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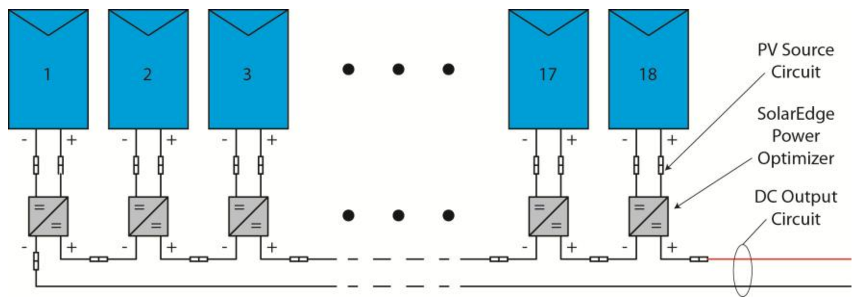
String Fusing Requirements in SolarEdge Systems, Technical Note

Introduction

String design and installation is significantly different in a SolarEdge system when compared to a traditional string inverter. PV modules do not get connected in series directly. Every PV module in the array is first connected to the input of a SolarEdge power optimizer, and the power optimizer output cables are connected to each other in series.



Consequently, the behavior of a SolarEdge system under fault conditions differs from that of a traditional string-inverter system.

This document compares the overcurrent protection mechanisms of both systems and analyzes the systems' responses to various fault scenarios. <u>From this analysis it follows that string fuses are not required in SolarEdge systems</u>.

NEC Requirements

For string inverter systems, NEC article 690.9 outlines the overcurrent protection requirements for photovoltaic source circuits. The intent is to provide overcurrent protection for circuits connected to more than one electrical source. All sources of current need to be considered: multiple series strings of PV modules connected in parallel to the inverter as well as the string inverter itself.

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String Inverter Systems

String Inverters

Grounded installations with transformer-based inverters contain Ground Fault Detector Interrupt (GFDI) which detects ground current ≥1A. However, if there is a ground fault from the array to ground, the fault current will not flow through the inverter and therefore will not be interrupted.

Transformer-less inverters have a built-in Isolation Monitor Interrupter (IMI) circuit, which disconnects the inverter and ceases power export as soon as leakage current to ground is detected. However, some inverters may have a backfeed current >0A.

Strings

To prevent backfeed current from strings from flowing through other strings, diodes are needed. This is a costly solution that is rarely implemented. Typically, fuses are installed, but they don't prevent backfeed current, rather they eventually limit it in overcurrent fault situations.

PV Modules

PV modules have a fuse rating, so that if backfeed current greater than the fuse rating occurs, the fuse will blow and the backfeed current will be stopped.

SolarEdge Systems

SolarEdge Transformer-less Inverters

The UL1741 safety standard requires that utility interactive inverters be evaluated under abnormal operating conditions. One of the abnormal tests determines the amount of current the inverter contributes to a faulted circuit connected to the inverter input terminals. SolarEdge inverters have been verified to provide zero backfeed current to the input source circuits, and have a built-in Isolation Monitor Interrupter (IMI) circuit, which disconnects the inverter and ceases power export as soon as leakage current to ground is detected.

The IMI circuit, which is evaluated as part of the inverter's UL1741 compliance, disconnects fault current flow above 150mA within less than 40ms (and disconnects lower fault currents within 300ms). Since the SolarEdge systems are ungrounded, once the inverter is disconnected there is no current flow to ground faults.

Strings with SolarEdge Power Optimizers

SolarEdge power optimizers provide internal current limitation as described in NEC article 690.8(B)(2). The power optimizers limit current at the PV module source circuit input to 10 amps and limit current at the optimizer DC output circuit to 15 amps. The SolarEdge power optimizers have been certified to provide zero backfeed current to the PV source circuit, and zero backfeed current to the rest of the string – i.e. the string current could flow in only one direction.

PV Modules

The power optimizer backfeed limitation of 0A prevents any backfeed current from reaching the modules, regardless of module fuse rating.

Fault Scenarios – Three-String System

There are two fault scenarios to consider:

- Scenario 1 – A fault to ground in the middle of a string (fault #1 in the diagrams below)
- Scenario 2 – A fault in the wires at the end of a string (fault #2 in the diagrams below)

Scenario 1

String Inverter System

Backfeed current from the other strings flows to the fault. Since there are 3 strings connected to the inverter in parallel, the fault current from the other strings is 2 x Isc, and is not interrupted. If 2 x Isc is greater than the module fuse rating, NEC requires fusing on each of the string in order to prevent the risk of fire due to overcurrent.

SolarEdge System

The power optimizers in the faulted string prevent the backfeed current from the other strings from reaching the fault (see current direction in red in diagram below), and the current is limited to the 15A of the single faulted string. Since the optimizers are rated for this current, there is no fire hazard. Furthermore, the inverter IMI will detect the ground current and shut down within 40 or 300msec (depending on the current value). Since the SolarEdge system is ungrounded, as soon as the inverter is disconnected there is no connection to ground and therefore the current flow immediately stops.

Scenario 2

String Inverter System

Current from all strings flows to the fault. The fault current is 3 x Isc, and is not interrupted. If 3 x Isc is greater than the NEC permitted PV wire ampacity, NEC requires fusing on each of the string in order to prevent the risk of fire due to overcurrent.

SolarEdge System

Current from all strings flows to the fault. The fault current is 3 x 15A. The inverter detects the ground current with its built-in IMI circuit and disconnects the inverter in less than 40ms (well below typical[1] fuse clearing times of 5s and longer). Since the SolarEdge system is ungrounded, as soon as the inverter is disconnected there is no connection to ground and therefore the current flow immediately stops.

[1] http://www.cooperindustries.com/content/dam/public/bussmann/Electrical/Resources/product-datasheets-a/Bus_Ele_DS_4203_PVS-R.pdf

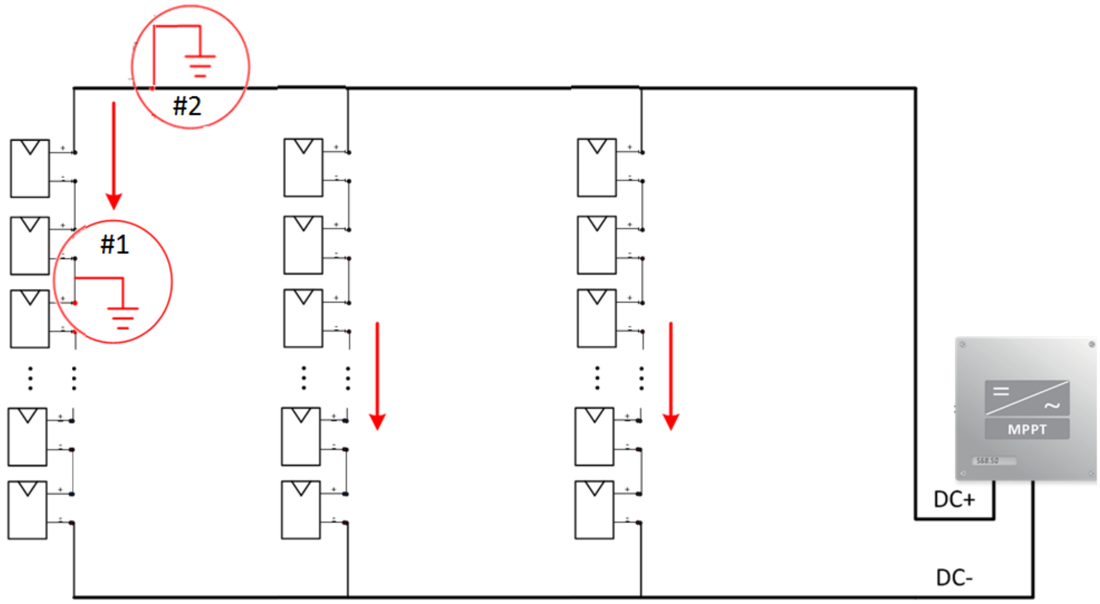

Figure 1 – Fault scenarios in a string inverter system

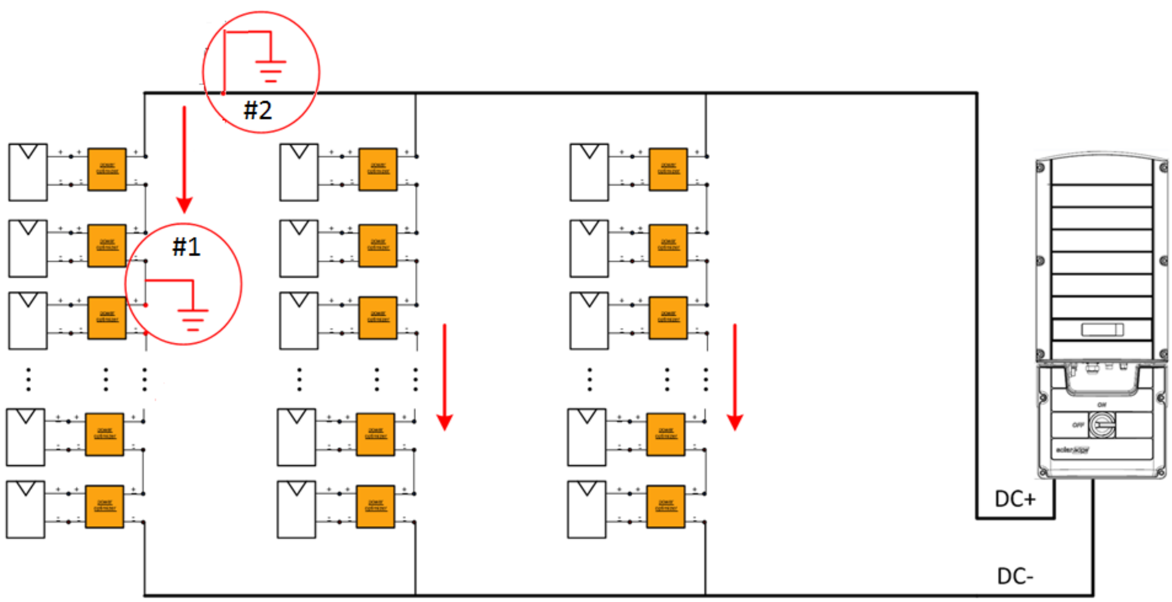

Figure 2 – Fault scenarios in a SolarEdge system

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RE: Protection of SolarEdge Power Optimizer Circuits

To Whom It May Concern:

This letter provides an explanation of the National Electrical Code (NEC) compliance of the protection of SolarEdge power optimizer circuits. What SolarEdge terms a power optimizer is referred to in the NEC as a dc-to-dc converter. The circuits connected to these power optimizers are termed dc-to-dc converter source circuits in the 2017 version of the NEC. This letter discusses NEC compliance related to the protection of these circuits from overcurrents due to fault conditions. The NEC only requires overcurrent protective devices to be installed on dc-to-dc converter circuits in a PV array when there is sufficient current to create an overcurrent situation. The SolarEdge power optimizers have 10 AWG output conductors which have an ampacity of greater than 30 amps. Each dc-to-dc converter source circuit is current limited to no more than 15 amps. This allows three source circuits to be combined on the inverter input without fusing the individual dc-to-dc converter source circuits.

The three primary versions of the NEC currently being enforced throughout the United States include the 2014, 2011, and the 2008. All three of these versions are nearly identical in how they state the exception to the requirement for overcurrent protection on circuits and equipment in NEC 690.9(A).

2008 NEC:
Exception: An overcurrent device shall not be required for circuit conductors sized in accordance with 690.8(B) and located where one of the following apply:
(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.

2011 NEC:
Exception: An overcurrent device shall not be required for PV modules or PV source circuit conductors sized in accordance with 690.8(B) ~~and located~~ 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 specified on the PV module nameplate.

2014 NEC:
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.

The NEC in section 690.9(A) is addressing overcurrent protection for all types of circuits in PV systems. While this section initially did not specifically address dc-to-dc converter source and output circuits, there are strong similarities between PV source and output circuits and dc-to-dc converter source and output circuits. The strongest similarities are related to the current-limited nature of these circuits which is the relevant concern with the exception in 690.9(A). So similar are these circuits that the 2017 version of the

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NEC adds dc-to-dc converter circuits in the 690.9(A) exception to clarify that they should be treated identically to other PV circuits with respect to overcurrent protection.

<u>2-Circuits Without Fusing</u>:
It is well understood in the PV industry, but 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. In the same way, two dc-to-dc converter circuit can be connected to the inverter input circuit without fusing on these circuits—provided that the inverter is not capable of backfeeding current into the dc-to-dc converter array. The SolarEdge inverter meets this requirement of not providing backfeed current.

<u>3-Circuits Without Fusing</u>:
What may be less understood in the PV industry is that occasionally it is possible to parallel 3 PV source circuits without fusing. Since many modules have wiring capable of handling the current from the 2 interconnected neighbor strings in a fault, the limiting factor becomes the overcurrent device rating of the PV module. Many PV modules have a maximum overcurrent device rating of 20-amps. The rated short-circuit output of most 6" cell crystalline PV modules is about 8.5 amps so according to 690.8 these modules produce a maximum current of 10.6 amps (8.5A x 1.25 = 10.6A). This narrowly misses the ability to put 3 circuits in parallel as the short circuit current would be 2 times 10.6 amps, or 21.2 amps—exceeding the 20-amp maximum overcurrent device rating. A PV module with an 8.0-amp short circuit current rating and a 20-amp maximum overcurrent device rating would be allowed to parallel 3 strings without overcurrent protection.

Using this same logic, the SolarEdge power optimizer has conductors capable of handling over 30 amps and the converter will not allow more than 15 amps to pass through it without shutting down. This means that the worst case scenario for a SolarEdge power optimizer array is a fault in the source circuit conductors that allow 30-amps to flow. To keep the current from exceeding 30-amps in the source circuit conductors, only 3 strings should be allowed to be connected without overcurrent protection. Three strings will limit the maximum fault current in the converter array to no more than 30-amps, keeping the current within the ampacity of the conductors. The actual conditions that would cause this 30-amp fault current to flow is extremely unlikely, but it is a worst-case scenario that the NEC is intended to address.

Summary:
<u>SolarEdge power optimizer arrays are code compliant with up to three parallel source circuits without overcurrent protection on these circuits</u>. For four or more source circuits in parallel, these arrays would be required to have a maximum of 30-amp (20-amp minimum—15A x 1.25 = 18.75A) overcurrent protective devices on each source circuit prior to any paralleling. The 2014 NEC and earlier versions would require overcurrent devices on the positive and negative conductors whereas the 2017 NEC only requires overcurrent devices on either the positive or the negative conductors.

Sincerely,

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