If It Happened To Me, It Can Happen to You!

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Sponsored By The Photovoltaic Systems Assistance Center, Sandia National Laboratories

It all started last year when I received a call from Chris Cameron, Manager of the Photovoltaic Systems Application Department at Sandia National Laboratories. He was having some rewiring done on his house, and the electrician had installed a multiwire branch circuit (two branch circuits sharing a common neutral). Chris, being the sharp person that he is, immediately thought about the hundreds of thousands of stand-alone PV systems in the US with single 120-volt inverters that might be hazardous with this type of wiring.

He called me and I distributed the warning through letters, faxes, and Home Power magazine (see Code Corner in HP 54). Last week, I was doing some rewiring on my house, and guess what. I found seven multiwire branch circuits! All were being driven by a single Trace 4024 inverter with a 30+ amp output that could easily overload those number 14 and 12 AWG neutral conductors! If my house has them, your house may too.

These multiwire branch circuits are wired with three-conductor-with-ground cables which have a black conductor, a red conductor, a white conductor, and a bare conductor contained in a single jacket and connected to two 15 or 20-amp circuit breakers. Removing the cover panel of the ac load center (after the power has been turned off–caution: the main breaker(s) will still be hot) will easily reveal the existence of these circuits. They should not be confused with the larger conductor (8 AWG and up) 120/240-volt range or dryer circuits which typically are connected to a common, ganged circuit breaker at 40 amps and above.

When these multiwire branch circuits are operated from the grid or from a 120/240-volt inverter system, they are completely safe and comply with the National Electrical Code (NEC). When they are operated from a single 120-volt inverter rated at more than 1800 watts, they can pose a safety hazard and do violate provisions of the NEC. Inverters rated above 1800 watts can overload the number 14 AWG white neutral conductor in these circuits. The 15-amp circuit breakers used to protect these circuits will not even trip. If the multiwire branch circuit is wired with 12 AWG conductors and protected with 20-amp circuit breakers, then inverters rated at 2400 watts or more can overload the white neutral conductor, and again the circuit breakers can provide no protection. Generator feed-through with many stand-alone inverters can be at current levels significantly higher than the rated ac output of the inverter, alone. Trace 4000 and 5500 watt sinewave inverter users-take note!

There are a couple of solutions that can be employed if these multiwire branch circuits are found. One of the hot conductors (red or black) can be disconnected from its circuit breaker and the load outlets. A new two-conductor-with-ground cable can then be installed to replace this conductor. By disconnecting one of the two hot conductors in the multi-wire branch circuit cable, overloading the neutral is avoided. Such rewiring is difficult to accomplish in an existing home and would have to be accomplished by an electrician with a permit issued. Each multiwire branch circuit would have to be rewired in this manner.

A second method is to use only one circuit breaker by disconnecting one of the hot conductors from its circuit breaker (for example, the red wire) and connect it to the circuit breaker for the black conductor. This should be done only by an electrician who must determine that the circuit breaker is listed to accept two wires. If the circuit breaker is listed for only one conductor, then the red and black conductors can be spliced to a third conductor and this third, single conductor can be connected to the circuit breaker. While this method protects the neutral conductor from overloads, it may violate provisions of the NEC that limit the number of receptacles on each branch circuit. The single circuit breaker protecting two circuits also means that the total current that can be drawn from both circuits is limited by the rating of the circuit breaker–a fact that may restrict the simultaneous use of both circuits at their full rating.

If you are a renewable energy user and have a single 120-volt inverter powering your house, get out there and check for multiwire branch circuits now! Fixing them may save your home, your life, and the life of your family.

System Longevity and Safety

PV modules will produce energy for 20 or more years. The system (called balance of system or BOS) connected to these PV modules must be designed and installed so that it too will safely and reliably handle that energy for the next 20+ years.

An interrelated group of industries, codes and standards, and regulating agencies have, for the last 100 years, been working together to ensure that electrical power systems in the United States are the safest and most cost effective in the world. These organizations include the National Fire Protection Association (publisher of the National Electrical Code), the Insulated Cable Engineers Association, the International Electrical Inspectors Association, the Institute of Electrical and Electronic Engineers, other standards organizations like ANSI and ASTM, and the manufacturers of electrical cables and equipment.

Standards are written for the equipment. The equipment is built and tested to the standards. The equipment is installed in a manner that meets the applicable codes and is then inspected to ensure that the overall system is safe.

In this and subsequent Code Corners columns, we will discuss the details of how various components in the PV system can be selected to meet the codes and achieve reliability and safety.

Conductors, Cables, and Wires

These terms are used interchangeably, but not always correctly. A conductor may be either bare with no insulation or insulated when it is covered with electrical insulation. The material of the conductors is normally copper although aluminum may be used in limited applications. A cable can have a single conductor or can have multiple conductors. There may or may not be an outside sheath covering a multiple-conductor cable. Not all conductors of a multi-conductor cable have to be insulated and, frequently, one conductor (the equipment grounding conductor) is not insulated. Unsheathed multi-conductor cables used as service entrance cables use an uninsulated neutral conductor in most installations.

All cables that may be used in electrical power systems are described in the NEC and are tested and listed by an approved testing laboratory to standards that are published by Underwriters Laboratories. Cables that are not described in the NEC are not allowed in NEC compliant electrical systems. Cables are described by the size of the conductor or conductors and by the type of insulation.

Conductors that are commonly used in PV installations are classified in two categories. The first are conductors that are used in fixed (non-moving) installations and are discussed in Chapter 3 (Articles 300-365) of the NEC. Table 310-13 identifies all of the acceptable cables. These cables are generally rather stiff with from one to 13 or so strands of copper wire making up each conductor, but they may be obtained on special order with a high number of strands that makes them more flexible and easier to install.

In installations where there is significant movement such as PV trackers, conductors known as flexible cords and cables may be used. These cables are covered by Article 400 in the NEC and Table 400-4 identifies them. These Article 400 flexible cords and cables may not be used in fixed installations where there is no movement, but there are a few exceptions to this rule. For example, flexible cables may be used as inter-cell battery cables where stiff cables might deform battery cells.

Conductors come with numerous and differing insulations. The type and thickness of the insulation determines the temperature and moisture rating of the conductor and how it can be installed-in free air, in conduit, direct buried, etc. The temperature and moisture ratings of the insulation along with the conductor size are used to determine the ampacity or current-carrying capacity of the cable in various installations.

In most residential and commercial electrical power systems, conductors are required to be installed as part of a multi-conductor sheathed cable assembly (such as type NM non-metallic sheathed cable a.k.a. Romex ®) or in a conduit or other raceway-either metal or nonmetallic. Single-conductor cables are not permitted, either exposed or installed inside walls. The wiring between PV modules is an exception.

PV Module Wiring

Because PV modules operate at high temperatures and are installed in exposed locations, the cables used to connect them require special attention. Some PV modules have separate positive and negative junction boxes, one at each end of the module. With these types of modules, the NEC allows exposed single-conductor cables to be used for module-to-module connections. The cable must be insulated properly for the exposed, outdoor conditions. This generally means that it must be rated for high temperatures (90°C insulation is required), wet-rated (it does rain), sunlight resistant (part of the UL Listing information), and otherwise suitable for the environment. Cable types that meet all of these requirements (although not marked as such) are USE-2 (Underground Service Entrance), UF (Underground Feeder where marked sunlight resistant), and SE (Service Entrance). Both USE and SE are tested and listed as sunlight resistant although they are not so marked. Single-conductor UF cable is acceptable when marked sunlight resistant because it has a 90°C insulation.

If the PV array is accessible to the general public (children of all ages), then consideration should be given to placing all wiring in conduit for maximum wiring and public protection. Local codes generally require that all wiring in commercial and multifamily dwelling installations be placed in conduit.

Other wiring methods that are generally acceptable for any electrical wiring, including multiple conductor sheathed cables and conductors in conduit may be used to connect PV modules. The use of UF cable as a multiple-conductor sheathed cable for PV module interconnections should be avoided because it is rated as a 60°C cable, which is not useable on PV modules that require 90°C cables.

PV modules are installed in exposed locations (NEC definition) and, when conduit is used, the cables installed in the conduit must be wet-rated and rated for high temperatures. Single conductors, that are intended for use in conduit, meeting these requirements include types THWN-2, RHW-2, and XHHW-2. The “T” in these type ratings refers to a thermoplastic insulation. The “R” represents a rubber insulation, and the “X” represents a cross-linked synthetic rubber. The letter “H” represents a high-temperature (75°C) insulation under dry conditions, and “HH” represents a higher temperature (90°C) insulation. The “W” represents an insulation rated for wet areas. The “N” represents a nylon jacket. The “-2” designation represents an insulation that is rated for both high temperatures (90°C) and wet locations.

Many commonly available cables have multiple markings such as THHN/THWN-2 or USE-2/RHW-2/XHHW-2. This allows a single cable to be used throughout an installation without having to splice two different cables together as the installation method varies. After the wiring from the PV array has left the immediate vicinity of the PV modules, the single-conductor exposed cables are no longer allowed and one of the NEC Chapter 3 wiring methods must be used. This transition, where exposed cable has been used, usually takes place in a junction box fastened to the array mounting frame. The transition is required to provide greater degrees of physical and fire protection for wiring run inside a building. Even the exposed, single-conductor cables used for PV module connections should be fastened securely to the module and array frames for physical protection.

Inside Wiring

The wiring for a PV system, both ac and DC, that is installed away from the PV array must conform to the standard electrical wiring practices used throughout the country for ac wiring. These numerous wiring methods are described in Chapter 3 of the NEC and differ between residential and commercial installations. Since batteries are usually fixed installations mounted inside a structure, the wiring to and from the battery bank must also comply with the Chapter 3 NEC requirements.

Battery Wiring

Nearly all cables and wiring methods listed in Chapter 3 are suitable for batteries. These conductors will usually be larger in size than other conductors in the system, because the currents that they are required to handle will be higher. The use of metal conduits and metal-sheathed cables near batteries should be avoided due to the potential for corrosion and short circuits.

Inside battery enclosures, single-conductor cables may be used for battery interconnects, but outside the enclosure, a standard wiring method must be used. Welding cables and automotive battery cables are not acceptable cables for meeting NEC requirements unless they have been permanently attached to the battery cells by the battery manufacturer.

Battery cables in the battery enclosure are typically THWN, RHW, or USE type cables. In the smaller sizes (up to about number 1 AWG), standard building wire with 7-13 strands of copper is generally used. In the larger sizes (1/0 AWG and up), flexible, multiple stranded (400+ strands) cables of the USE or RHW type are used. These cables are suitable for use in the battery enclosure and then in conduits between the battery enclosure and the power center or inverter.

Where to Buy

Most types of cables are available from local electrical supply stores and building supply stores like Home Depot. Some of the more specialized cables like number 10 AWG stranded USE cable used for module wiring and the extra-flexible USE/RHW cables used for battery-to-inverter connections are available from the larger PV distributors and dealers that advertise in *Home Power Magazine.*

In the next Code Corner Column, the correct sizing of the various cables in a renewable energy system will be covered. The missing fuse and the dodo diode may also be addressed.

Questions or Comments?

If you have questions about the NEC or the implementation of PV systems following the requirements of the NEC, feel free to call, fax, or write me at the location below. Sandia National Laboratories sponsors my activities in this area as a support function to the PV Industry. This work was supported by the United States Department of Energy under Contract DE-AC04-94AL8500. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

Access

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