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TECHNICAL BRIEF

SUBJECT: Protection of dc and ac cables in a PV system with HiQ Truestring inverters

DATE: April 2016

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Introduction:

Providing adequate overcurrent and fault protection for cables and conductors in a rooftop or ground-mounted PV system is essential. The National Electrical Code (NEC) governs the installation of electrical wiring methods in the United States. The dc side of a PV system has become well understood among contractors and code enforcement over the past decade. What is less familiar to many in the electrical industry is how to install the ac side of PV system network of inverters. The microinverter industry has paved the way for a better understanding of these ac cable systems, but there remain many questions even with experienced engineers in the PV industry. This technical brief is intended to help clarify the proper application of the NEC for these ac cable systems.

How Does the NEC Address Cables for a HiQ PV System?

Dc Wiring Methods with HiQ Inverters:

First, we will address the dc side of the inverter. A current HiQ product line includes two 3-phase inverters, the TrueString 480V 8kW Inverter, and the TrueString 208V, 5.75kW Inverter. Both of these inverters are designed to receive up to two series strings of PV modules. Both the 480V version and the 208V version can accept strings with a maximum voltage of up to 1000Vdc. Since each inverter is designed for only two input strings, and the inverter itself does not backfeed current into the array, the NEC does not require string fusing on the input to these inverters in accordance with 690.9(A) Exception.

2014 NEC:
690.9(A) ***Exception:*** *An overcurrent device shall not be required for PV modules or PV source circuit conductors sized in accordance with 690.8(B) where one of the following applies:*
(a) There are no external sources such as parallel-connected source circuits, batteries, or backfeed from inverters.
(b) The short-circuit currents from all sources do not exceed the ampacity of the conductors or the maximum overcurrent protective device size rating specified on the PV module nameplate.

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2-Circuits Without Fusing:
It is well understood in the PV industry, by contractors and enforcement alike, that two PV source circuits can be connected to a PV inverter input circuit without fusing—provided that the inverter is not capable of backfeeding current into the PV array. A two string PV array of this type complies with the second exception (b) in 690.9(A) shown above since the HiQ inverter meets this requirement of not providing backfeed current. In a fault condition on the dc-side of the inverter, the conductors for each PV source circuit will never see more than the current that one string can produce. As long as the string wiring is adequate for the current of the string, no additional ampacity is required and no string fuses are required. Adding string fusing to a two-string PV array, when the inverter does not backfeed current, does not improve the safety of the PV array and its conductors. In fact, installing fuses in a PV array reduces reliability as fuses can fail over time due to thermal cycling in hot rooftop applications. Benefits of a two-string PV array include lower cost, enhanced reliability and fewer components with the elimination of string fusing.

Ac Wiring Methods with HiQ Inverters:

Traditional wiring methods in the United States place the ac inverter output circuit conductors in conduit. However, just as the dc circuits connected to PV modules are all done with exposed cabling systems, ac circuits on small microinverters are all done with exposed ac cabling systems. The term "microinverter" does not exist in the NEC so the size of the inverter, and its connection to an exposed ac cabling system is simply an issue of sufficient conductor ratings. These ratings include environmental ratings such as sunlight resistance and all current and voltage conditions to which the cable is exposed.

Properly defining the necessary current ratings for ampacity and fault currents are the most challenging ratings to address. Since the inverter has a very well-defined current output, the current flow under normal conditions is simple. The maximum current from an inverter is defined in 690.8(A)(3) as the continuous output current rating of the inverter. The maximum current for the HiQ Truestring 8kW unit is 9.6 amps and for the 5.75kW unit is 16 amps. It is simple to size conductors for maximum current. What is less simple is determining the adequacy of the cable system to perform properly in a fault condition since the cable is connected to an ac circuit breaker with the ability to supply upwards of 5,000 amps in a short circuit condition.

While the tap rule in section 240.21(B) of the NEC is a logical place to start the discussion on the validity of the overcurrent protection and circuit sizing for the HiQ system, the most appropriate sections related to the HiQ inverter are found in sections 705.60 and 705.65(A) of the NEC. Clearly, the ampacity of the branches and the trunk of the HiQ cable system meet the ampacity requirements of 705.60 since this requirement only requires that the conductor have sufficient ampacity for the maximum current of the inverter. The provisions of 705.65(A) are not extremely explicit for the HiQ configuration, so engineers and authorities having jurisdiction (AHJs) could differ on the application of 705.65(A). Since 705.65(A) cites Article 240, this draws the line back to section 240.21(B). Section 705.65(A) is provided below for reference.

2014 NEC:

> **705.65 Overcurrent Protection.**
> **(A) Circuits and Equipment.** Inverter input circuits, inverter output circuits, and storage battery circuit conductors and equipment shall be protected in accordance with the requirements of Article 240. Circuits connected to more than one electrical source shall have overcurrent devices located so as to provide overcurrent protection from all sources.
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> *Exception: An overcurrent device shall not be required for circuit conductors sized in accordance with 705.60(B) and located where one of the following applies:*
> *(1) There are no external sources such as parallel connected source circuits, batteries, or backfeed from inverters.*
> *(2) The short-circuit currents from all sources do not exceed the ampacity of the conductors.*
>
> Informational Note: Possible backfeed of current from any source of supply, including a supply through an inverter into the inverter output circuit and inverter source circuits, is a consideration in determining whether adequate overcurrent protection from all sources is provided for conductors and modules.

As may be recognized in this section, the language originated from Article 690 on sizing PV source circuits so some of the language is a little confusing as it relates to utility-interactive inverters. That being said, the short-circuit current of a utility-interactive inverter is exactly zero amps since all utility-interactive inverters are required to cease to energize the circuit in the case that the voltage drops outside of the ac voltage operating window of the inverter. This feature of the utility-interactive inverter also prevents the inverter from backfeeding another inverter in the case of a fault since backfeed current requires a low ac voltage which would trip the inverter within a few cycles. The exception provides the basis for the HiQ cable design. Since the inverters have a current limited output, just as PV source circuits are current limited, and the inverter has no short circuit or backfeed contribution, it follows that the conductors need only to be sized according to the operating current as the HiQ installation instructions show. The only location where overcurrent protection is needed is at the connection to the utility source.

Since the HiQ inverter is rated for connection to a 40-amp OCPD, it follows that the cables be capable of withstanding the short circuit current of a 40-amp circuit breaker. A typical circuit breaker (thermal or thermal-magnetic) will interrupt a short circuit within one cycle or less. Therefore the damage curve of the cable must be capable of the short circuit current of the utility supply for one cycle (16.6 msec). The smallest conductors in a HiQ whip are 12 AWG copper conductors and can withstand over 20,000 amps for one cycle without damaging the copper or the insulation system (Insulated Cable Engineers Association, ANSI Standard 32-382-2007). A typical rooftop PV system installation even with an extremely high utility short circuit current of 65,000 amps and relatively short conductor lengths, will have a maximum short circuit current at the 12 AWG whip of less than 3,000 amps due to the impedance in the circuits from the service entrance to the inverter.

For those who would argue that a 65kA utility service is not sufficiently conservative to cover all possible installation conditions, we can look to the sizing of load taps in the NEC. Section 250.21(B) covers the sizing of load taps for various circuits. Circuits inside buildings are more restrictive given the higher risk should a conductor fail. The 25' tap rule in 250.21(B)(2) is based on conservative fault calculations that apply to all building wiring systems without limitations based on utility available fault currents. These conservative conductor sizing allowances permit conductors to have an ampacity of 1/3rd the current rating of the utility supply breaker for taps up to 25 feet. Since the supply breaker is specified as 40-amps in the HiQ installation manual, the tap would have to have an ampacity of 13.3-amps if it were to meet the requirements of 240.21(B)(2). Keep in mind this is hypothetical since the HiQ whip is not technically a load tap as defined in the NEC. The 12 AWG conductor used in the HiQ whip has an ampacity of 17.4 amps even in the hottest installation location in the United States. (12 AWG ampacity = 30 amps x 0.58 = 17.4 amps). The temperature correction factor was chosen based on installation in Yuma, Arizona over 0.5" above the roof surface. The ampacity of 17.4 amps is sufficient for the 16-amp maximum current of the HiQ Truestring 5.75kW inverter.

This examination of the rule for taps in 240.21(B) shows that the HiQ design is conservative for branches off of the trunk cable of 25 feet or less. This is comparing the conductor sizing to limitations for tap circuits inside buildings. The limitations for tap circuits outside buildings is far more liberal in 240.21(B)(5). Taps are permitted of unlimited length provided that an overcurrent device is at the end of the tap. Some might misconstrue this provision in 240.21(B)(5) as indirectly requiring an overcurrent device at the HiQ inverter. Keep in mind that 240.21(B) applies to sizing load taps that could have an undetermined amount of load on the tap. The HiQ inverter has a very defined current so a circuit breaker at the inverter would serve no practical purpose. If the inverter develops an internal short circuit, fault current will flow from the 40-amp circuit breaker and trip without damaging the conductors.

In summary, the basic conductor design of the HiQ cable system appears to be technically sound and compliant with the NEC even when compared with indoor load taps up to 25 feet in length. Since these whip conductors are necessarily installed outside

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buildings, whips of unlimited length would be compliant with 240.21(B)(5) even though that section is intended for load circuits. HiQ has recently certified their ac cabling system, by a national recognized testing laboratory (NRTL), for whips up to 35 feet in length by performing the necessary fault evaluations for cabling systems.

The compliance of the HiQ cabling system is open to some interpretation on the adequate sizing of the whip circuits that are field installed. What is clear based on the conservative calculations in 240.21(B)(2), field installed whips up to 25 feet in length are more than adequately sized. Given the recent certification of the whips, the installer can install whips up to 35 feet in length and provide definitive documentation to the inspector that the circuits are properly protected.