Code Writing Processes and Series Diodes

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Some readers that have written to *Home Power Magazine* and to me have expressed concerns about the contents of the National Electrical Code® (NEC®). They have also asked for reasons for some requirements and also how proposed changes related to PV systems for the code come about. A brief review of how recent 1999 code changes were developed will answer most of these questions and will give some background on "Article 690 - Solar Photovoltaic Systems." The Code Corner articles that I have been writing have been an important effort to extend the PV industry activities related to the NEC to *Home Power* readers.

Article 690 - Solar Photovoltaic Systems

Article 690 first appeared in the 1984 issue of the NEC, several years after the first terrestrial PV systems were installed to power homes or to tie them to the utility grid. The Code Corner column actually started with issue #13 of *Home Power Magazine* (in Oct./Nov. 1989) and has appeared in nearly every issue since then. Thanks to a successful *Home Power Magazine*, and in response to years of Code Corner articles, I get more than a half dozen calls a month from *Home Power* readers with questions about the code requirements. One call recently came from the Falkland Islands while others have come from as far away as England and South Africa. No one can doubt the scope of the *Home Power Magazine* international audience.

I have discussed the manner in which the NEC is developed in a number of Code Corner Columns. Readers of issues 51, 52, 53, and 54 were given the name of a person to contact for anyone that desired to participate with a Task Group in the process of formulating proposals for the 1999 NEC. The National Fire Protection Association (NFPA) appointed this nine person Task Group named "CMP#3 Task Group, Article 690 - Photovoltaic Solar Systems" to review and propose changes to bring the Article up to the state-of-the-art for PV systems. In *HP* #55, PV industry representation for the group of volunteers that served on the Task Group was identified. That Task Group helped to formulate and approve for submittal some of the proposals for Article 690 for the 1999 NEC. Proposals were also submitted by individuals outside the Task Group.

The formation of the Task Group was at the request of the CMP#3 Chairperson. I was elected the Secretary of that Task Group, therefore my name is used as submitter of all the Task Group proposals and comments. More important than the Task Group in this process was the PV industry support provided by a team of experienced people belonging to the Solar Energy Industries Association Technical Review Committee (TRC) on Standards and Codes. They prioritized issues and then proceeded to formulate code language to address those issues. The TRC consisted of more than 60 volunteers representing the entire spectrum of the PV industry. The group included customers, dealers, installers, systems houses, electrical contractors, utilities, university researchers, and module, inverter, and charge controller manufacturers plus two from the national laboratories. This group met two to three times each year during 1995, 1996, and 1997 to work on the 1999 NEC proposals.

Each Task Group proposal submitted to the NFPA for the 1999 NEC contained the following statement: "This proposal is the result of work by NFPA Ad Hock Task Group to CMP-3; Task Group-Article 690-Solar Photovoltaic Systems and supported by the Solar Energy Industries Association (SEIA) Technical Review Committee on Standards and Codes." Each proposal was balloted within the TRC and the Task Group before submittal.

The proposals for the 1999 NEC were submitted to the NFPA in November 1996, nearly two years before the publishing date of the NEC. They have also gone through an extensive NFPA technical and public review process. The process and suspense dates for the 1999 NEC, for those who read the NEC in detail, are printed in the back of each copy of the 1996 NEC. Everyone is invited to participate by the NFPA and the NFPA proposal form is printed in the NEC. All it takes to propose changes are some good, well substantiated requirements, needs, or solutions. Put them on the form, drop them in an envelop with a 32 cent stamp and mail them to the NFPA before the NFPA established deadline. Once in the system, code making panels must pass proposals by a 2/3 majority before they can become code.

Series Diodes — Old Technology with New Applications

Blocking diodes have been used for years to prevent batteries from feeding current back into PV arrays at night. Only in recent times have they been eliminated from low voltage PV systems. In *HP* #59 it was mentioned that diodes were one possible way to protect PV modules from reverse currents caused by module or wiring faults. Overcurrent protection is required on all modules and the requirement is marked on the back of all listed modules. Fuses are currently required, but these are seldom used to provide this required protection. There are cost and performance considerations involved in the selection of any device used to provide this protection for the PV module.

Although the use of diodes in this manner does not currently meet UL or code requirements for module protection, future consideration might be given to changing the UL Standards to allow such use. As Dave Katz pointed out, there are some performance impacts of using diodes. These impacts are nothing new and have always been associated with the use of diodes, especially in low voltage PV systems (12 to 24 volt).

In utility interconnected systems that employ peak power trackers in the inverters, power lost in the diodes is due to the PV current through the diode and the voltage drop across the diode. Since most utility interactive systems operate at 48 volts and above, the diode losses, while measurable, are not significant. For example, a 2,000 watt PV system operating at 200 volts and 10 amps might have 14 watts of loss in the diodes — only 0.7%.

Low voltage, stand alone PV systems using crystalline silicon PV modules that charge batteries may have the available battery charging current reduced when series protection diodes are used. These reductions in available charging current are primarily a function of the system voltage (12 or 24), battery charging voltages (ranging from low states of charge to equalizing voltages), the PV module characteristics, and the module operating temperature.

The use of a diode in series with each string of PV modules in 12 or 24 volt systems causes the module(s) to shift the module operating point to a higher voltage. The shift in operating point is a function of the battery (charging) voltage and the module operating temperature. The resulting shift in available PV module current is an inverse function of the battery voltage and module operating temperature. The shift (with the diode and with the operating voltage higher than the maximum power point voltage) lowers the available PV current that can flow to the battery. The table below was generated using a generic 49 watt PV module that at standard test conditions of 25° C cell temperature and 1000 watts per square meter of irradiance, has the following parameters: Isc=3.18 amps, Voc=21 volts, Vmax=16.6 volts, Imax=2.95 amps, and Pmax=49.

As an example, a PV module simulation and performance program was used to obtain the numbers shown. Battery temperatures were assumed to be constant and were not considered in this analysis. I ran the simulation at module temperatures of 45° C (113° F), 55° C (131° F), and 65° C (149° F) to represent the range of temperatures that modules operate at when ambient temperatures are 25° C (77° F) to 40° C (104° F). In windy conditions, or conditions with lower or higher ambient temperatures, the modules may operate at temperatures higher or lower than the 45 to 65° C range.

I used battery voltages of 12, 13.4, 14.8, and 15.5 volts (twice those values for 24 volt systems) to simulate a battery at various states of charge. The 15.5 volt (31 volts on 24 volt systems) operation represents an equalizing voltage of a flooded lead acid battery.

Percentage of Current Reduction when Diode is Added to Circuit

	12 Volt System		*24 Volt System*	
° Module Temp.	*Battery Voltage*	*Current Reduction*	*Battery Voltage*	*Current Reduction*
45	12.0	0.6%	24.0	0.3%
45	13.4	1.6%	26.8	0.6%
45	14.8	4.2%	29.6	1.6%
45	15.5	7.1%	31.0	3.0%
55	12.0	0.6%	24.0	0.3%
55	13.4	2.5%	26.8	1.0%
55	14.8	7.4%	29.6	3.4%
55	15.5	11.8%	31.0	5.4%
65	12.0	1.6%	24.0	0.6%
65	13.4	4.5%	26.8	2.3%
65	14.8	12.3%	29.6	5.4%
65	15.5	19.4%	31.0	8.9%

When the battery voltages are low (low states of charge) and the module temperatures are moderate (cool ambient temperatures), the reduction in the available current is very small. On the other hand, when the batteries are at a higher voltage (mid to high states of charge or being equalized) and the PV modules are at high temperatures (in hot climates) the reduction in available charging currents can approach 20% on a 12 volt system. For a 24 volt system, the reductions in current due to the use of a diode are less than half the reductions in a 12 volt system.

All voltage drops in a PV system shift the operating point of the PV module. Once the operating voltage of the PV array is higher than the maximum power point voltage, then each additional voltage drop (including the drop caused by the use of a diode) enhances the decrease in available current from the PV modules. All PV systems, especially low voltage systems, should be designed for low voltage drops, code compliant wiring, and tight connections.

Dave Katz was on the money, so to speak. If you live in the hot sunny southwest and your PV system is sized such that your batteries operate in a high state of charge (high voltages) for much of the day, measurable reductions in available charging current (if a diode is inserted in the system) are likely. On the other hand, the reduction of charging current may not be critical since the charge regulation process will also result in average current reductions as the battery becomes fully charged. When low voltage systems operate in cooler climates, the reductions are less.

Miscellaneous Material

Drake Chamberlin, in his letter in *Home Power* #62, made some interesting points about code practice. Drake is a practicing electrician who installs PV systems. I would urge caution, however, when using 90° C wiring on Square D circuit breakers and fused safety switches. All of those devices that I can find require 60° C or 75° C conductors and some require 75° C conductors without allowing 60° C conductors. The reason that 60° C conductors are not allowed on some circuit breakers is that these devices normally operate at high temperatures that would damage conductors with 60° C rated insulation. Even where the devices are rated for 60° C/75° C or 60° C conductors, 90° C conductors may be used if operated at currents that keep the conductor cooler than the 60° C or 75° C. This can be easily accomplished by using the 60° C or 75° C ampacity columns from NEC Table 310-16 and 310-17 when using 90° C conductors. Such temperature limitations may also apply to terminals used for splices and even terminals used on switches.

Drake also pointed out that he thought there wasn't much reason to use 90° C conductors on PV modules. However, with a very few exceptions, most listed PV modules are marked on the back that 90° C conductors must be used. UL and the PV industry are considering a 90° C marking for all listed modules. In some installations, the J-box temperature exceeds 65 to 70° C where conductors rated at only 75° C lose most, if not all, of their current carrying rating.

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, email, or write me. 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 multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

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