Codes and Standards: Cost and Performance Impacts

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PV systems and components may be assembled from components that comply with established standards, and they may be installed in a manner that meets local and national code, or they may be assembled and installed in a manner that does not comply with any code or standard. Users, designers, and manufacturers of PV systems and components make this choice every time they make, install, or buy PV systems. There have been concerns in certain segments of the PV community that compliance with codes costs too much and imposes performance penalties. These concerns are addressed in the following paragraphs.

Introduction

Terrestrial PV power systems are well into the second decade of widespread application. With the number of PV systems increasing, there has come an expansion in the number and types of codes and standards that apply to PV systems. These codes and standards impact the design, installation, performance, and costs of PV systems.

Many systems use components manufactured and tested to the various standards published by the IEEE, the National Electrical Manufacturers Association (NEMA), and Underwriters Laboratories (UL). On the other hand, there are numerous PV components, both small and large, manufactured without adherence to any standard. While installations with either set of components may result in a similar degree of customer satisfaction, the use of listed (built and tested to a standard) components is rapidly becoming the established and legally required practice.

The National Electrical Code (NEC) and supplemental state, county, and municipal electrical codes govern the legal installation of PV power systems just as they govern the installation of other electrical power systems. Many PV systems are installed in a manner that meets the applicable codes. These systems are required to have components manufactured and tested to UL Standards.

Standards and codes are not developed arbitrarily. They are the product of many people working countless hours using professional experience and a knowledge of the current technology to write requirements and guidelines that will result in safe, durable, and high performance PV systems. These standards and codes are the joint product of a collaboration among the PV industry, standards developers like UL, the academic community, electrical inspection officials, and government agencies with input from the end user.

There are costs associated with installing systems that comply with the various codes and standards. There are also benefits for installing such systems, in terms of increased safety for users and maintainers as well as the potential for enhanced performance. On the other hand, there may be penalties for not installing code-compliant systems such as equipment failures, safety hazards, and failure to obtain occupancy permits.

Codes and Standards

The system (and equipment) used for the generation, distribution, and end use of electrical power in the United States represents one of the most complex and safest systems in the world. The U.S. electrical power system performance and safety record is judged outstanding. This record is the result of a process of developing and applying safety and performance codes and standards to the electrical power system for over a century.

The end result is that the electrical utility industry uses a number of standards established by the IEEE for the generation, transmission, and distribution of electrical power. At the end-use facility, both the NEC and IEEE Standards apply to the equipment and installation of electrical systems.

The National Electrical Code (NEC-ANSI NFPA 70), published by the National Fire Protection Association (NFPA) establishes requirements for the installation of field-installed and wired electrical power systems. The NEC was first published in 1897 and has been revised and updated on a regular basis since 1911 by the NFPA.

The NEC does not cover electrical utility facilities used for the generation, transmission, and distribution of electrical power that are owned and operated by the utility on utility property. Neither does it cover electrical power systems in automotive vehicles, recreational boats, or railway cars. It does, however, cover house boats and recreational vehicles. Voltage ranges from zero to 40,000 volts and frequencies from direct current (dc) to radio frequencies are covered by the code.

The NEC Committee (charged with developing the code) is composed of a Technical Correlating Committee supervising and integrating the results of twenty NEC Panels that study, evaluate, and revise the entire NEC (over 1000 pages) every three years. The panels are composed of volunteer professionals representing the NFPA, UL, the International Association of Electrical Inspectors (IAEI), electrical equipment manufacturers, electrical installers unions, the academic community, and various other involved parties. Proposals from these panel members, other interested parties, and the general public are used to revise and update the NEC.

Photovoltaic power systems are addressed specifically in Article 690 (10 pages) of the NEC, but 80-90 percent of the rest of the 1000-page NEC applies to PV systems as it does to all electrical power systems. The PV industry, through the support of the Solar Energy Industries Association, has a member on Code Making Panel 3 (CMP-3) who votes on items dealing with PV systems in Article 690 of the NEC.

The NFPA has tasked CMP-3 to establish a Task Group to specifically address issues associated with PV systems for the 1999 NEC. This seven-person Task Group is supported by a Technical Review Committee of about 30 people representing all phases of the PV Industry. They are dealing with the code changes that will be required to implement advanced technologies such as those associated with the AC PV Module and Building Integrated PV Systems. The Task Group is also addressing the safety requirements associated with dc electrical systems that have not been updated in the NEC in recent years. The Task Group has been meeting about three times a year, and the activities will culminate with a set of proposals for the 1999 NEC that will be forwarded to the NFPA in November 1996.

While the NEC is just a published document, it has been adopted as a legal requirement in more than 40 states and in most large cities throughout the U.S. The NEC is supplemented by local jurisdiction codes in many areas. Enforcement of the NEC, where it has been adopted, varies significantly. In some areas only permits are required and the installer is charged with code compliance. In many areas, a comprehensive, rigorous inspection system has been established. The more intensive, extensive applications of the code are found in urban areas where high population densities have dictated stricter safety measures.

The NEC represents a set of installation requirements, and establishes requirements for the equipment used. All equipment installed under NEC requirements must be examined for safety. The electrical inspector or other authority having jurisdiction (AHJ) usually interprets this as a requirement that all equipment be tested and listed. Testing and listing is a formalized process, carried out by a few major laboratories, that verifies that the equipment meets standards written and published by UL. The NEC also requires that all equipment be installed in accordance with the conditions established by the listing, any applied markings or labels, and the instructions supplied by the manufacturer. Finally, the NEC requires that good workmanship be used and the inspector makes evaluations based on the experience with numerous non-PV residential and commercial electrical power installations.

The National Electrical Manufacturers Association (NEMA) publishes a number of standards that deal with the manufacture of equipment enclosures, wiring devices (plugs and sockets), batteries, conduits and raceways, and connectors, among other things. The NEMA and UL standards are both written to harmonize with the NEC, and much of the non-PV-related equipment such as enclosures and raceways are made to NEMA Standards.

Federal, state, and local governmental agencies usually specify compliance with certain IEEE Standards as well as with the NEC. These IEEE Standards deal with battery system design and installation, inverter performance, utility-intertie specifications and, in the near future, PV module qualification. The IEEE Standards establish performance as well as safety requirements.

The Impact of Using Listed Components

There are cost increments inherent in installing PV systems that comply with the NEC. In many jurisdictions, installation of any electrical system requires that permits be applied for and inspections be conducted on the finished work. The local jurisdictions also require that the installer have the appropriate business and professional licenses. Admittedly, permits and licenses cost money and, while the authority having jurisdiction may have less knowledge of PV systems than the installer, there is a strong case for having these PV electrical power systems permitted and inspected like other electrical installations. PV systems are used by and accessible to the untrained general public and must meet the necessary minimum safety standards. The permitting and inspection process provides an extra layer of safety and liability insurance to the installation. In many parts of the country it may be possible to install a PV system without a permit, but to do so in other areas is to break the law.

The NEC requirement that all electrical equipment be listed requires that standards published by UL be used to evaluate the safety of products used in the United States. Products are tested against these standards by UL, ETL, and other testing laboratories recognized by the local jurisdiction. Such mundane items as the twenty-five cent cover plate for the electrical outlet are listed. The costs associated with testing, listing, and follow-up services by these laboratories can vary greatly depending on the product. A PV load center made entirely from components that are themselves listed, may be relatively inexpensive (less than $10,000) to have tested and listed. A PV charge controller that uses components that are only recognized (a less rigorous category of certification than listing) by the testing laboratories in a newly designed (non-listed) enclosure may require additional testing and additional costs before a listing can be issued. A PV component, such as a PV module, that is manufactured mainly from new (unlisted and unrecognized) components may require significant amounts of testing. Such testing may take more than a year, require the services of many people working in a number of different testing laboratories, and is not cheap.

It is not always easy to conform with the requirements of the published standards or the listing process. The component design must be relatively mature since any change, however small, in the materials or design must be reevaluated by the testing laboratory. Another point is that, unfortunately, some current PV components are not able to meet the safety standards without a complete redesign. The use of exposed terminals and flammable materials are generally not allowed in electrical power equipment.

The listing of all components is an NEC requirement and is being enforced by increasing numbers of jurisdictions. If no listed equipment is available in a particular category, the inspector may issue a waiver that allows unlisted equipment to be used. For PV systems, however, there are now listed components available in nearly every category, including source-circuit combiner boxes, load centers, charge controllers, and inverters, but excluding gasoline/propane/diesel-driven generators and batteries which are generally not listed.

Even in the non-listed category of batteries, there are some manufacturers that are making batteries that are recognized by UL. That means the batteries are made to the manufacturer's specification (not to a UL Standard) and UL verifies that the batteries are consistently made to that specification.

While the cost may not be insignificant, the listing process does provide several significant advantages. PV systems that use listed components have access to a greater market than do systems with non-listed components. Listed components provide a well-defined liability trail should a PV system or component fail. When greater market penetration is added to the reduced liability issues associated with marketing a listed product, the costs of such listing are not at all imposing. In fact, the greater sales volume of listed products may allow the manufacturer to keep prices lower, provide newer technologies, and better customer services. Implicit in the listing process is the fact that a third party (the listing laboratory) is watching the manufacturing process very carefully and is very interested in hearing about and correcting faulty products.

The Impact of Complying with the NEC

Compliance with the NEC requires that proper types of cables, conductor sizes, overcurrent devices, and disconnects be used. A PV system could be assembled meeting none of these requirements (and many have), but safety and common sense seems to indicate that at least these items should be used and used correctly.

Cables

Increasing the size of the cable to the next larger size to meet the temperature-derated ampacity requirements of the NEC may increase the cost of the system as the table below shows. Using a wet-rated cable such as a THWN-2 conductor in conduit instead of a damp-rated conductor like THHN may cost a little more, but many cables are dual rated THHN/THWN-2 at the same cost as THHN. Most USE cables, are triple rated USE-2/RHH/RHW-2 and can be used in free air as module interconnects and as conductors in conduit.

Typical Cable Costs

AWG	Type	Cost per 200'
12	THHN	$ 9.00
10	THHN	15.00
8	THHN	23.00
12	THWN-2	$ 11.00
10	THWN-2	17.00
8	THWN-2	28.00
12	USE-2	$ 19.00
10	USE-2	26.00
8	USE-2	42.00

While large cables cost more than smaller cables, the use of larger cables results in lower voltage drops and less power loss and this may offset the added costs of the larger cables over a 20-year life of the PV system. The table below assumes that 25 amps of current is flowing from the PV array to the rest of the system over a 100 foot (one-way) length of cable. Number 12, 10, or 8 AWG cables could possibly be used to carry the 25 amps of current although the NEC might require number 8 AWG conductors.

The power lost in each cable is shown in the table below. If the modules are about 50 watts each, the number 12 AWG conductor loses about five modules worth of power, the number 10 AWG cable about three modules worth of power, and the number 8 AWG cable about two modules worth of power. With modules priced at about $5.00 per watt, switching from number 12 AWG to number 8 AWG would save about $600 (3 modules x 40 watts/module x $5/watt). The $23.00 price differential for using the number 8 AWG USE-2/RHW-2 is very much less than the $600 worth of lost module output.

Power Losses in 200' of cable at 25 amps

AWG	Current	Ohms/200'	Voltage Drop	Power Lost	Equivalent Modules
12	25	0.396	9.9	248	5
10	25	0.248	6.2	155	3
8	25	0.156	3.9	97	2

Overcurrent Protection

The addition of fuses costs more than using no fuses, but there are few PV designers and installers that would be willing to install a PV system without some type of overcurrent protection. DC-rated fuses cost more than ac-rated fuses. In some cases, DC-rated circuit breakers like the Square D QO breakers cost less than DC-rated fuses and fuse holders. When Square D QO circuit breakers are used on 12-volt PV systems, the total cost of the breaker and the enclosure is usually less than the cost of a similarly rated fuse, fuse holder, and enclosure. The installation of the circuit breaker is considerably easier also.

PV systems with batteries can deliver very high short-circuit current, so the battery circuits should always contain current-limiting fuses to protect other circuits and components. In some cases, these fuses can be eliminated by installing circuit breakers with high interrupt capabilities (such as the Heinemann E-Frame units) throughout the system. Original Equipment Manufacturers (OEM) can implement cost-effective solutions such as these because custom enclosures are required.

Performance Impact

The impact on performance that compliance with the NEC and other standards may have has been the subject of much discussion. Several areas that have received attention are discussed below.

Code compliance requires that several devices be added to the system that may affect performance. The NEC requires that all conductors be protected from overcurrents from all sources. It also requires that disconnects be provided so that all sources of power can be disconnected from the system; and requires that system components can be isolated from all sources of power during servicing. These safety requirements are specified so that the unqualified (untrained, general public) person can safely operate the equipment without electrical shock hazards and that faults in the field-installed wiring will trip the appropriate protective device with little damage to the equipment or surroundings. The NEC requirements are also designed to allow the unqualified person to reset or replace tripped overcurrent devices without coming into contact with electrically live contacts.

These extra components may create losses in the system. Admittedly, each electrical component that is added to a PV system such as a diode, switch, fuse, or circuit breaker has some resistance that results in a measurable voltage drop and some measurable power loss. In small, 12-volt systems that are used for remote, stand-alone power, these losses may pose problems - especially where adequate attention has not been given to the overall system design. In these systems, night-time battery voltages are normally below 12 volts, and excessive voltage drops can affect the operation of 12-volt, dc appliances.

However, with proper design and suitable components, even in 12-volt systems, these voltage drops and losses can be tolerated. In the larger, higher voltage systems (or systems with inverters), these small losses are not as critical, and the overall design process usually takes them into account. Often, adherence to NEC requirements may result in enhanced, rather than reduced, system performance.

Circuit breakers generally have less power losses and voltage drops than fuse/switch combinations because the circuit breakers have fewer contacts and connections. The use of higher-quality, magnetic-trip circuit breakers can result in less losses than the use of thermal-trip circuit breakers because the internal resistances are lower.

The NEC requires that all conductors be large enough in size (American Wire Gage-AWG) so that they never carry more than 80% of their rated current (ampacity) on a continuous basis. The NEC also requires that conductors be derated (oversized) for the ambient operating temperature, which in the case of PV modules may be as high as 70-80°C. Both of these requirements result in conductor sizes that are larger than would otherwise be installed. The larger conductors yield better performance through lower voltage drops and less power loss as shown in the tables above.

A listing by a testing organization indicates that a component has passed a number of rigorous safety tests which results in fewer problems in the field. While these tests may not be directly related to performance, they do ensure that the components are robust enough to withstand heavy-duty usage (e.g., the interrupting of direct-current (dc) circuits). A robust construction will result in better performance (lower losses) than can be obtained with a component that is not designed well enough to pass the listing tests. For example, a few installers (mostly do-it-your-self homeowners) have used switches rated for ac-only in the dc circuits of PV systems. These switches quickly develop high resistance and fail to operate on the dc circuits. Switches rated and listed for operation on DC circuits do not experience such problems.

The use of automotive electrical components such as the inexpensive plastic-bodied automotive fuse may reduce cost, but may also reduce performance and create significant safety problems. These fuses, and the earlier glass and ceramic auto fuses, are designed to operate in relatively high resistance circuits where the available short-circuit currents are low. They have little interrupt capability and, when called upon to open a high-current fault on a low-resistance renewable energy system, they may explode, melt or catch fire.

Proper grounding of the PV system, as required by the NEC, may also result in enhanced performance from reduced radio frequency interference (from inverters and fluorescent lamps) and better protection from lightning-induced surges. Equipment grounding of the metal housings on 12-volt fluorescent lamps has been shown to improve lamp starting at low voltages.

Surge suppressors (required by the NEC) do not, when properly rated, result in any deterioration in the performance of a PV system and may reduce damage to conductors and equipment when nearby lightning strikes occur. Surge suppressors, when used in conjunction with blocking diodes and the NEC-required overcurrent devices, may provide even more system protection.

Safety vs. Performance

Performance must be balanced with the need for safety and reliable operation. Safety is one of the first requirements for any PV installation that is going to be accessible to the general public. The PV system must be at least as safe as any other electrical power system.

Safety must also be addressed as it impacts the normal operation and maintenance of the system. Although a qualified, well-trained, and experienced person might install the system, there is little reason to expect that operation and maintenance will be carried out by such a person. Since the installer is not continually on-site, the system must stand alone not only in an operational sense, but in a safety sense. Following NEC requirements will result in a system design that can be operated and maintained in a relatively safe manner.

There are, however, exceptions from certain safety requirements in the NEC if it can be ensured that the system is accessible only to qualified persons. This generally points to the PV system that can be fenced and locked so that the general public and untrained persons do not have access under any condition. The NEC does, however, dictate some safety requirements to allow for safe system maintenance, even by qualified persons. For example, there should be adequate working clearances around the storage batteries used in PV systems so that water can be added and the terminals tightened without danger of shocks, acid splashes, or short circuits.

The Bottom Line

In a system using listed components that has been installed following the requirements of the National Electrical Code, safeguards are available that minimize the hazards to persons and the damage to equipment when these unexpected events occur. There will be a battery disconnect switch that can be quickly opened when the batteries in the garage are hit by an automobile. Overcurrent devices automatically open when cables are accidentally shorted by a nail in a wall. The fire department will have access to switches that can be used to shut down the system if necessary in the case of fires. During normal operation by the untrained, unqualified user, switches are available that allow the batteries, fuses, and other components to be safely serviced.

Systems are not always installed or operated in optimum or benign environments. Insulation on conductors may be accidentally damaged during installation or at a later time by environmental factors or mechanical abuse. Components may be stressed physically or electrically by unanticipated operating or environmental conditions. Thermal cycling, inherent in the daily operation of a PV system, may pose unanticipated stresses on the system.

PV systems may certainly be designed and installed without regard to any codes or standards and without the use of any listed components. Such systems may operate satisfactorily for years. There are no guarantees that a system that is installed with listed components in full compliance with the NEC and other applicable standards will operate reliably and perform at high levels. In each case, the basic system design usually determines the level of performance.

In the non code-compliant system, few, if any, safeguards are available. There may be no way for the user or the maintainer to shut the system down for normal repairs or for an emergency. In the event of system failure and/or damage to property, there is no well-defined legal chain of liability.

In the code-compliant system, the following all work in a carefully defined, integrated manner to ensure the success and durability of the PV system:

- Developers of the standards
- Testing and listing agencies
- Manufacturers of listed components
- Developers of the NEC and other codes and standards
- Licensed installer who follows the NEC
- Permitting authority
- Local jurisdiction
- Electrical inspector
- Insurance company

PV systems that are designed and installed in full compliance with the NEC by licensed installers and fully inspected will receive wider acceptance by the general public and the institutional customer. Photovoltaic power systems have the highest probability of success when they are planned and installed by a team consisting of the owner/user, the PV designer, a licensed installer, and the electrical inspector.

Access

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