

Chapter 1

The Photovoltaic Revolution

In This Chapter

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 - ▶ Refreshing yourself on the basics of electricity and the solar resource
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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



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.

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 jargony, 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.



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.)



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.



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.



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



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.



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.



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.)



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.



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.



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.



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.



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.