
Evaluating the loads that the battery bank must serve	216
Calculating the energy required during an outage for utility-interactive systems	219
Determining the average daily energy consumption for stand-alone systems	219
Sizing the Battery Bank	222
Inverter efficiency	222
The days of autonomy	223
The temperature used for battery operation	223
The depth of discharge	224
Nominal voltages	225
Figuring out the battery capacity you need	226
Strung along: Wiring the battery bank	227
Sizing the PV Array	229
Sizing the array in a utility-interactive system	229
Sizing the array in a stand-alone system	230
Sizing the Charge Controller	232
Voltage specifications	233
Power or amperage specifications	234
A check before you move on: Comparing the array size to the battery capacity	236

Sizing the Inverter	236
Viewing voltage output	237
Calculating the power draw	237
Staying in charge	238
Looking at surge ratings	238
Evaluating inverter and array power output	239
Incorporating a Generator	239
Generator features	240
Generator sizing	241
CHAPTER 13: Sizing Conductors, Conduit, and Safety Components	243
Conductor Sizing 101	244
Defining the PV circuits' maximum and continuous current	245
Calculating non-PV circuits' maximum current	246
Considering conditions of use with some handy tables	247
Putting together the details to determine conductor sizing	250
Accounting for voltage drop after you size your conductors	253
Sizing Conduit	257
Sizing Overcurrent Protection Devices and Disconnects	258
Beginning with a few basics	258
Placing protection on PV circuits	259
Protecting inverter circuits	260
PART 4: INSTALLING A PV SYSTEM	261
CHAPTER 14: The Permitting Process	263
Obtaining Permits before You Install a PV System	263
In the beginning: Having the right licenses and certifications	264
Home grown: Permitting for residential systems	265
Big business: Permitting for commercial systems	269
Not Just Pretty Pictures: Creating Drawing Sets	272
Calling out components clearly	273
Depicting equipment locations	273
Showing conductor-sizing calculations	273
Jotting down job notes	274
CHAPTER 15: Staying Safe Anytime You Work on a PV System	275
Getting a Grip on General Construction Site Safety	276
Identifying job-site obstacles and putting on protective gear right away	276
Safely working alone and with others	277
Taking in tips for tool safety	278

Limiting your exposure to the elements	278
Stowing a first-aid kit on the job site	279
Looking at Ladder Safety	279
Selecting your stash of ladders	279
Properly setting up any ladder	281
Raising the Issue of Rooftop Safety	282
Restraining yourself with fall protection	283
Storing your tools	283
Maintaining safe walkways	285
Examining Electrical Safety	285
Staying aware of general shock hazards	285
Working with circuits.	286
Charging Ahead with Battery Safety.	290
CHAPTER 16: Assembling the Mechanical Parts	293
Surveying PV Array Mounting Methods	294
Roof mounting.	295
Ground mounting	300
Top-of-pole mounting.	302
Building-integrated mounting	303
Considering Loading When You Mount an Array on a Roof	305
Following building codes	305
Accounting for additional dead load	305
Looking at live loads	307
Properly Attaching an Array to a Roof	309
Making attachments with lag screws	309
Sealing roof penetrations with flashing	310
Supporting Ground and Top-of-Pole Mounting	313
CHAPTER 17: Integrating the Electrical Elements	315
Location Is Everything: Knowing Where to Place Electrical Equipment	316
Manufacturers' requirements for equipment locations	316
Locations for disconnecting means	317
Combiner boxes and junction boxes and wiring, oh my!	318
Working on Wiring.	319
Seeing red (and green and white): Color-coding.	319
Managing wires on PV modules	321
Protecting wires with conduit	322

Bonding Yourself to Grounding.	323
Equipment grounding.	323
System grounding	326
Connecting to the Utility.	329
Determining the utility's requirements	329
Making a load side or line side connection	331
CHAPTER 18: Commissioning, Inspecting, and Maintaining a PV System.	335
Making a List and Checking It Twice: Preparing for Commissioning	336
Mechanical elements? Check!	336
Electrical elements? Check!	337
Start 'Er Up: The Commissioning Process	341
Putting safety first	342
Gathering the gear you need.	342
Commissioning different types of systems	343
Verifying that the system is working.	347
Arming Yourself for Inspection Issues	349
Not having "a neat and workmanlike manner".	350
Forgetting about aesthetics	350
Failing to manage conductors on the array.	350
Neglecting to label the system	351
Surveying System Maintenance	353
Mechanical maintenance	354
Electrical maintenance	354
Maintenance on a higher level: Taking care of battery banks . . .	355
PART 5: THE PART OF TENS.	359
CHAPTER 19: Ten Ways to Avoid Common Code Mistakes.	361
Providing Proper Working Clearance	362
Supplying the Right Structural Support	362
Keeping Water out of Buildings with Flashing.	363
Ensuring All Conductors Have the Necessary Ratings.	363
Managing the Conductors on Modules	364
Selecting the Correct Conduit	364
Locating the Disconnects	365
Grounding the Equipment.	365
Grounding the System	366
Labeling the System Properly	366

CHAPTER 20:	Ten Ways to Maximize Energy Production for Your Clients	367
	Select the Right Site	367
	Orient the Array Correctly	368
	Configure the Array Properly	368
	Work within the Limits of the Utility Voltage	369
	Choose the Correct Inverter	369
	Size Conductors Appropriately	370
	Keep the Components Cool	370
	Advise Clients to Monitor Their System	371
	Clean the Array Periodically	371
	Inspect the Array Annually	372
INDEX		373

Introduction

Solar electricity is one of the most accessible forms of renewable energy available, and it can be adapted to fit anyone's specific needs. The source of it, sunlight, allows photovoltaic (PV) modules to produce electricity and perform useful work, such as running electrical loads or putting energy back into the utility grid.

Globally, there has been an incredible increase in demand for solar modules and PV systems since the turn of the 21st century. No longer is PV technology limited to NASA spacecraft and backwoods cabins. Nowadays, PV systems are within reach for many people. This global demand and increased accessibility and affordability have helped transform the PV industry from a small cottage industry into a world-wide megabusiness.

As a renewable energy educator, advocate, and user, my primary goal is to see the solar industry grow successfully and sustainably — two things that require consistent high-level performance from the people “in the trenches” or, more appropriately, “on the roofs.” PV system designers and installers are tasked with providing high-quality systems that can benefit clients for more than 20 years. If you follow the information, advice, and tips I present in this book, you'll be well on your way to completing this task with the best of them. (Of course, no perfect power source is out there. To be a good PV system designer and installer, you have to realize the limitations of PV systems, which is why I help you consider those limitations in this book, too.)

About This Book

As the PV industry expands and captures the attention of more and more individuals, so does the amount of information about these systems. *Photovoltaic Design & Installation For Dummies* adds to this ever-expanding mass of information, but it stands out in its ability to provide you with practical, hands-on specifics. My intention with this book is twofold: to give you the ability to jump headfirst into the PV industry and to arm you with the knowledge you need to competently install a system (more or less) on your own. I use my real-world experience and

desire to see every roof holding a well-designed and properly installed PV system to help you.

My approach is to give you the information you need in easy-to-understand sections that are relevant to the work you'll be expected to perform as a PV designer and installer. (I don't expect you to read this book from cover to cover, but if you do, I'll take it.)

Note: This book is focused on the applications used to power homes and small businesses — with or without the electrical utility present — but you can take the principles and guidelines I present and adapt them for just about any application you need.

Conventions Used in This Book

Even though the title of this book has the word *photovoltaic* in it, most folks in the industry don't throw that word around day in and day out. Instead, we prefer to say *PV* — it's simpler, and it creates far fewer tied-up tongues.

Also, throughout this book you'll see references to *PV array* and *PV system*. The former term refers to the collection of PV modules that makes up the PV array, and the latter term refers to the PV array and all the associated components (disconnects, inverters, batteries, and so on) that make it operational and useful.

In addition, all time references throughout this book are based off solar time (which I cover in Chapter 4). *Solar noon* is the time of day exactly between sunrise and sunset, when the sun is at its highest point in the sky that day. Your longitude, the time of year, and whether you're subjected to daylight saving time influence the relationship between your clock and solar time.

Last but not least, the following conventions help you more easily sort through all the new ideas I throw at you:

- » The key words in bulleted lists and the action steps I ask you to follow in a specific order appear in **boldface**.
- » New terms that are important for your understanding of PV systems are in *italics*, as are words I choose to emphasize.
- » Web addresses appear in monofont. (Note that when this book was printed, some Web addresses may have needed to break across two lines of text. There's no extra punctuation, though, so just type in exactly what you see, pretending as though the line break doesn't exist.)

What You're Not to Read

So many interesting side notes about PV technology, politics, and installation techniques exist that I could easily use all the pages of this book for nothing but various tangents. I think I've done a good job of sticking to the main points to give you the most important information you need, but some stories and bits of knowledge are just too good to keep to myself. These stories and tidbits are included in the gray-shaded boxes (sidebars) and paragraphs marked with the Technical Stuff icon. Don't feel bad for skipping over this text if that's what you choose to do; you aren't going to miss out on the essential information a PV system designer and installer needs to know.

Foolish Assumptions

Simply by picking this book up, you've already proven my first assumption, that you have an interest in finding out more about PV systems, to be true. I also make some other assumptions about you; here they are, for your viewing pleasure:

- » You're one of the many individuals ready to make a career move that includes PV design and installation; you're either already a building-trade professional or you're enrolled in classes and want to secure an entry-level position in the PV industry.
- » Perhaps you're a homeowner looking for a better understanding of PV systems; you're thinking about having one installed and want to be as knowledgeable as possible when working with a PV system designer and installer.
- » You're interested in technically challenging projects, and you can accept that good designs and installations don't happen overnight. You want to prepare yourself and gain some knowledge first.

How This Book Is Organized

Photovoltaic Design & Installation For Dummies is arranged in five different parts. Each part can stand alone or be read in conjunction with the others. If one of the following parts (or a particular chapter within that part) excites you more than the others, by all means, head there first.

Part 1: Here Comes the Sun: Shedding Some Light on PV Systems

Get ready to discover the fundamentals of PV design and installation in this part. Here, I introduce you to the major components used in the systems you'll most likely be working with. And in case you need a refresher course on (or an introduction to) the fundamental electrical principles, this part has you covered. It also explains the specific relationship between the sun and the earth and how this relationship affects where you should position a PV installation.

Part 2: Digging into Complete System Details

Everything you ever wanted to know about the major components of PV systems can be found in Part 2. If you've been wondering how a PV module works and how the acid inside a battery can make electricity, here's your chance to find out those things. This part also covers the basic functions of the other major components of PV systems: charge controllers, inverters, and wiring. And because safety should always be your top priority, I also get you acquainted with essential safety devices (think fuses and circuit breakers).

Part 3: Sizing a PV System

In this part, I walk you through the different methods for *sizing* your PV systems (figuring out how many PV modules you need), whether they're grid-direct or battery-based, and the necessary wiring and safety devices. Sizing is the area that can make or break your system. If you properly size and *specify* (select) all the system components, your system will likely pass inspection much faster, and your client will be left with a safe, efficient way of capturing and using solar energy. If, however, you make major errors in your preparation and design, fixing those errors after the system is already installed can be a difficult (and sometimes dangerous) task.

Part 4: Installing a PV System

Part 4 is where I cover the physical installation process, as well as the activities that precede and follow it. I kick things off by walking you through the permitting process so you have the permission you need to install the system. Next, I cover the safety considerations you need to have in mind when you're out installing systems. (After all, PV construction sites offer a number of hazards for everyone on-site; by preparing for these hazards, you can avoid them altogether.) After that,

I break the installation process into the mechanical and electrical portions. Then I give you a process to follow when you're ready to *commission* (turn on) the system and get the modules working prior to the mandatory building department inspection. Finally, I address proper PV system maintenance.

Part 5: The Part of Tens

The Part of Tens is designed to give you small chunks of information for a quick and easy read. Prepare to find out some of the common mistakes made in PV installations so you can do your best to avoid them, as well as some quick tips on how to keep the PV systems you design and install working as well as they should.

Icons Used in This Book

Throughout this book, I use the following icons to bring your attention to interesting, important, or even downright critical information.



REMEMBER

Although I'd love it if you remembered everything in this book, I know that's practically impossible. That's why I mark ideas I want you to keep in mind no matter what with this icon.



TECHNICAL
STUFF

Every now and then I tend to “nerd out” on you with interesting but nonessential information. I promise to keep these asides (relatively) short and to warn you that they're coming with this icon.



TIP

This little bull's-eye brings your attention to information that may make your job a little easier.



WARNING

Don't let anyone fool you. PV systems pose real dangers. This icon alerts you to a situation that requires special attention and caution.

Where to Go from Here

Wondering where to start reading? If it were me, I'd jump to Chapter 6; this is where I get into the PV modules themselves — far and away the most interesting part of PV systems (in my humble opinion). If you'd rather choose the approach my children take — which is to decide what you think is best despite

my advice — flip to the table of contents. There you can breeze through all the chapters and see what jumps out at you.

After you get what you want out of this book, I strongly suggest you find a way to put that knowledge into action. Numerous organizations that provide hands-on training and experience are available, and these classes are an excellent way to get your hands on some equipment and have access to individuals who are knowledgeable and eager to help you master PV systems. Then, if you have the means, install a PV system on your own home. Doing so lets you run the show and gives you some personal insight into what it takes to install PV systems (plus it provides you with a slightly less stressful situation for your first solo installation because you don't have a client or supervisor looking over your shoulder).

Wherever you end up going first in this book, realize that you're jumping into an exciting and rapidly evolving technology and industry. No matter where you go within the pages of *Photovoltaic Design & Installation For Dummies*, you'll be well on your way to becoming involved with one of the most dynamic and exciting industries you can imagine.

1

Here Comes the Sun: Shedding Some Light on PV Systems

IN THIS PART . . .

Understanding the fundamentals of photovoltaic (PV) systems is the key to designing and installing high-quality systems that'll perform beyond your (and your clients') expectations. That's why this part provides the foundation you need to move forward with designing and installing PV systems.

Chapter 1 gives you an understanding of where PV systems started, where they are now, and where they're headed; Chapter 2 gives you a feel for the major components used in all types of PV systems and how they relate to each other. Chapter 3 provides an overview of the electrical fundamentals that drive system designs and installations, and Chapter 4 outlines the relationship between the sun and the earth and guides you on assessing the solar resource. Rounding out the bunch, Chapter 5 walks you through the process of selecting where on a client's property to install a PV system; it also helps you quantify the solar resource at a particular location.

IN THIS CHAPTER

- » Taking a look at the PV timeline
- » Refreshing yourself on the basics of electricity and the solar resource
- » Selecting a site for a PV system and outlining the different system components
- » Making the sun work on your client's behalf with proper system sizing and installation
- » Getting to know Code

Chapter **1**

The Photovoltaic Revolution

In recent years, photovoltaic (PV) systems have popped up on people's homes and businesses all over the United States. Believe it or not, this desire to use the sun to power people's electricity needs is anything but new. Ever since scientists discovered materials that can produce electrical current by simply being exposed to light, people have been excited about this energy source. Get ready to dive into the exciting and ever-expanding world of solar power with the overview I provide in this chapter.

Peeking into the Past, Present, and Future of PV Installations

To truly appreciate PV, it helps to have an understanding of where the technology came from, where it's at now, and where it's going.

The operating principles for modern PV cells were first discovered in 1839 by a French physicist named A.E. Becquerel. After that, a number of scientists played with and improved on Becquerel's original discovery. In the 1950s, Bell Labs created the first piece of PV technology designed for use in space. This technology soon found its way back down to earth for use in telecommunications applications in remote areas. In the 1970s and 1980s, people began using PV modules to charge batteries and then used those batteries to run various lights and appliances in their remote homes. These early PV pioneers helped set the stage for today's PV industry.

The first PV cells weren't very efficient or widely used outside of space programs. They were also quite costly. Yet over the years, researchers and manufacturing companies increased efficiencies and reliability and managed to drive down costs drastically. All of these contributions have led to the widespread use of solar modules and their availability to you and me. In the following sections, I describe some common PV applications, a few brief pros and cons of PV systems, and the future of the PV industry.

Acquainting yourself with typical PV applications

Modern PV systems can be found in a wide variety of applications. They power calculators, pump water, help offset the energy used by floodlights along highways, and, of course, power homes and businesses.

For you and me, electricity is available nearly everywhere we go, and PV systems are able to integrate with the existing utility grid. In remote, developing areas, PV systems provide valuable energy for powering lighting systems, running refrigerators, and helping deliver clean drinking water.

Checking out PV pros and cons



REMEMBER

PV systems have some serious advantages on their side. Producing electricity from the sun has environmental benefits because the power source is an abundant renewable resource that's available every day (even though PV systems aren't as effective during cloudy weather, they still produce a small amount of power on those days). PV is also a highly adaptable power source. You can use individual cells to power small electronics and individual panels to power specific loads. You can build small arrays to power homes, or you can build utility-scale projects to send massive amounts of power into the utility grid. And after PV systems are installed, they can provide many years of clean, reliable power at virtually any location on earth.

On homes and businesses connected to the utility, PV systems are considered *distributed generation*, a power source that produces electricity close to the location

where the power is used. They're able to offset the requirements on the central power plants sending out the electricity most people use.



WARNING

PV systems aren't the right answer for all applications. They have some disadvantages too. For example:

- » **The sun isn't a continuous power source.** At night, the PV modules can't produce power, so in some scenarios, you have to use a method to store the energy for later use (adding cost and complexity to the system design and installation).
- » **The amount of area required to produce power is large in comparison to other sources of power.** For large-scale projects, significant portions of land or roof space are necessary. Not every homeowner or business owner has access to such space.

Looking into the future of PV

Most people accept that “alternatives” to the “conventional” power sources acquired by burning fossil fuels must be developed, and so, to use a really bad pun, the solar industry has a bright future ahead of it. The worldwide demand for solar electricity continues to grow on a global level, and the amount of time, effort, and money being put into the industry is amazing. Many research and development projects are underway that will help drive down costs further, increase efficiency, and deliver better PV systems.

I'm reluctant to make any bold predictions about the future of PV technology; ideas I had just a few years ago that I wrote off as too far-fetched and nearly impossible are proving to be real solutions in the PV industry. However, I *am* comfortable saying that the overall acceptance of PV systems and their integration into the built environment will do nothing but increase in the years to come. Solar power is no silver bullet, though. It'll take a movement on many fronts to make the global shift away from over-reliance on fossil fuels.

Introducing PV Components and Systems

PV systems can be ridiculously simple (connect a module to a load and use the load as you wish), but they can also seem overwhelming when you first look at them. Every time I go to design and install a PV system, I look at the whole process as a real-life puzzle that must be arranged and put together just so. Each project is unique in its own way, and that's part of the fun.



Yet despite the differences in the details, the PV systems you connect to homes and small businesses have some specific and very necessary components (all of which have an important role to play in the system).

- » **PV modules:** The individual units that you place in the sun to produce electricity from the sun are called *PV modules*. A number of modules connected together in different configurations form a *PV array*.
- » **Battery bank:** Batteries provide a way of storing the energy produced by the PV array. Individual batteries connected together make up a PV system's *battery bank*.
- » **Inverters:** Devices that take power from the PV array or the battery bank and turn it into AC power used to operate loads are *inverters*.
- » **Disconnects and overcurrent protection:** These components are necessary for ensuring the safety of the system and the people who come into contact with it.

Grid-direct PV systems, which send power back to the utility grid, have become the most popular type of PV system at locations where the utility grid is present. They offer increased efficiency and reduced maintenance as well as decreased costs compared to their battery-based counterparts. What they give up, though, is the ability to use the PV array whenever the utility power goes out. Luckily for most people who have utility power present, utility outages are relatively rare; when they happen, they're generally short-lived.

Battery-based systems operate independently from the grid (stand-alone) or as a backup to the grid (utility-interactive).

In Chapter 2, I run through all the major components you need to install in a PV system — whether it's a grid-direct one or a battery-based one — and what their relationship is to the other pieces of the puzzle. There, I also explain how to determine which type of system is best for any given client.

Knowing Your Electricity A-B-Cs

A good understanding of electrical concepts and fundamental equations is vital to designing and installing PV systems correctly. My goal is to have you feeling comfortable and confident in your understanding of the basic electrical terms and equations (don't worry — no calculus here). If you design and install PV systems long enough, I guarantee you'll find yourself using these concepts on a daily basis.

If you've never opened an electrical box for fear of the unknown monsters lurking behind the cover, or if you just need a refresher on all the terminology, check out the information I present in Chapter 3. The jargon, industry-specific terms that

the PV world is filled with (many of which are born from the electrical trade) will be much clearer if you do.

Solar Resource 101

The *solar resource* is defined as the amount of solar energy received at a particular site. Following are some of the terms used to describe the intensity of the sunlight striking the earth (these terms are used pretty frequently in PV system design, so I suggest getting familiar with them; for specifics on the relationship between the sun and the earth, see Chapter 4):

- » **Azimuth** describes the position of the sun (and the modules) in terms of how many degrees the sun or the array is from north.
- » **Irradiance** describes how intense the sunlight is at a particular moment in time.
- » **Irradiation** refers to the quantity of solar energy received for a given amount of time (a day is a typical time frame).
- » **Solar window** refers to the portion of the sky where the sun appears at a particular location on earth. The solar window varies based on your latitude. You want to do your best to keep any obstructions out of the PV array's solar window.
- » **Tilt** describes the number of degrees that the PV modules are off of the horizontal surface.

But that's not all you need to know about the solar resource. A PV system's location on the earth has a definite effect on the overall system installation. Also in Chapter 4, I help you look out at the sky and see the big window that must be kept open for your PV system to perform as well as it possibly can; I also describe the specific effects of the sun's path on the earth.

Surveying a PV System Site

PV systems are wonderful, magical things, but they can't perform miracles all on their own. You have to give them a fighting chance for them to knock your client's socks off. In other words, you have to survey the area where the array will be located and make sure nothing will block sunlight's path to the array.



REMEMBER

Shade is your enemy, so take a critical look at the potential PV location when you conduct your site survey. A tiny bit of shade on the array may be unavoidable at certain parts of the year, but it's your job to predict and limit these scenarios to the best of your ability.

In Chapter 5, I show you what to keep an eye out for and how to properly assess your site's potential. I also outline the most common tools you should have on hand in order to perform a successful site survey.

Delving into PV System Details

PV systems use a number of interesting components that can leave even the most seasoned electrician gawking in amazement. I walk you through the major components in the sections that follow. My goal is to boost your comfort level with the capabilities, limitations, and basic construction of all the major pieces of a PV system. I strongly encourage you to read these sections (rather than skip over them) so you can acquire some basic understanding; without it, any system you design is just a bunch of parts and boxes that likely won't get the job done.

PV modules

PV modules are truly where all the magic of PV systems begins. They produce voltage and current, and, when wired correctly, they perform useful work. (To me, that's more magical than making entire bridges disappear.) In Chapter 6, I show you the module specifications you'll refer back to many, many times during the system design and installation processes. I also show you how the modules are at the mercy of their surrounding environment and will react to whatever sunlight and temperatures they're exposed to.

Batteries

When you need to store the energy produced by a PV array and use it at a later time, you need batteries. I list your many options and go over the basic construction and operation of batteries in Chapter 7. (This information will prove invaluable when you start *specifying* [selecting] batteries for your battery-based PV systems.)



REMEMBER

Whenever you need to incorporate batteries in a PV system, you need to define the following parameters:

- » The amount of energy the client needs daily
- » The number of days the client wants to be able to go without having to recharge the batteries
- » The amount of solar energy that's available for charging the batteries
- » The temperature at which the batteries are stored

Charge controllers

When you use batteries, you have to make sure they're properly charged by the PV array — that's where a charge controller comes in. In Chapter 8, I show you how to evaluate the different charge controller technologies that are used most often and explain how the different technologies interact with the array and batteries to deliver the maximum amount of energy to the batteries. I also outline the different feature sets commonly found on charge controllers and introduce the specifications to consider when selecting a charge controller for a battery-based PV system.

Inverters

Because PV arrays and battery banks produce and store DC electricity, you almost always need to include an inverter in a PV system (or more than one, depending on the size of the array). An inverter takes DC electricity and turn it into the AC power used by most electrical loads in homes and businesses.



REMEMBER

I go over the inverter categories used in PV systems in Chapter 9, but in general, you can classify inverters as either grid-direct or battery-based:

- » All grid-direct inverters are also classified as utility-interactive (meaning they can take power from the PV array and send it into the grid).
- » Battery-based inverters, on the other hand, can be classified as utility-interactive or stand-alone (meaning they can't send power into the grid and are meant for off-grid applications).

Wiring and safety devices

Safety is one of the most important considerations you make during the design and installation process. To achieve proper equipment safety, you need to install a number of safety devices, not least of which is the right wiring. In Chapter 10, I introduce you to the different types of *conductors* (wires), the conduit that protects those conductors from damage, and the overcurrent protection devices you have to use to protect the conductors from having too much current flowing through them.

Another important piece of safety equipment is the disconnect switch that allows you to (no surprise here) disconnect the PV array from the inverter. When a disconnect switch is in the off position, you can safely access the components of a PV system for servicing.



REMEMBER

Because other people (such as emergency personnel) may come into contact with the system, you need to make sure it's safe for them by installing labels that explain how to quickly and safely access the system.

As a final note on safety precautions, you need to keep in mind that at some point the wiring in the PV system may become damaged and pose a risk. Ground fault protection (GFP) devices help protect against fire hazards in the case of damaged conductors. In grid-direct inverters, this protection is preinstalled; for battery-based systems, you must install GFP separately.

Sizing a PV System



REMEMBER

In order to have a PV system operate properly and meet your client's expectations, you need to spend some time in the design phase evaluating the individual components of the system and their interaction with all the other pieces. During this *sizing* process (which is when you determine the number of modules to use in a particular system), you have to consider the client's available budget for the project, the PV array location, and the specifications for the individual pieces of equipment.

In this section, I explain the basics of sizing and installing the two main system types and talk about sizing the safety equipment used in your systems.

Grid-direct systems

Grid-direct systems offer more design flexibility than battery-based systems because you don't have to worry about storing any energy; the grid will usually be there to make sure all the loads can run when the user wants them to. Even with this flexibility, you need to carefully consider the PV array you design and the components you connect to it. In Chapter 11, I show you what you need to consider in the sizing and design process, from evaluating the energy consumption at the site to the utility requirements for connecting to the grid to the calculations used when matching a PV array to an inverter.

Battery-based systems

Before you can size a battery-based system (either utility-interactive or stand-alone), you must evaluate the energy consumption used by the loads that will be powered via the battery bank. After you complete this step, you're ready to move on to sizing the different system components, specifically the battery bank, the PV array, the charge controller, and the inverter. Chapter 12 has the how-to on sizing these components. (If you need to incorporate a generator into any battery-based system design, Chapter 12 has you covered as well.)

Conductors and safety devices

PV systems have some rather unique properties that need your attention when sizing wiring and safety components. The conductors are exposed to some extremely high temperatures, the current values passing through those conductors are at the mercy of the sun, and on top of all that, the DC current passing through the system requires you to seek out components that are specially listed for the application. Never fear. I walk you through the processes of properly choosing and sizing conductors, conduit, and overcurrent protection devices in Chapter 13.

Bringing a PV System to Life

After you spend all the required time designing a PV system, you're ready for the real fun: going out in the sun and putting the modules to work. The next sections are dedicated to the different portions of the installation process to help get you up to speed. Of course, every situation you encounter will be slightly different from the last, but the fundamental ideas and processes behind PV system installation remain constant.

Permitting

An important activity takes place before a PV system is ever installed: permitting. The local building department is responsible for providing permits for any PV installation. You must apply for this permit, just like you would if you were doing any other major construction project.



REMEMBER

Generally, you need to have two permits issued to you: an electrical permit and a building permit. The electrical permit is required so that the building department can ensure that the electrical portion of the system is safe, and the building permit helps keep the building safe from mechanical failure. (For full coverage of the permitting process, turn to Chapter 14.)

Staying safe

The safety of all individuals on the job site should be the most important factor during any installation — period. When you're installing a PV system, you'll be on a construction site with numerous hazards. The Occupational Safety and Health Administration (OSHA) rules regarding construction-related trades will be in full effect, and you need to be sure to address these requirements. The OSHA Web site, www.osha.gov, is full of information and resources to help you make your work sites as safe as possible.



REMEMBER

Just because PV systems deal with solar power doesn't mean they don't possess the same electrical hazards associated with any other electrical system. Always keep this fact in mind. Also, because PV systems run on energy they obtain from the sun, you're going to be working on ladders, accessing roofs, and working in locations that are fully exposed to the elements — all of which add even more safety hazards you need to be aware of. (For a review of the major safety elements you need to consider, as well as methods you can use to keep yourself and others safe during a system installation, turn to Chapter 15.)



WARNING

It takes a single accident to not only seriously injure an individual but also cripple an entire business. So do whatever you have to do to keep safety top of mind during each and every installation job.

Putting together the mechanical parts

For many PV system installers, the truly difficult part of any PV installation is the mechanical portion, which includes setting up the rack to hold the modules and evaluating the interaction between the PV array and the building. Depending on the location of the array (on a roof or on the ground), the installation of the mechanical components can represent a large portion of the time spent on the job site. Refer to Chapter 16 for a complete rundown of the issues you'll face as you install the mechanical components of a PV system, as well as effective solutions for them.



REMEMBER

A number of PV installations occur on rooftops, especially for residential systems. Whenever you're working with a rooftop system, you need to carefully consider the methods used to attach the racking system to the roof. For ground-mounted systems (including top-of-pole mounting), you have to evaluate how you plan to keep the array in place without overtaxing the racking system or constructing a structure that can support a small country.

Adding the electrical parts

The electrical installation is always the portion of PV systems that receives the most attention — and rightly so given the numerous regulations you must comply with. The majority of these regulations are spelled out in the PV-specific portion of the *National Electrical Code*® (NEC®), specifically Article 690. I point out the highlights of Article 690 later in this chapter; consider this information a primer on the NEC®, not a complete review of the Code. (**Note:** Some local building departments may have additional requirements, so be sure to check in with the local office to make sure you're on the same page.)

As I walk you through the different portions of the electrical installation in Chapter 17, I refer to the NEC® and point out specific requirements. I cover the required locations for different electrical components such as disconnects and overcurrent protection, and I guide you through the ever-fun topic of grounding the PV system (as well as grounding methods that are commonly used throughout the United States). I also note the requirements you need to follow when connecting the PV system to the local utility grid.



REMEMBER

You don't have to memorize specific passages of the NEC®, but you do have to be knowledgeable about the layout and format of the Code so you can effectively refer to it while designing and installing your systems.

Commissioning, inspecting, and maintaining a system

After you install the system, you're ready to *commission* it (in other words, you're ready to flip the switch and release the magical electrons from the PV modules and put them to work). Before you get too excited, though, you need to take some time and make sure the system has been installed properly so you don't have to spend the next three weeks on-site fixing a problem that could've been discovered earlier. I walk you through this self-inspection, as well as the commissioning process, in Chapter 18.

When you know for sure that the system works, you need to turn it off and await the official inspection from the local building department. You must set up an appointment for an inspector to come out and look everything over. The inspector's job is to make sure you followed the basic requirements and installed the components you said you would. If he sees any major problems, he'll document them and require you to fix them before he'll pass the system and allow you to turn it on. Turn to Chapter 18 for the full scoop on inspection requirements and common problem areas in PV installations.



TIP

To avoid getting hung up for too long in the inspection process, speak with an inspector early in the process (even as early as when you apply for the permits). This way you can make sure you're clear on the local building department's guidelines and get initial approval on things like grounding and labeling while you're in the design phase (when it's easier to make changes).

Don't think you're done as soon as the system receives approval from the inspector. No matter how low maintenance it may be, every PV system still requires maintenance now and then. I outline the common maintenance issues you need to be aware of and share advice on how to approach them (as well as who's responsible for them) in Chapter 18.

Introducing the Sections of Code You Need to Know

As you begin to install PV systems, including the electrical elements, you need to make sure you're familiar and comfortable with the *National Electrical Code*® (*NEC*®), also referred to as NFPA 70®. I reference the *NEC*® (also known simply as the Code) throughout this book, directing you to specific sections and applications.



REMEMBER

Here are some basics related to the *NEC*® that you may find helpful:

- » If you've never referenced the *NEC*® or look at it only on rare occasions, I suggest you purchase a copy the *NEC*® *Handbook*. It contains the entire *NEC*®, along with some pretty pictures and helpful explanations that make the Code easier to understand. Perhaps the easiest way to obtain a copy of the handbook is to head to the National Fire Protection Association's Web site (www.nfpa.org) and click the Buy NFPA codes & standards link on the left-hand side of the page. From there, just search for the *NEC*® *Handbook*. The handbook is a little pricey, and you'll have to keep purchasing new editions periodically. Rest assured, though, that the cost is worth it.
- » Always make sure you're using the correct version of the handbook for your area. The *NEC*® *Handbook* is released every three years, but the local *jurisdiction* (the office that issues building permits) may not be using the most current version. To find out which version the jurisdiction in your client's area is using, call the local building department.
- » As you work more and more with the Code, you'll realize that people interpret the same section differently. The powers that be who author Code sections try for concrete language, but there's no way to achieve total clarity with a document like this. If you ever have a question, your best bet is to research your question and maybe even consult with your electrical inspector to make sure you're on the same page as he is (literally and figuratively). **Note:** The local *authority having jurisdiction* (AHJ) — in other words, the electrical inspector — has the final ruling on the Code interpretation; the Code is there as a guideline, but the enforcement is up to the AHJ.
- » Although a specific section in the *NEC*® covers PV systems, you don't get to ignore the other sections. The entire *NEC*® applies to PV systems, so reference the other sections as appropriate. However, there may be situations where the requirements set in Article 690 are different than in other sections. In this situation, Article 690 supersedes the other Code sections because it relates to PV installations.

- » Identifying the major parts of a PV system
- » Distinguishing between battery-based and battery-less systems
- » Helping your customers select the correct system for their needs

Chapter 2

Checking Out Common Components and Systems

This chapter may seem trivial and worth skipping when all you want to do is dive into a new-to-you technology and design systems that'll be the envy of your peers (not to mention major moneymakers). My advice to you? Remember that it's all about the details. Before you can design and install that envy-inducing, moneymaking PV system, you need to have a grasp on exactly what goes into a PV system. Each component has a unique and important role in the whole system. You, the designer and installer, have to understand these components and their purpose, as well as how they fit together as a whole, in order to help your customers select the best system for their needs. This chapter gives you the knowledge base you need to start working with and recommending PV systems.

Introducing the Components That Make Up PV Systems

Even though you and I probably drive a different kind of vehicle, the major components inside each one are identical. Both vehicles have an engine, some wheels,

and a steering wheel to help us navigate, although your vehicle may have a bigger engine than mine, and my vehicle may have bigger wheels and a smaller steering wheel than yours. You can look at PV systems in a similar manner. The basic components, such as the PV modules and the inverter, are the same even though the types of components differ based on the user's needs and what the local regulations require. In the following sections, I take a look at the major components of a typical PV system and explain how each component relates to the others.

Note: The following information isn't all-inclusive. Rather, it's a primer designed to help you understand PV systems as a whole. Each of these components receives much more attention in later chapters, so please don't feel overwhelmed with the descriptions I provide here.

PV modules and racking

PV modules are the source of power in a PV system. They produce DC electricity, which is easily stored in battery banks but needs to become AC power via an inverter for use in homes. (I present the features and limitations of different types of PV modules in Chapter 6.)

Racking components hold the PV array to the location where you choose to place the modules. One typical way to mount the entire array is on the roof of the structure you're working with. Other options include *building-integrated mounting* (where the PV array becomes a substitute for the roofing or window materials) and mounting the array on a racking system down at ground level. Another common option is mounting the PV array on top of a pole rack. I give you the scoop on mounting methods and considerations in Chapter 16.

No matter where they're mounted, PV modules are always connected to these particular components: disconnects, inverters, and charge controllers.



TIP

The terms *PV module* and *PV panel* are often used interchangeably (I've been fighting myself for years on getting it straight when talking to people). You also see and hear *PV array* quite a bit. The fact is, different definitions describe these terms. If you're discussing modules, panels, and arrays with someone, you need to make sure you're both talking the same language.

- » A *module* is a single unit consisting of PV cells contained in an environmentally secure package.
- » A *panel* is a group of modules fastened and wired together.
- » An *array* is all the modules (and panels) and racking components used to produce DC electricity.

Battery bank

For systems that require energy storage (namely, any system that needs to operate without the utility grid; see the later “Battery-based systems” section for more information), a *battery bank*, multiple batteries wired together to achieve the specific voltage and energy capacity desired, is the best option.

The battery bank is typically housed in a container to keep the batteries safe. The PV array connects to it in order to provide charging, with a charge controller located somewhere in between. The battery bank is also connected to the inverter to provide power for the AC loads. If the system also uses DC loads, the battery bank is wired to a DC load center. (Don’t know what loads and load centers are? I cover both later in this chapter.)



REMEMBER

Just like your car’s fuel gauge tells you when you need to fill up, a battery monitor tells you how full the battery is. In battery-based systems, a monitoring system is very important in keeping track of the battery level.

I describe the different battery technologies in detail in Chapter 7, but the most common batteries used for the typical PV system are as follows:

- » **Sealed batteries:** These come in a sealed container that requires a reduced amount of maintenance by the end user.
- » **Flooded batteries:** These come in an open (or flooded) container that requires a higher level of user interaction.



WARNING

Sealed batteries are often referred to as “maintenance-free batteries.” Don’t believe the hype! Sealed batteries are indeed a reduced-maintenance option compared to flooded batteries, but they still need some attention. If you don’t advise your clients to monitor and properly maintain a battery bank, the batteries will die prematurely. Relatively simple battery monitoring can not only keep the system owner updated on the batteries’ status but it can also keep her from experiencing poor results when using the batteries. (Chapter 18 has details on the maintenance required for battery-based systems.)



WARNING

All batteries give off gas when they’re charging, releasing hydrogen. Sealed batteries release minuscule levels of hydrogen; flooded batteries can give off substantial levels of it. A wise choice (actually a requirement in most locations) is to keep all batteries inside a protective container that vents to the outside to avoid the possibility of hydrogen buildup and an explosion hazard.

Charge controller

A *charge controller* is a piece of electronics that's placed between the PV array and the battery bank. As you can probably guess, its primary function in life is to control the charge coming into the battery bank from the PV array. Charge controllers can vary from a small unit intended to connect a single PV module to a single battery all the way to a controller designed to connect a multiple-kilowatt PV array to a large battery bank.

Flip to Chapter 8 for more information about charge controllers, including their features, technology, and sizing.

Inverter

Inverters turn the DC power produced by PV arrays or stored by battery banks (in battery-based systems) into the AC power used in homes and businesses. They come in many different shapes and sizes. An inverter can be as small as the 100-watt unit you plug into the DC plug in your car or as large as a megawatt unit installed in conjunction with a utility-scale PV project. (I delve into the details of inverter specifications in Chapter 9.)



TIP

If the PV system is only going to supply power for DC loads such as lighting, water pumping, or small electronics, an inverter isn't a requirement. DC loads in standard residential applications don't show up much anymore, but they're common in recreational vehicles.

The inverters in PV applications fall into two major categories:

- » **Utility-interactive:** These inverters can connect to a utility and either supply power to the connected loads or send electricity back into the grid, essentially running the meter backward.
- » **Stand-alone:** These inverters aren't designed to interact with the utility and work by supplying power to loads.



WARNING

Utility-interactive and stand-alone inverters have a similar appearance. If you were to look at two inverters from the same manufacturer, you wouldn't be able to tell the difference because manufacturers try to put multiple inverters in the same *chassis*, or outer shell, to reduce the number of parts they have to use and cut costs. The only way to know for sure which inverter is which is to look at the label on the side of each inverter.

Utility-interactive inverters come in two flavors:

- » **Grid-direct:** These are primarily used in systems for homes and businesses with utility power present. They don't provide the user with any energy storage, which means if the utility power isn't present, the inverter can't work. In grid-direct inverter systems, the PV array is connected to the inverter on the DC side, and the inverter is connected to the utility grid on the AC side.
- » **Battery-based:** These require a stable voltage source of power, typically a battery bank, to keep the inverter running. A PV system using this inverter requires more components and is generally more complicated, but it allows the user to have backup power for times when the utility goes out. Battery-based inverters use a PV array and charge controller on the DC side and connect to the utility on the AC side.

Stand-alone inverters are quite similar to utility-interactive, battery-based inverters. The main difference is the source of AC power. In a typical stand-alone system you have an AC engine generator to supply power to the loads and allow for battery charging when the PV array can't keep up with the user's energy consumption. On the DC side, a stand-alone inverter is connected to the same components as its utility-interactive, battery-based counterpart, but on the AC side, the inverter sends power only to AC loads.

Loads

Loads are all the pieces of electrical equipment people want to use in their homes and offices. You can have DC loads or AC loads (and sometimes even both). You just have to make sure you supply the correct type of power to the load. For instance, you can't use a DC light bulb when AC power is provided.

Loads are served differently depending on the system used (you can find out more about different systems later in this chapter).

- » In grid-direct systems, loads are primarily served by the utility. The PV system can send power directly to the loads or back into the utility grid.
- » In battery-based systems, the inverters are designed to directly run the loads connected to the inverter in the load center. This requires sizing the inverters differently based on the inverter technology used. **Note:** Occasionally, DC loads are present in battery-based systems; when they are, they receive their power from the battery bank via a DC load center.



TIP

In a utility-interactive, battery-based system, the system owner defines the exact loads that get backed up. Although people would like to back up their entire suburban home, that's a very difficult task. Bring them back to reality with this list of loads that *can* be backed up with success: refrigeration, well pumps, lighting, and computer equipment.

Load centers

A *load center* is the place where electrical loads (see the preceding section) receive their power. In a typical scenario where the utility is present, the utility sends power to a building at a single location. The utility's wires are connected to a meter; from that meter, a connection is made to the *main distribution panel* (MDP; also called a *main load center*). The individual wires running throughout the building are ultimately connected to the MDP via a circuit breaker.

When a number of electrical circuits are connected within a building, or if a detached structure is present, such as a garage, often an AC subpanel is used to help reduce the number of wires running all the way across the house. Figure 2-1 is an example of how a main panel and subpanel can be laid out in a residential setting. Usually, a circuit breaker in the MDP sends electricity to the subpanel. The subpanel then uses multiple circuit breakers to send electricity to loads and outlets that are physically close to the subpanel.

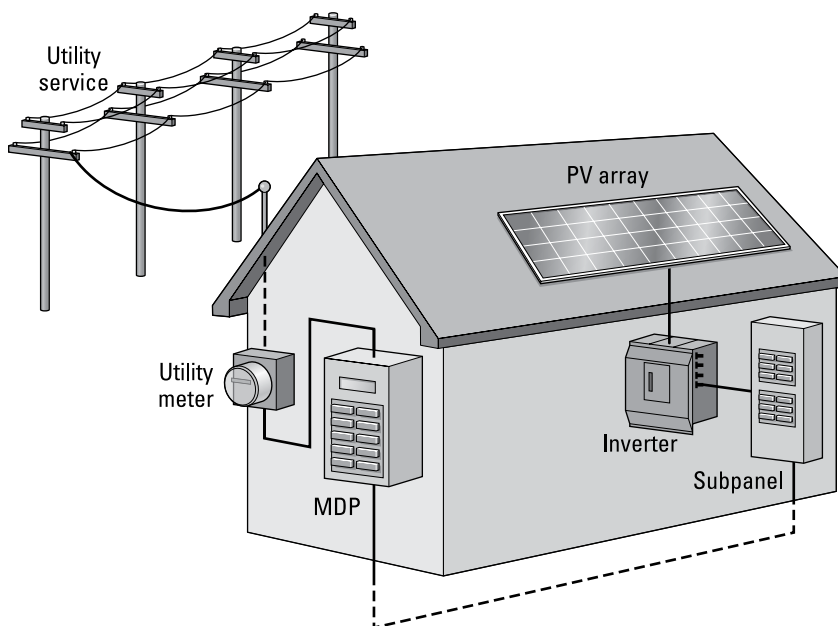


FIGURE 2-1:
A main distribution panel and a subpanel in a residence.