Designing PV Systems to Meet the National Electrical Code

John Wiles

Thinking about a new PV system or an update to the old system? Got an electrical inspector driving by the homestead once a week and wondering what's going on? Thinking about upgrading the safety of the system for those times when the non-technical spouse and kids are home alone? If so, then pull up a chair and let's talk codes and PV systems. With this Code Corner, we start the full cycle of how to design and install a PV system that will meet the National Electrical Code (NEC).

Systems that are designed and installed in a manner that will meet the NEC are usually safer to operate and maintain than those systems that do not meet the NEC. They also are usually more durable and reliable.

Although the system requirements described in these columns will be based on the 1993/1996 National Electrical Code, anyone installing PV systems should be aware that there are local codes that supplement the NEC and that the electrical inspector has the final say on what is acceptable.

System Design—Sizing

PV system sizing is outside the scope of this column, and the information that follows here and in successive columns will assume that the basic PV system has been sized. Most of the PV module manufacturers have sizing programs that are used by the dealers and distributors to assist in determining the size of the PV array, the battery bank, the generator, and other components. The size of the system is usually based on either the required electrical loads or available funds.

If a do-it-yourself approach is desired, then back issues of *Home Power Magazine* provide much useful information, and there are several books (see advertisements in *HP*) that have good design information. Sandia National Laboratories has a Stand-Alone PV Design Manual available for the professional (See access).

After the system is sized, the PV modules, the battery bank, the inverter, and the charge controller are selected. The use of components that are listed to the standards established by Underwriters Laboratories (UL) will ensure that these components have passed rigorous electrical compatibility, electrical shock, and fire safety tests. The use of listed components will make for greater compliance with the NEC requirements and allow the system to pass electrical inspections more readily.

It is now time to design the balance of system (BOS) and select the various cables, switches, overcurrent devices, and other items that will connect the main components. Careful attention to the BOS design process will result in a system that is safe, durable, reliable, and meets the NEC. The following sections will outline the general BOS design considerations. Subsequent Code Corner columns will provide detailed information on each area in the PV system.

PV Module and Source-Circuit Wiring

The selected PV system voltage (12, 24, 48, or ?) and the total number of modules will determine the number of modules connected in series and parallel. The name plate rating (marked on the back of each module) will give the open-circuit voltage and short-circuit currents of each module. These numbers will be used to determine the size of the module interconnect cables and the size of the cables from the inverter to the charge controller or power center.

The types of cables used and the insulation on them will be determined by how they are to be mounted. The NEC allows exposed single-conductor cables between the modules. Several other wiring methods are also allowed between the modules and from the modules to the power center. Multiple conductor, sheathed cables and single cables in plastic and metal conduit are frequently used. Since the cables are used in an area exposed to the outdoors, cables rated for wet environments are required.

The PV module operates at temperatures that can be

20-40°C above the ambient temperature. All PV modules should be wired with cable rated at 90°C. The ampacity (current carrying capacity) must be derated for these high operating temperatures.

Since most fuses and circuit breakers are designed to use cables with 75°C insulations, some cross checking must be done to ensure that the 90°C cables are not operating at a temperature higher than 75°C.

In very cold climates, the PV module can operate at temperatures below 25°C, and these low temperatures increase the open-circuit voltage of the system. Calculations must be made to determine the maximum open-circuit voltage so that the voltage rating of the cable, fuse, or circuit breaker is not exceeded.

Battery and Battery-to-Inverter Wiring
In stand-alone systems with battery banks and inverters, the cables between these two devices usually carry the highest currents in the system. These are single-conductor cables that are installed in conduit between the battery and the inverter and a power center or DC load center. Inverter input current must be calculated so that these cables can be properly sized. Building-wire type cables should be used. Inspectors are looking closely at systems to ensure that welding cables and automotive battery cables are not being used.

Grounding
There are two types of grounding—equipment grounding and system grounding. All renewable energy systems that have exposed metal surfaces (module frames, mounting racks, enclosures, inverter and charge controller chassis, pumps, etc.) must have those exposed metal surfaces grounded by connecting them to a ground rod (eight feet long of copper or copper coated steel). This equipment grounding requirement applies to all systems (even 12-volt) unless they are listed as double insulated and have no exposed metal surfaces—at this time, there are no such systems.

System grounding refers to the connection of one of the current-carrying conductors to the ground rod at one and only one location in the system. This is optional for 12-volt systems, but required for any higher voltage system. In most systems, the negative conductor is grounded; the rare exception is a PV system supplying a telephone system, which usually requires a positive ground.

Grounding also affects the ability of the system to reject the effects of nearby lightning strikes.

Load Circuit Wiring
All wiring to both ac and DC load circuits should have three conductors. In the DC circuits, these are the positive, the negative (usually the grounded conductor), and the equipment ground. In the ac wiring, these are the hot, the neutral (the grounded conductor), and the equipment ground. All connecting sockets must have provisions for three conductors. While there are some listed, double-insulated ac devices that can use two-prong plugs, most DC equipment is not so listed and must have the equipment grounding conductor in the attached cord and plug. These DC appliances should have the exposed metal surfaces connected to the equipment grounding conductor.

Two-conductor automotive cigar-lighter plugs and sockets do not meet NEC requirements and are usually not durable or safe.

Overcurrent and Disconnect Devices
Each ungrounded conductor in the system should be protected by an overcurrent device (fuse or circuit breaker). The array, the battery, other renewable energy sources, and the generator or the grid are sources of potentially hazardous currents. If the option of an ungrounded system (12 volts only) is elected, then overcurrent devices must be installed in both of the (now) ungrounded conductors.

Disconnects are required so that all sources of energy (PV, battery, generator, and grid) can be disconnected from the system. Disconnect switches are also required to isolate equipment (charge controllers and inverters) and fuses for servicing. Like overcurrent devices, disconnect switches are required in ungrounded conductors; and in an ungrounded system, two-pole disconnects are required—one pole in each of the ungrounded conductors.

Enclosures
Since the system must have disconnect and overcurrent protection for the battery to inverter cables and for the charge controller to battery to array cables, then one or more enclosures must be used to house the necessary devices. In some cases an all-in-one power center is used, and in other installations several separate enclosures are used. These enclosures should be standard, listed electrical equipment enclosures. They may be either metal or PVC and should have provisions for the necessary conduit fittings.

Batteries must be mounted in some sort of enclosure (preferably non-metallic) to keep the terminals from being exposed and to provide some containment for spilled electrolyte and acid fumes. Adequate ventilation around the batteries is necessary, and they should not be mounted in living areas.

Some charge controllers have appropriate enclosures, complete with knockout fittings. Others without enclosures that have exposed terminals are best mounted in a separate box.

Summary

Designing and installing PV and other renewable energy systems that comply with the National Electrical Code can result in safer, more reliable, and more durable systems. In the next *Home Power* "Code Corner," the NEC requirements for PV module wiring will be covered in great detail.

The author is willing to answer questions on PV design and code issues relating to this and previous Code Corner Columns. Phone, Fax, or write to him at the address below.

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1996 NEC and the 1996 NEC Handbook: The National Fire Protection Association • 1 Batterymarch Park • Quincy, MA 02269-9101 • 800 344-3555

Stand-Alone Photovoltaic Systems Design Manual: The PV Design Assistance Center • Sandia National Labs • Mail Stop 753 • P.O. Box 5800 • Albuquerque, NM 87185-0753.