NEC and UL Requirements Too Conservative?

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As the photovoltaic (PV) power industry moves into a mainstream position in the generation of electrical power, some persons question the seemingly conservative and redundant requirements established by Underwriters Laboratories (UL) and the National Electrical Code (NEC) for system and installation safety. This Code Corner will attempt to address those concerns and highlight the unique aspects of PV systems that dictate the requirements.

The National Electrical Code (NEC) is written with the requirement that all equipment and installations are approved for safety by the authority having jurisdiction (AHJ) to enforce the NEC requirements in a particular location. The AHJ (known as the electrical inspector) readily admits to not having the resources to verify the safety of the required equipment and relies exclusively on the testing and listing of the equipment by independent testing laboratories such as Underwriters Laboratories (UL). The AHJ also relies on the requirements for field wiring specified in the NEC to ensure safe installations and use of the listed equipment.

The standards published by UL and the material in the NEC are closely harmonized by engineers and technicians throughout the electrical equipment industry, the electrical construction trades, the national laboratories, the scientific community, and the electrical inspector associations. The UL Standards are technical in nature with very specific requirements on the construction and testing of equipment for safety. They in turn are coordinated with the construction standards published by the National Electrical Manufacturers Association (NEMA). The NEC is deliberately written in a non-technical manner for easy understanding and application by electricians, electrical contractors, and electrical inspectors in the field.

The use of listed (by UL or other laboratory) equipment ensures that the equipment meets well-established safety standards. The application of the requirements in the NEC ensures that the listed equipment is connected with field wiring and is used in a manner that will result in an essentially hazard-free system. Use of listed equipment and installing that equipment according to the requirements in the NEC will contribute greatly to not only safety, but also the durability, performance, and longevity of the system.

Sometimes Controversial Areas

The NEC does not present many highly detailed technical specifications. For example, the term "rated output" is used in several cases with respect to PV equipment. The conditions under which the rating is determined are not specified. The definitions of the rating conditions (such as Standard Test Conditions for PV modules) are made in the UL Standards that establish the rated output. This procedure is appropriate because of the NEC level of writing and the lack of appropriate test equipment available to the NEC user.

UL Standards

UL Standard 1703 requires that the instructions for listed PV modules contain specific requirements for the installation of such modules. The rated (at Standard Test Conditions) open-circuit voltage and the rated short-circuit current of crystalline PV modules are to be multiplied by factors of 125% before further calculations are made for conductor and overcurrent devices.

The 125% factor on the open-circuit voltage (Voc) is needed because, as the operating temperature of the module decreases, Voc increases. The rated Voc is measured at a temperature of 25°C and while the normal operating temperature is 40-50°C when ambient temperatures are around 20°C, there is nothing to prevent sub-zero ambient temperatures from yielding operating temperatures significantly below the 25°C standard test condition.

A typical module will have a voltage coefficient of -0.38 %/°C. A system with a rated open-circuit voltage of 595 volts at 25°C might be exposed to ambient temperatures of -30 °C. This voltage (595) could be handled by the commonly available 600-volt rated conductors and switchgear. At dawn and dusk conditions, the module will be at the ambient temperature of -30°C, will not experience any heating, but can generate open-circuit voltages of 719 volts (595 x (1 + (25 + 30) x 0.0038)). This voltage substantially exceeds the capability of 600-volt rated conductors, fuses, switchgear, and other equipment. The very real possibility of this type of condition substantiates the UL requirement for the 125% factor on the rated open-circuit voltage.

For 24-volt stand-alone systems, this 125% factor presents a problem when using Square D circuit breakers which are UL-Listed for 48 volts DC. With a 44-volt open-circuit voltage, the 125% factor gives a system voltage of 55 volts which exceeds the 48-volt rating on the breaker. When a load center, like the Ananda Power Center, is listed as a unit, these breakers are tested at the higher voltages and are approved for the use. When the QO breakers are plugged into a Square D load Center (also listed for 48-volts DC), they should be used only for a maximum system voltage of 48 volts which means they are suitable for nominal 12-volt systems only.

The UL Standard 1703 also requires that the rated (at STC) short-circuit current of the PV module be multiplied by 125% before any other factors are applied such as those in the NEC. This UL factor is to provide a safe margin for wire sizes and overcurrent devices when the irradiance exceeds the standard 1000 w/m^2. Depending on season, local weather conditions, and atmospheric dust and humidity, irradiance exceeds 1000 w/m^2 every day around solar noon. The time period can be as long as four hours with irradiance values approaching 1200 w/m^2, again depending on the aforementioned conditions and the type of tracking being used. These daily irradiance values can increase short-circuit currents 20% over the 1000 w/m2 value.

Enhanced irradiance due to reflective surfaces such as sand, snow, or white roofs, and even nearby bodies of water can increase short-circuit currents by substantial amounts and for significant periods of time. Cumulus clouds also can increase irradiance by as much as 50%.

Another factor that must be addressed is that PV modules typically operate at 30-40°C above the ambient temperatures. In crystalline silicon PV modules, the short-circuit current increases as the temperature increases. A typical factor might be 0.1%/°C. If the module operating temperature were 60°C (35°C above the STC of 25°C), the short-circuit current would be 3.5% greater than the rated value. PV modules have been measured operating as high as 80°C. The combination of increased operating temperatures, irradiances over 1000 w/m2 around solar noon, and the possibility of enhanced irradiance certainly justify the UL requirement of 125% on the rated short-circuit current.

NEC Requirements

The NEC requires that the short-circuit current of the module, source circuit, or array be multiplied by 125% before calculating the ampacity of any cable or the rating of any overcurrent device used in these circuits. This factor is in addition to the UL required 125%. It is required because the terminals on most fuses, circuit breakers, and panel boards are designed and tested by UL to operate continuously at only 80% of their rated values. The 125% NEC factor ensures that these terminals are operated within their ratings and are not subject to overloading which can cause excess heating, expansion, loosening, and possible overheating of connected overcurrent devices. Both cable and overcurrent devices must be derated to avoid stressing these terminals.

Since short-circuit currents in excess of the rated value are possible from the discussion of the UL requirements above, and these currents are independent of the NEC requirements, good engineering practice dictates that both factors should be used at the same time. This yields a multiplier on short-circuit current of 1.56 (125% x 125%).

The NEC also requires that the ampacity of conductors be derated for the operating temperature of the conductor. This is a requirement because the ampacity of cables is given for cables operating in an ambient temperature of 30°C. In PV systems, cables are operated in an outdoor environment and should be subjected at least to a temperature derating due to an ambient temperature of 40°C. PV modules operate at high temperatures and in some installations as high as 80°C (concentrating modules operate at even higher temperatures). The temperatures in module junction boxes approach these temperatures and conductors in free air that lie against the back of these modules are also exposed to these temperatures. Temperatures this high require that the ampacity of cables be derated by factors of 0.33 to 0.58 depending on cable type, installation method (free air or conduit), and the temperature rating of the insulation.

Cables in conduit where the conduit is exposed to the direct rays of the sun are also exposed to elevated operating temperatures.

Cables with insulation rated at 60°C have no ampacity at all when operated in environments with ambient temperatures over 55°C. This precludes their use in most PV systems.

Redundancy and Conservatism or Not?

There appears to be little question that the 125% UL factor on voltage is necessary in any location where the ambient temperatures drop below 25°C. Even though the PV system can provide little current under open-circuit voltage conditions, these high voltages can damage electronic equipment and stress conductors and other equipment by exceeding their voltage breakdown ratings.

In ambient temperatures from 25 to 40°C and above, module short-circuit currents are increased at the same time conductors are being subjected to higher operating temperatures. Enhanced irradiance can occur at any time. Therefore the UL and NEC factors for short-circuit current output and NEC conductor temperature deratings are not redundant.

Good engineering practice suggests that the UL Standard 1703 requirements and the NEC requirements are neither conservative or redundant and that they should be applied to all systems.

Implementation of these Requirements

The table below shows some common cable sizes (in free air and in conduit), the 30°C(86°F) ampacity, the 65°C(149°F) temperature derated ampacity, and the amount of short-circuit current (Isc) they can handle in typical installations. Underground Service Entrance cable type USE-2 cable has been selected for this example which has a 90°C insulation in wet and dry locations. A back-of-module temperature of 65°C has been assumed which is typical for installations in the US. For other cables and hotter or colder operating conditions, Tables 310-16 and 310-17 in the NEC should be used. A temperature derating factor of 0.58 is used and when combined with the 125% for the UL requirement and the 125% for the NEC requirement, the overall derating factor on the ampacity of the cable at 30°C is 0.3712.

	Installed in Free Air Ampacity			Installed in Conduit Ampacity		
Cable Size	30°C	65°C	Max Isc	30°C	65°C	Max Isc
14 AWG	35	20.3	13.0	25	14.5	9.3
12 AWG	40	23.2	14.9	30	17.4	11.1
10 AWG	55	31.9	20.4	40	23.2	14.9
8 AWG	80	46.4	29.7	55	31.9	20.4

To apply the table, just divide the short-circuit current of the module being used into the appropriate “Max Isc” number in the table. This will give the number of modules that can be connected in parallel using that cable size. If the number of modules in parallel is inadequate, a larger cable should be selected and the calculation repeated. Note that for long cable runs, these numbers do not take into account voltage drop. Also note that no more than three cables can be installed in a conduit. More than three require an additional derating factor to avoid overheating.

For example, a module has been selected that has a short-circuit current of 3.8 amps. With number 10 AWG cable in free air, five modules can be connected in parallel (20.4 / 3.8 = 5.4). Always round down for safety.

If the number of modules required to be in parallel exceeds the ampacity of number 8 AWG cable (the largest size that can be used with typical modules), then the array should be divided into subarrays with each set of subarrays protected by an overcurrent device.

Overcurrent Protection

The overcurrent device (fuse or circuit breaker) should have an ampacity rating of not less than 1.56 times the short-circuit current in the circuit being protected. This is derived from the UL and NEC requirements (125% x 125% =156%). The overcurrent device will normally have a rating less than the temperature derated ampacity of the cable.

For example, the five modules with an Isc of 3.8 amps each are connected in parallel with number 10 AWG USE-2 cable which has a temperature derated ampacity of 31.9 amps in free air from the table. The overcurrent device protecting this cable should be rated at 30 amps (3.8 x 5 x 1.56 = 29.6) which is less than the 31.9 amps ampacity of the cable.

In the next Code Corner, a series of examples will be started showing how the balance of systems (everything except the sizing of the array, batteries, and inverters) are designed for several different systems.

Access

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