Bill Brooks and Sean White

ROUTLEDGE

# PV and the NEC

SECOND EDITION

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BASED ON THE 2020 NEC

# PV and the NEC

Used throughout the United States and many other countries, the National Electrical Code (NEC) is the world's most detailed set of electrical codes pertaining to photovoltaic (PV) systems.

*PV and the NEC* presents a straightforward explanation of the NEC in everyday language. This new edition is based on the 2020 NEC, which will be used widely until 2026, with most of the interpretations and material staying true long after. This book interprets the distinct differences between previous versions of the NEC and the 2020 NEC and clarifies how these code changes relate specifically to PV installations.

Written by two of the leading authorities and educators in the field, this book will be a vital resource for solar professionals, as well as anyone preparing for a solar certification exam.

**Bill Brooks** is Principal Engineer at Brooks Engineering, Vacaville, CA, USA.

**Sean White** is a Solar PV professor, trainer and contractor in the USA.

**Praise for the previous edition:**

"I have had the opportunity to get to know Bill over the past several electrical code cycles and he is a key driver in developing and improving the NEC for solar PV systems. This book that he and Sean have put together is a helpful addition to any library of resources for understanding the NEC requirements related to solar PV systems."

Mike Holt, NEC Expert, USA

"Bill Brooks' and Sean White's version of the NEC Handbook … The authors break down the code with historical context, using their decades of experience developing standards and educating contractors and inspectors. An expert's complement to the code book!"

Anna Bautista, Vice President, Construction and Workforce Development, GRID Alternatives, USA

**Praise for the authors:**

"Very few people have Bill's breadth of knowledge and understanding of PV-related codes and standards … His tireless work has improved the knowledge and understanding of proper installations for PV systems … . I have known Dr. Sean White for more than 7 years. I have participated in and attended several of Sean's courses taught at photovoltaic conferences, and he excels at presenting complicated topics in a clear and concise manner to a diverse audience."

Ward Bower, Inventor of Grid-Tied Inverter at Sandia Labs 1977, NEC Code Making Panel 4, USA

# PV and the NEC

Second Edition

**Bill Brooks and Sean White**

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# Introduction

## The sun is on the cover of the 2020 NEC!

Photovoltaic (PV) is growing fast, and the PV material in the National Electrical Code (NEC) is changing faster than anything the NEC has seen since the days of Thomas Edison and Nikola Tesla hashing it out over dc vs. ac. It appeared that Tesla was right when 2-phase ac power[1] was installed at Niagara Falls: ac was the way of the future, but the future is always unpredictable, and with PV and energy storage, dc is making a comeback.

This book is designed to relay to the layperson working in the PV industry the NEC PV-related material and changes as simply as possible. We hope that professional engineers (PEs) and sunburnt solar installers alike will be able to comprehend its writing style and be entertained just enough to not be bored learning about a Code that has been known to work better than melatonin on a redeye flight.

Since this book is about PV, rather than starting at the beginning of the NEC, we will start with the most relevant article of the NEC, which is **Article 690 Photovoltaic (PV) Systems**; we will then cover the new **Article 691 Large-Scale Photovoltaic (PV) Electric Supply Stations**, which modifies Article 690 for large PV systems, and then dive into the interconnections of **Article 705 Interconnected Electric Power Production Sources**, where we understand how PV and other power sources can connect to and feed other power sources such as the utility grid. The next articles we will cover are those on energy storage, which are the old **Article 480 Storage Batteries** and the newer (and more relevant in 2020) **Article 706 Energy Storage Systems**. While we are on the subject of energy storage, we will cover the newer **Article 710 Stand-Alone Systems** (which was formerly 690.10), and this will lead us to another newer and renewable themed **Article 712 Dc Microgrids.** Articles 706, 710 and 712 were first brought into the

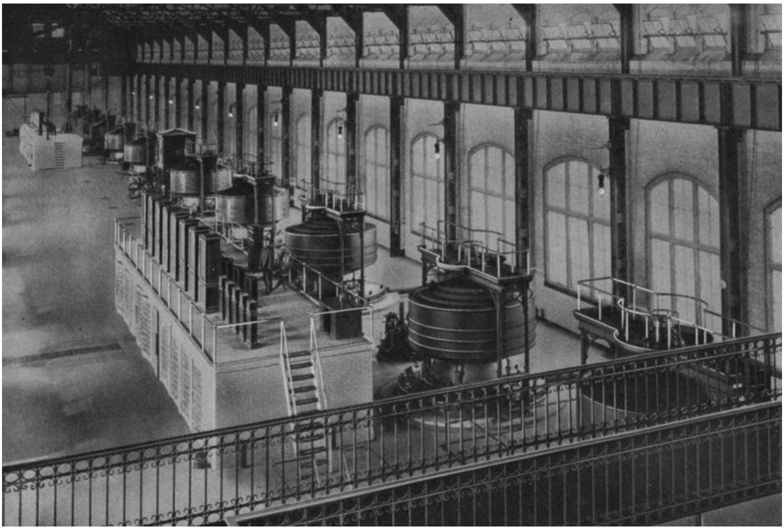

*Figure 0.1* 1895 Niagara Falls power plant

*Source:* courtesy Wikimedia https://en.wikipedia.org/wiki/Adams_Power_Plant_Transformer_House#/media/File: Westinghouse_Generators_at_Niagara_Falls.jpg

NEC in 2017. We will then go back to the beginning of the NEC and look at Chapters 1 through 4 of the NEC, which apply to all wiring systems, including PV. We will see that, in covering the new and renewable PV-centric articles, we already covered the more important parts of Chapters 1 through 4 used for PV systems and all electric installations, such as Article 250 Grounding and Bonding, and Article 310 for wire sizing. There will be many times when we are covering material in Article 690 where we will go back and forth to other articles, since this is the way to properly use the NEC.

The NEC is updated every three years with a new Code cycle. This edition of *PV and the NEC* reflects the 2020 NEC and will discuss earlier versions of the NEC. When the 2023 NEC comes out, this material will not be obsolete; in fact, more than half the PV in the United States is installed in places that adopt the NEC three years after a Code is released. For instance, the state with half of the solar in the US is California, and in California, the 2017 NEC was adopted in 2020 and used until the 2020 NEC is adopted in 2023. It is also interesting to note that the proposals for changes to the NEC are crafted three years earlier, so the material in the 2017 NEC was proposed in 2014 and will be used on a regular basis by inspectors until nine years later.

Since the equipment changes so fast in the PV industry, the Code writers intentionally leave parts of the Code open-ended to make way for new inventions that you may come up with, which will save lives and may make you rich.

The 2020 NEC proposals for Article 690 and for other solar-relevant parts of the Code were first proposed at meetings at NREL in Colorado in 2017 and put in a Word document by Bill Brooks. This Word document grew, and the proposals were refined with a lot of input. These future Codes were later proposed to the top dogs at the National Fire Protection Association by Ward Bower (inventor of the grid-tied inverter in 1977) and Bill Brooks of NEC Code Making Panel 4 in Hilton Head, North Carolina.

Now is the time to take out your 2020 NEC and follow along to understand PV and the NEC.

## Note

1 The first power plant at Niagara Falls had two phases that were 90° out of phase with each other (weird) (see https://en.wikipedia.org/wiki/Two-phase_electric_power). Now we use single (split), or three phases that are 120° out of phase with each other. This is interesting!

# 1 Article 690 Photovoltaic (PV) Systems

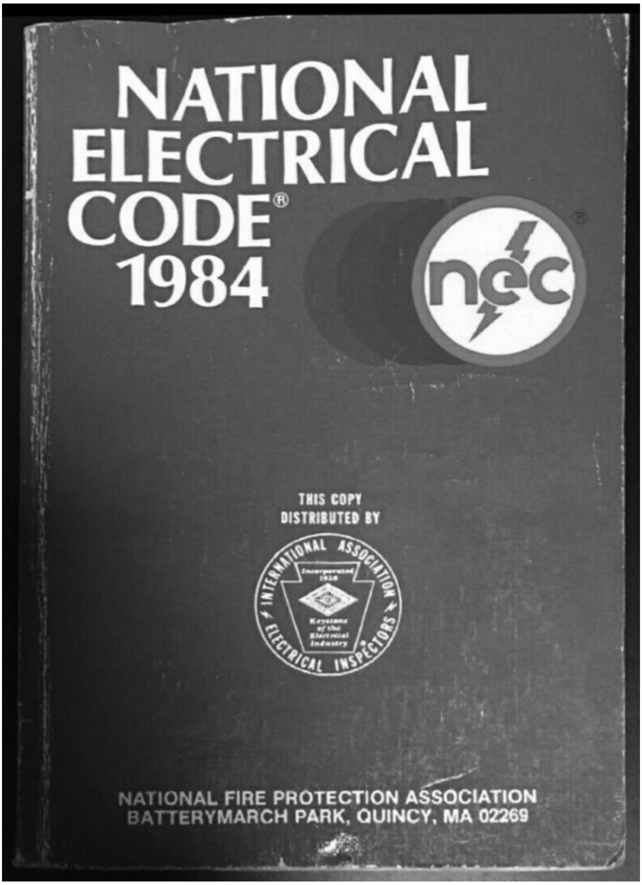


*Figure 1.1* 1984 NEC (a much smaller Code book)

*Source:* Sean White

Article 690 first came out in a little book known as the 1984 NEC and has been updated and mostly lengthened ever since.

In comparing the original 1984 version of Article 690 to today's NEC, there are many similarities, yet also quite a few differences. Time to dig in!

Let us first list what we are dealing with in Article 690 before we dig deep. This will give us perspective and familiarize us with how to look things up quickly.

The NEC is also known as NFPA 70 and is divided into Chapters, then Articles, and then Parts and Sections.

For example, rapid shutdown requirements are found in:

NEC **Chapter** 6 Special Equipment
**Article** 690 Solar Photovoltaic (PV) Systems
**Part** II Circuit Requirements
**Section** 690.12 Rapid Shutdown of PV Systems on Buildings

Here is what we find in Article 690:

Article 690 solar photovoltaic (PV) systems

Part I general (part)

690.1 Scope [Section 690.1.]
690.2 Definitions [There are more NEC definitions in Article 100, such as the definitions for PV, ac and dc.]
690.4 General Requirements [They could not come up with a better title for this category.]
690.6 Alternating Current (ac) Modules

Part II circuit requirements

690.7 Maximum Voltage
690.8 Circuit Sizing and Current
690.9 Overcurrent Protection [Article 240 is also Overcurrent Protection.]
690.10 Stand-Alone Systems [This had been moved to Article 710 in the 2017 NEC.]
690.11 Arc-Fault Circuit Protection (Direct Current)
690.12 Rapid Shutdown of PV Systems on Buildings [Big changes.]

Part III disconnecting means

690.13 Photovoltaic System Disconnecting Means
690.15 Disconnecting Means for Isolating Photovoltaic Equipment

Part IV wiring methods and materials

690.31 Wiring Methods
690.32 Component Interconnections
690.33 Mating Connectors
690.34 Access to Boxes

Part V grounding and bonding [Article 250 is also grounding and bonding.]

690.41 System Grounding
690.42 Point of System Grounding Connection
690.43 Equipment Grounding and Bonding
690.45 Size of Equipment Grounding Conductors
690.47 Grounding Electrode System [Experts argue over a lot of this article, which is interesting to observe.]
690.50 Equipment Bonding Jumpers

Part VI marking

690.51 Modules and Ac Modules
690.53 Dc PV Circuits
690.54 Interactive System Point of Interconnection
690.55 Photovoltaic Systems Connected to Energy Storage Systems
690.56 Identification of Power Sources [This includes Rapid Shutdown signs.]

Part VII connection to other sources

690.59 Connection to Other Sources [Directs us to Article 705.]

Part VIII energy storage systems

690.71 General [Directs us to Article 706.]
690.72 Self-Regulated PV Charge Control

Now it is time to dive into the detail of Article 690.

## Article 690 Solar Photovoltaic (PV) Systems Part I General (part)

### *690.1 Scope (section 690.1)*

Word-for-word NEC:

> "690.1 Scope. This article applies to solar PV systems, other than those covered by Article 691, including the array circuit(s), inverter(s), and controller(s) for such systems. [See Figure 690.1(a) and Figure 690.1(b).] The systems covered by this article include those interactive with other electric power production sources or stand-alone, or both. These PV systems may have ac or dc output for utilization.
>
> Informational Note No. 2: Article 691 covers the installation of large-scale PV electric supply stations."

Discussion: For the most part, 690.1 is self-explanatory; however, if we compare the 2014 and the 2017/2020 NECs carefully, we will notice that energy storage systems (batteries) are no longer part of the PV system as they were in the 2014 NEC.

So, what does this mean for us? Batteries are no longer part of the PV system and are part of a separate energy storage system that is covered in the new Article 706. Consequently, rapid shutdown and other requirements that are specific to PV systems do not apply to the batteries.

Next, we see diagrams that will show us the dividing line between the PV system and *not* the PV system.

Section 690.1 also has some figures that we can look at in order to get a picture of what we are talking about.

Figure 1.2 is an image from the 2020 NEC

Pay attention to the insertion of the dc-to-dc converters in Figure 1.2. The writers of the NEC left the dc-to-dc converter definition open-ended for your billion-dollar invention. 2020 dc-to-dc converters are usually one for every module, rather than three modules per converter in this image. Take note that, as we will learn in Section 690.12 Rapid Shutdown, we essentially have module level shutdown as the main method to comply. However, new inventions in the meantime could introduce other methods not currently foreseen.

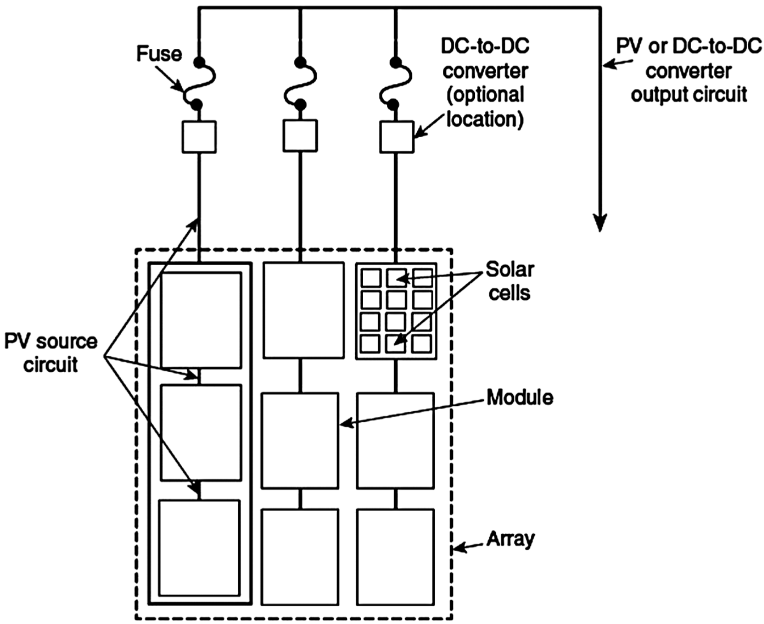


*Figure 1.2* 2020 NEC PV Figure 690.1(a) PV power source
*Source:* courtesy NFPA

For someone first learning about solar, it could be confusing to see a solar module with 12 cells. It would be even more confusing to have one dc-to-dc converter per three modules that is being connected with fuses to a dc-to-dc converter combining busbar, and then off to a dc-to-dc converter output circuit. Dc-to-dc converters being installed in 2020 have one or two PV modules with a dc-to-dc converter under the module, and then a number of dc-to-dc converters connected in series as a source circuit, and then the dc-to-dc converter source circuit is connected directly to the inverter. The 2020 NEC removed the word “panel” (as in solar panel) from this image and from 690.2 definitions. This was because, historically, in the NEC, a solar panel consisted of more than one module, and on the street, a solar panel is a solar module.

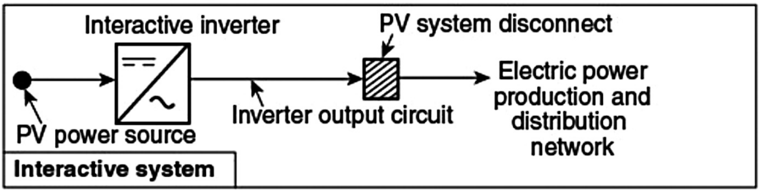


*Figure 1.3* Interactive system [2020 NEC Figure 690.1(b)]
*Source:* courtesy NFPA

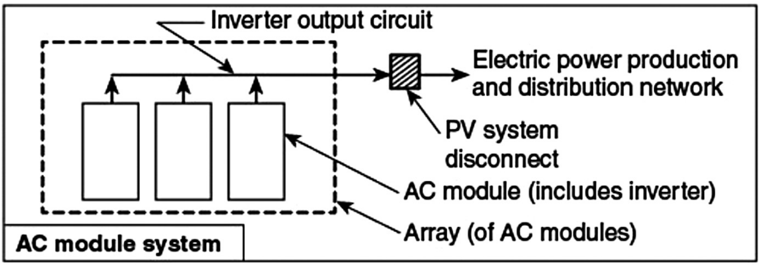


*Figure 1.4* Ac module system [2020 NEC Figure 690.1(b)]
*Source:* courtesy NFPA

Images are good to learn from. Next, we will go over the different images in Figures 690.1(b), paying close attention to the various PV system disconnecting means, which separate the PV system covered here in Article 690 from systems covered in other areas of the 2020 Code.

Interactive (grid-tied) inverter circuits are very simple. The inverter is used only for PV power; it has no other purpose and therefore is part of the PV system.

A big question installers have is: "What is the difference between an ac module and a microinverter bolted to a PV module?" The answer is that if the PV module was listed to UL 1703 while the inverter was bolted to it, and if the inverter was tested and listed to UL 1741 while bolted to the PV module, then it is an ac module and we do not consider the dc part of the product when installing this module.

If the module and microinverter were not listed together, then we are responsible for applying the NEC to the dc circuit, going from the module to the inverter. It is also interesting to note that the word "microinverter" does not appear in the NEC. The NEC looks at a microinverter as nothing more than a small (micro) inverter.

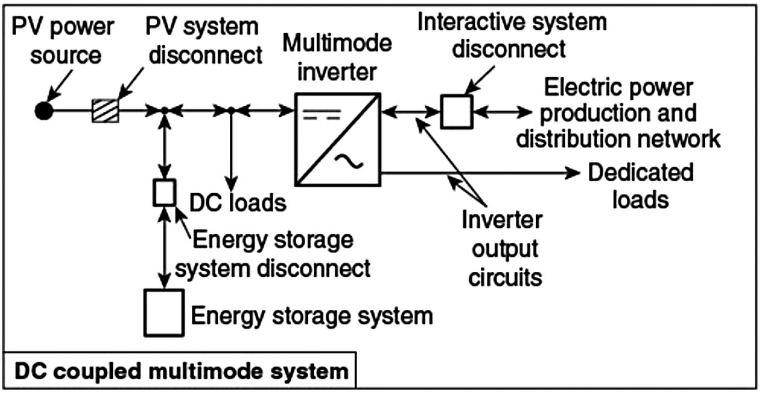


*Figure 1.5* Dc coupled multimode system [2020 NEC Figure 690.1(b)]
*Source:* courtesy NFPA

There is a lot of information in Figure 1.5. First of all, dc coupled and multimode are different things, which can go together. A dc coupled PV system is a PV system that is typically charging batteries with a charge controller connected to a PV array. The inverter in a dc coupled system will be coupled with the inverter and the charge controller working with dc voltage. In fact, it is possible to have a dc coupled system that does not have an inverter, but most people would like to utilize ac electricity with their dc coupled systems.

> Energy storage professionals also talk about the energy storage system (ESS) being ac coupled and dc coupled. In fact, an ESS can also be high voltage ac coupled and low voltage ac coupled, depending on which side of the transformer it is connected to. Our examples of ac and dc coupling in Article 690 are referring to the PV system connection.

As we can see in Informational Note Figure 690.1(b), a multimode inverter is an inverter that can work in different modes, such as stand-alone (off-grid) and interactive (grid-tied). This type of inverter was also known as a bimodal inverter for a time and will have different outputs. One output will go to the stand-alone (backed up) loads, and the other output will go to the loads that are not backed up and to the grid. When the power goes down, the interactive output of the inverter will act exactly as an interactive inverter and anti-island (it will stop sending voltage or current to the grid). No interactive inverter circuit is allowed to be an "island of power" and must disconnect from the grid. The **multimode inverter** definition was moved from 690.2 Definitions in the 2017 NEC to Article 100 Definitions in the 2020 NEC due to solar going mainstream (and since these terms are used in multiple Code articles).

### Multimodal vs. hybrid

There is often confusion about multimodal inverters and hybrid PV systems.

A **hybrid** system is defined in Article 100 Definitions as, "**A system comprised of multiple power sources. These power sources could include photovoltaic, wind, micro-hydro generators, engine-driven generators and others, but do not include electric power production and distribution network systems. Energy storage systems, such as batteries, flywheels or superconducting magnetic storage equipment do not constitute a power source for the purpose of this definition**." What we are saying here is that being connected to the grid has nothing to do with being hybrid. Hybrid has to do with having multiple sources of power, not including energy storage or the grid. A **multimode inverter** is, as we have mentioned, one that can work in grid (interactive) or off-grid (stand-alone) mode.

If you are one of the exhibition floors of the largest solar and energy storage conferences in the world, you will notice that everyone is calling an inverter that works with PV and batteries a "hybrid" inverter. These products are not correctly named according to the NEC, even when it says hybrid right on the inverter. This is very much like people calling solar modules solar panels.

Ac coupled systems are becoming more popular. There are arguments on each side, whether it is best to add energy storage to PV systems via ac coupled and dc coupled systems (or both). Ac coupled systems have the benefit of being able to use regular, mass produced, reliable and relatively inexpensive interactive (grid-tied) inverters in the system, and the drawback of having two kinds of inverters.

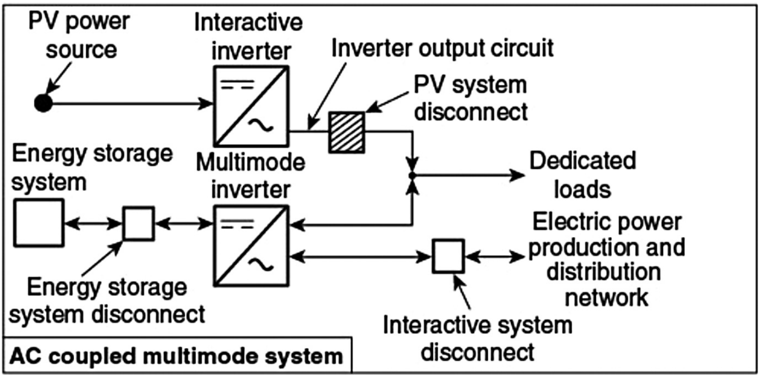


*Figure 1.6* Ac coupled multimode system [2020 NEC Figure 690.1(b)]
*Source:* courtesy NFPA

In Figure 1.6, starting at the upper left, we have a PV array and an interactive inverter, which is the PV system according to the 2020 and 2017 NECs. On the other hand, according to the 2014 NEC, almost everything in the image is the PV system. We can see that the border that separates the PV system from the rest of the ac coupled multimode system is the PV system disconnect. It is surprising to many that the multimode inverter is not connected to PV. This inverter is connected to an energy storage system (usually batteries) on the dc side, and to the grid (electrical production and distribution network) on one ac output and to what I like to call the "ac microgrid" on the other ac circuit, where backed up loads and interactive inverters can operate. It is also interesting that some manufacturers can make ac coupled systems that will not operate at all when the grid is down. This can be for what is often called "self-consumption" in the industry. These systems will be able to send electricity from the batteries to the loads or the grid when it is beneficial to do so because of utility demand charges, time-of-use rate schedules or because, in some places, utility customers are not allowed to export energy. Utility scale ac and dc coupled systems are often like self-consumption systems, but on a larger scale.

The stand-alone system (Figure 1.7) has a few differences with the average stand-alone system we see in the field. First of all, there is usually a charge controller that is connected to three different things. First is the PV array, second is the energy storage system and third is the inverter. These days, it is unusual to have dc loads as shown

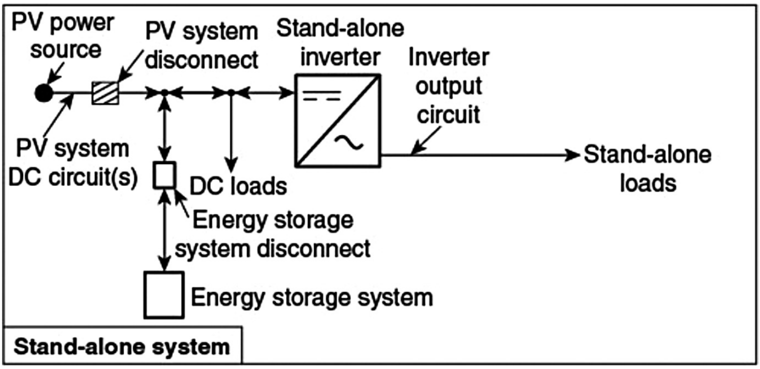


*Figure 1.7* Stand-alone system [2020 NEC Figure 690.1(b)]
*Source:* courtesy NFPA

in Figure 1.7. We could say that the charge controller is part of the energy storage system in the image.

Figure 1.7 could also be considered a dc coupled system without a multimode inverter.

### *690.2 Definitions*

Because this book is meant to be read with an actual NEC book handy or to be read by someone already familiar with the NEC, we will not repeat every easy to understand definition in Article 690. We will repeat the language of some of the newer and more difficult to understand definitions that a solar professional will have a tendency to use in their career. We will also add discussion to some definitions.

### *Bipolar Circuit*

Discussion: A bipolar circuit (according to Article 690) is dc power analogy of 120/240Vac power on a house in the US. In a bipolar circuit, there is a positively grounded monopole circuit and a negatively grounded monopole circuit on the same inverter. This means that we can have voltage to ground that is half of the total voltage that the inverter is getting the benefit of processing. The interesting thing about this is that, with the 1500Vdc to ground equipment, we can have an inverter with a 3000Vdc input benefit with a ground-mounted PV system!

This is not something anyone is likely to see in his or her backyard, but according to the Code, it is a possibility.

> At NREL in 2014, Sean and Bill made a proposal to require lithium batteries for bipolar arrays for the 2017 NEC, but everyone just laughed at them.

### *Dc-to-dc Converter*

Moved from 690.2 to Article 100 Definitions in 2020 NEC. Moving something to Article 100 usually indicates mainstream importance. See page 203 in Chapter 11.

### *Dc-to-dc converter source and output circuits*

Discussion: Dc-to-dc converter source and output circuits are like PV source and PV output circuits; however, they are dc-to-dc converters connected together rather than PV modules. Just like how PV modules connected together in series are a PV source circuit, dc-to-dc converters connected together in series are dc-to-dc converter source circuits. The conductors going from the PV module to the dc-to-dc converter make up the PV source circuit.

> **String theory**
>
> We often call a PV source circuit a "string." The term string is not in the NEC but is used in the IEC (International Electrotechnical Commission) and many other international codes and standards. Since everyone in the industry is calling PV source circuits "strings," would it be acceptable to call dc-to-dc converter source circuits "strings"? Perhaps it is as correct as calling a PV source circuit a "string."
>
> On another note, we often hear installers calling microinverters that are connected together in parallel a "string." We need to correct the microinverter "string" concept by calling it a "branch" rather than a "string," since microinverters connected together are generally connected in parallel, like a branch circuit, and do not have that "series-string thing" happening.

It is possible for someone to come up with a microinverter technology that requires microinverters to be connected in series with other microinverters that would be lower voltage ac micro-inverters and the voltages would add.

**Dc-to-dc Converter Output Circuits** are dc-to-dc Converter Source Circuits connected together in parallel and could be connected together in a **combiner**. Dc-to-dc Converter Output Circuits can be seen on some large rooftops.

### *Electronic Power Converter (new in 2020 NEC)*

A device, such as an inverter, dc-to-dc converter or electronic charge controller, which can limit current capabilities based on the device ratings at continuous rated power.

Discussion: These devices often limit power by increasing PV voltage, which decreases current as seen on the IV curve.

### *Grounded, Functionally (term was Functional Grounded PV System in 2017 NEC)*

This was a huge change in the 2017 NEC, which was kept in the 2020 NEC, and turned everything we formerly thought we knew about PV system grounding upside down—or, we should say, right side up!

Common interactive inverters that are either system grounded via a fuse (old-style, formerly known as grounded inverters) and systems that are non-isolated (formerly known as ungrounded or transformerless) and do all their magic through electronics in the inverter are hereby considered **functionally grounded inverters**!

Let's talk about the "**formerly known as grounded**" fuse grounded inverters first (may Prince rest in peace). These inverters are system grounded through a fuse. This means that usually a negative, but sometimes a positive, dc busbar in the inverter is connected to the ground busbar via a fuse inside of the inverter. When *enough* current goes through the ground wire during a ground fault, the fuse blows and suddenly the grounded conductor becomes ungrounded. So, in this type of system, when there is a ground fault, what has been white to formerly indicate it is a grounded conductor may be ungrounded when we are working on it. This previously required us to have a sign telling us that, if a ground fault is indicated, then the grounded conductor may be energized, which we no longer have to do. This is a very confusing label to someone who is not familiar with PV systems. Electricians are used to white-colored grounded conductors (neutrals) to be near ground potential! (Remember: a grounded conductor is a current-carrying conductor that has the same voltage as ground due to a single point of system grounding.)

These "**formerly known as grounded**" inverters had a problem. Large PV systems would often have a few milliamps per module of leakage currents taking the parallel fuse pathway home to the negative bus as some of the electrons took the path through glass, frames, cables, insulation and rails when there were no ground faults. As the system became larger, the leakage became greater, and the immediate cure was to upsize the ground fault detection and interruption (GFDI) fuse. With a larger GFDI fuse and a foggy day, some systems would not be able to catch a real ground fault. Even without a foggy day, a ground fault that was not severe would stay hidden and the system would keep on making good, clean solar energy. Then what would happen in a few cases is the dangerous outcome. A second ground fault would occur, and we would have what in tennis they call a double fault. An entire array can get short-circuited, start backfeeding through a single string and, *poof*, smoke and the rest we will leave up to your imagination before someone uses this against us in court.

The solution: "**Formerly known as ungrounded**" inverters are also known as transformerless inverters, non-isolated inverters or, as I like to call them, magic boxes. It is easier to call these inverters magic than it is to explain the internal workings of these inverters and to explain the workings of a non-isolated grounded ac circuit. Non-isolated inverters have a reference point to ground related to the internal workings of the inverter, but do not have a grounded conductor. We used to call these inverters European inverters, since having something ungrounded on your house was historically an AHJ no-no in the United States. Then, after some modernization, a few puffs of smoke (not a pun) and some explaining, these formerly known as ungrounded inverters soon became the safer norm. After all, they are safer, cheaper and more efficient; safer being the key. These inverters can detect ground faults that are way less than the other inverters. Every day these modern inverters do insulation testing on the PV circuits. They are very sensitive and can detect minor ground faults. They can be so sensitive at finding ground faults, that when you replace an old fuse-grounded inverter with a new non-isolated inverter, that there can be very minor ground faults indicated with the new inverter that are difficult to find.

With all of this being said, it is still possible to have a **solidly grounded PV array**; it's just not common in the modern era. Perhaps you have a small PV system running a water pump. Your PV array negative might be solidly connected to a ground rod. That would be a solid ground and it would be safe to say that the system is more than "functionally" grounded.

> The term functional grounding was taken from Europeans by someone on NEC Code Making Panel 4. "Hey Bill, the Europeans called and they want their functional grounding back!"

Because most of our PV systems are functionally grounded systems, we have a set of rules that covers all of these functionally grounded systems. No more 2014 NEC white negatives (or positives), no more 2014 NEC required PV wires (USE-2 is also good), and no more fuses on two polarities. Opening positive and negative in the dc disconnect is required to be functional. We will cover this again as soon as you almost forget it and force it into your long-term memory when we get to the meat of Article 690. The 2020 NEC also brings DG (distributed generation) cable into the mix of exposed dc PV circuit conductors.

***Generating Capacity***

Moved from 690.2 Definitions to Article 100 Definitions in 2020 NEC. See page 205 in Chapter 11. (Ac output of inverter at 40°C.)

***Interactive System***

Moved to Article 100 Definitions in 2020 NEC. See Chapter 11 page 205. (Grid-tied.)

***Module***

A rectangular object that makes magic crystal energy from starlight; AKA a complete, environmentally protected unit, consisting of solar cells and other components designed to produce dc power.

### *Multimode Inverter*

Moved to Article 100 Definitions in 2020 NEC. See Chapter 11 page 206. (Inverter, Multimode.)

**Solar panels do not exist**

For so long in the solar industry, us technical people would find ourselves correcting those not-in-the-know by pointing out that a solar panel is actually a group of solar modules; however, at the instigation of Bill, who was widely supported by those people being corrected, **solar panels have been taken out of the NEC**. Now when someone says solar panel, we can just say, there is no such thing, since it is not in the almighty Code.

Back in the early days of solar in the 20th century, most solar modules had 36 solar cells and were a lot smaller and less powerful than today's solar modules. The solar cells were the expensive part, so it was better for the manufacturers to make something that people could afford. Also, it was common to be charging 12V batteries, and 36 solar cells in series is a good design for charging a 12V battery without maximum power point tracking (MPPT) charge controllers, which is why you still see 36-cell modules around and you hear them being called 12V solar modules. When 12V modules were what we had to choose from, they were made with screw terminals on the back to attach wires to. These pioneer solar installers would usually put a few modules on a workbench, put some sort of primitive rail behind the modules, connect them together and, if they were really good, they would put conduit between the junction boxes of the modules. Conduit between modules was also nice, having no exposed wires on the backs of the modules, so we did not need to put a fence or other structure around the PV system to keep the small fingers from getting in dangerous places. Some commercial PV systems still "panelize" solar modules and connect them together before installing them. I saw this happening in an air-conditioned Phoenix warehouse in the summer, which was a cooler way to do a desert install.

### *PV Source Circuit*

A PV source circuit consists of the dc circuit conductors between modules and from modules to dc combiners, electronic power converters or a dc PV system disconnecting means. PV modules connected together in series are commonly referred to as a **string**, which is the IEC (International Electrotechnical Commission) term for a PV source circuit.

### *PV Output Circuit*

If PV source circuits are connected together in parallel at a dc combiner, then the output of the combiner is defined as a PV output circuit.

Discussion: Most PV systems on buildings these days have PV source circuits that go straight to the inverter and avoid having PV output circuits and dc combiners. There are also large GW scale PV systems that use “string inverters” and avoid having PV output circuits and combiners.

Benefits of not having PV output circuits/dc combiners:

1 There is no need for a dc combiner.
2 There are no dc combiner fuses.
3 If one or two strings are going to a single MPP, which is commonly the case, then no dc fuses are needed.
4 Having strings go straight to the inverter puts the dc arc-fault protection at the inverter, which is more convenient than having electronics detect dc arc-faults at dc combiners.
5 Having strings go to the inverter makes monitoring strings more convenient, since we do not need to have monitoring at combiners.

String inverters have been becoming popular at the expense of central inverters for the reasons mentioned above. Some people think that large central inverters will go out of style completely. The authors of this book will remain neutral and let the trade war generals decide.

**MPP or MPPT = maximum power point (tracking)**

Most modern string inverters have multiple inputs. These inputs are connected to separate dc-to-dc converters in the inverter. This means that different PV source circuits or groups of PV source circuits can operate at the perfect voltage for power production. This way different PV source circuits can have different numbers of modules or bypass contributions from shaded modules through the bypass diodes in the modules. Additionally, monitoring and dc arc-fault protection is easier. In the early days before MPPTs, it was a solar sin to have different numbers of modules on different source circuits on the same inverter. Now we have different inverter inputs that can operate independently of each other. An inverter with two PV series strings per input will not require fuses on the inputs. An inverter with three PV source circuits on one input will typically require fuses.

***Photovoltaic System Dc Circuit***

NEC wording: "Any dc conductor in PV source circuits, PV output circuits, dc-to-dc converter source circuits and dc-to-dc converter output circuits."

Discussion: PV system dc circuits are PV and dc-to-dc converter source and output circuits. A circuit going from a charge controller to a battery or a charge controller to an inverter is not a PV system dc circuit. As of the 2017 NEC batteries and charge controllers are not part of a PV system; they are part of different systems covered in articles 706 Energy Storage Systems, 480 Storage Batteries, and 710 Stand-Alone Systems.

***Stand-alone system***

Moved to Article 100.

### *690.4 General Requirements*

Outline of 690.4 General Requirements

690.4 General Requirements
- 690.4(A) Photovoltaic Systems
- 690.4(B) Equipment
- 690.4(C) Qualified Personnel
- 690.4(D) Multiple PV Systems
- 690.4(E) Locations Not Permitted

690.4(F) Electronic Power Converters in Not Readily Accessible Locations (new)

One of the more difficult things for someone learning to use the NEC is to remember to know where to look for something. This book is going to do its best to outline, organize, point to and discuss topics, so that the reader will be more familiar with and have a better idea of where to find what they are looking for.

Section 690.4 General Requirements, which is in Part I General of Article 690, is not very memorable, and it is going to stump a few people who are looking for this information, so let us state the obvious and dive into these General Requirements. If you can make something catch your attention for whatever reason, it will help you remember it.

### *690.4(A) Photovoltaic Systems*

In plain English: PV systems can supply a building at the same time as other sources of power.

Discussion: If you live in coal country and the AHJ refuses to let you put those fresh sunbeam electrons into the grid, you can support your argument here.

### *690.4(B) Equipment*

Equipment that needs to be listed (or field labeled) for PV applications according to 690.4(B):

Inverters (UL 1741) (UL 1741SA in California)
Motor Generators [Dc motors driving a rotating generator.]
PV Modules (UL 1703)
PV Panels [Products have been built that panelize modules and have been listed when shipped that way. Solyndra solar panels were a group of tubes, each being a module, which were listed and shipped with multiple tubes on a rack creating a solar panel and listed to UL 1703.]
Ac Modules [UL 1703 and UL 1741 tested as a unit.]
Dc Combiners (UL 1741)
Dc-to-Dc Converters (UL 1741)
Charge Controllers (UL 1741)
Rapid Shutdown Equipment (UL 1741)
Dc Circuit Controllers

> Discussion of listed and field labeled equipment: Listed products are found on a list of certified products that various certification labs develop. Field labeled products may not be on one of these lists but get evaluated by a certification lab who puts a label on the product after it has met whatever test requirement was requested to be tested.

### *690.4(C) Qualified Personnel*

What it means: Installation of equipment and wiring should be done by "qualified personnel."

There is an **informational note** that tells us that we can look to Article 100 Definitions to see the definition of **qualified person.** Article 100 **Qualified Person Definition:** One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved.

Discussion: Some would say that a qualified solar installer is NABCEP Certified. Others would say only an electrician should install solar and yet others say only a roofer should put a hole in a roof. There is also a UL Solar Certification. Where are all the UL Certified Installers?

> An informational note on informational notes:
>
> > Informational notes in the NEC are good ideas, but not requirements. Just like a yellow speed sign tells you it is a good idea to slow down for a corner, an informational note gives you good advice. Informational notes used to be called fine print notes and abbreviated FPN.

### *690.4(D) Multiple PV Systems*

What it means: multiple PV systems are allowed on a single building.

If multiple PV systems on a building are located away from each other, then there must be a directory at each PV system disconnecting means showing where the other disconnecting means are located in accordance with **705.10 Directory**.

Discussion: We do not want firefighters thinking they turned off all of the PV on the building when they hit one of the disconnects on the building, not knowing that there are other disconnects that will turn off other PV systems at a different location on the building. Tricking firefighters or utility workers is not cool nor is it allowed.

**Disconnecting means means** …

As you would like to think, a PV system disconnecting means is an off switch for a PV system. A disconnecting means is what separates a PV system from the rest of the electrical system. A PV system disconnecting means for an interactive (grid-tied) inverter would be on the ac side of the inverter, separating the PV system from what is not the PV system. Study PV System Disconnect in Figures 1.3 through 1.7 earlier in this chapter on pages 9 through 13 and also in the NEC Figure 690.1(b) Images.

We generally have one PV system disconnecting means and several equipment disconnects for a PV system. Complicated dc PV systems could have more than one PV system disconnecting means, but they have to be grouped for each system.

*690.4(E) Locations not Permitted*

PV equipment and disconnecting means are **not allowed in bathrooms,** just in case you had your heart set on mounting one next to your toilet—sorry, not allowed.

Think of "wet feet" and getting shocked.

*690.4(F) Electronic Power Converters Mounted in Not Readily Accessible Locations*

**Electronic power converters** (exciting new definition in 2020 NEC earlier in this chapter) can be on roofs or other exterior areas that are not readily accessible.

***690.6 Alternating-Current (Ac) Modules***

Outline of 690.6 Alternating-Current (Ac) Modules

690.6 Alternating-Current (Ac) Modules
(A) PV Source Circuits
(B) Output Circuit

Discussion: 690.6 is stating the obvious.

*690.6(A) PV Source Circuits*

What it means: ac modules are tested and listed as a unit, so we do not need to consider any dc circuits, such as PV source circuits.

It is interesting to note that, with a microinverter, we consider the dc conductors between the module and the inverter a PV source circuit, but not with an ac module.

*690.6(B) Output Circuit*

It says: The output of an ac module is considered an inverter output circuit.

Discussion: This is obvious, but needs to be explained in case an AHJ gives you a problem.

# 2 Article 690 Photovoltaic Systems Part II Circuit Requirements

Part II Circuit Requirements

690.7 Maximum Voltage
690.8 Circuit Sizing and Current
690.9 Overcurrent Protection [Article 240 is also Overcurrent Protection.]
690.10 Stand-Alone Systems [moved to Article 710 in the 2020 NEC.]
690.11 Arc-Fault Circuit Protection (Direct Current)
690.12 Rapid Shutdown of PV Systems on Buildings [big changes, discussed in Chapter 3.]

## 690.7 Maximum Voltage

Understanding 690.7 sets true solar professionals apart from the solar un-professionals. Understanding calculations using 690.7 is also very important to NABCEP, as reflected in their exams; however, the Module Level Power Electronics (MLPE) are reducing the need for string sizers, especially for those designing systems for buildings.

## Outline of 690.7

690.7 Maximum Voltage
- 690.7(A) Photovoltaic Source and Output Circuits
  - 690.7(A)(1) Calculations with low temperature and Voc coefficients
  - 690.7(A)(2) Using table 690.7(A) Voc Correction Factors for Silicon Crystal Modules
  - 690.7(A)(3) PV Systems Over 100kWac Under Professional Engineer (PE) Supervision

690.7(B) Dc-to-Dc Converter Source and Output Circuits
690.7(B)(1) Single Dc-to-Dc Converter
690.7(B)(2) Two or More Series Connected Dc-to-Dc Converters
690.7(C) Bipolar Source and Output Circuits

Electricians are used to having the grid as the voltage or a device that has a factory set voltage output. With PV, we have a lot of variables.

### *690.7(A) Photovoltaic Source And Output Circuits*

PV source and output circuits get their voltage directly from series connected solar cells. The NEC will consider two factors that increase PV source and output circuit voltage. First of all, putting modules in **series increases the voltage**. Secondly, **cold temperature increases the voltage.**

**PV output circuits are PV source circuits connected together in parallel** at a **dc combiner**. Since voltage is determined by series connections and not parallel connections, **PV output circuits have the same voltage as the PV source circuits that are combined to make the PV output circuit**. From here on out, we will just talk about PV source circuit voltage and understand that the PV output circuit has the same voltage as the PV source circuits that feed it.

### *690.7(A) Informational Note*

An **informational note is a good idea** (not a requirement) and the NEC tells us that a good place to find cold temperature data that we can use in determining voltage for locations in the United States is the ASHRAE Handbook. A very convenient place to find this data is at the website for the Expedited Permit Process: www.solarabcs.org/permitting.

> The Solar America Board of Codes and Standards website for the Expedited Permit Process is a document that was put together by Bill Brooks under contract of the United States Department of Energy (USDOE). On the left side of the www.solarabcs.org webpage, click on Expedited Permit Process and then click on “map of solar reference points” to find the low temperature data to use for calculating voltage. This webpage also has high temperature data

that can be used for wire sizing, which we will cover later in this book.

The Expedited Permit Process is a template, which includes fill-in forms that can be used to put together a permit package. Regardless of whether or not you use the templates, there is a lot of good information to study by downloading the 82-page Expedited Permit Process “full report.” Anyone in the solar industry will benefit from becoming familiar with this report. It also helps when studying for the NABCEP PV Installation Professional exam. There is another new version of this permitting process funded by the USDOE, called the Simplified Permit Process, that Bill put together at www.solsmart.org/permitting.

The 2020 NEC gives us three ways to determine voltage and we can make a choice of which method we will use. These methods will result in different values of voltage, depending on the method we chose to use.

The **three methods** for determining PV source circuit (**string**) **voltage** are:

690.7(A)(1) Calculations
690.7(A)(2) Table 690.7(a)
690.7(A)(3) Engineering supervision

*690.7(A)(1) voltage temperature calculation method*

The 690.7(A)(1) method is the most common method used by solar professionals for determining PV source circuit (string) voltage. This method is also required for anyone taking any NABCEP PV exam.

In order to calculate the module maximum voltage, you will need three things:

1 Rated PV Module Voc (open-circuit voltage)
2 Temperature coefficient of Voc
3 Low temperature

Module **Voc** and **temperature coefficient of Voc** is most commonly found on the PV module manufacturer’s datasheet. Low temperature data is most easily found on www.solarabcs.org.

Let us run through a **PV source circuit maximum voltage calculation** using a simple example with round numbers.

Example:

1 Cold Temp = –5°C
2 Temp. Coef Voc = –0.3%/°C
3 Voc = 40V
4 Number of modules in series = 10

Calculation:

1 Determine **delta T** (difference in temperature) from Standard Testing Conditions (STC)
   a All PV modules are tested at STC = 25°C
   b The difference between –5°C and 25°C is **30°C or –30°C**
2 Multiply delta T by Temp. Coef. Voc
   a 30°C × 0.3%/°C = 9% increase in voltage
   b Another easier method converts percent to decimal first
      30°C × 0.003 = 0.09
3 Add 1 to figure above to get 109% increase in voltage
   a 0.09 + 1 = 1.09
      This figure is a temperature correction factor
4 Multiply the temperature correction factor by Voc at STC to get cold temperature Voc
   a 1.09 × 40V = **43.6V = maximum voltage** for one module
5 10 in series × 43.6V = **436V maximum voltage for the PV source circuit** (string)

When practiced, the method above can be done in 10 seconds by fast calculator users. If you practice this 10 times fast, you will be an expert. This method can be done easily with a calculator and without writing anything down.

On the calculator keypad, press:

**25 + 5 = 30** (if the 5°C were above 0 then subtract 5 from 30 to get 20)
30 × .003 =.09
.09 + 1 = 1.09
**1.09 × 40 = 43.6V** = maximum voltage for one module

Often we do **string sizing** with this number, which means we divide it into the inverter maximum input voltage and then round down to get the **maximum number of modules in series** without going over voltage.

Example using 43.6V maximum voltage and 450V inverter:

450V/43.6V = 10.3
10 in series is the maximum number in series without going over voltage (always round down here)

In this example, if we have 10 in series, then the maximum system voltage is:

10 in series × 43.6V = **436V = maximum system voltage**

It is very common for solar un-professionals to incorrectly write that the maximum system voltage is 450V on the label on the dc disconnect in this example, which is incorrect. 436V is correct.

Once practiced, you should be able to do this calculation without paper using a calculator in less than a minute. The world record is 17.1 seconds.

You do not use this method for dc-to-dc converters (optimizers), which is a common mistake.

*690.7(A)(2) table method*

Using Table 690.7(a) is easier than performing the **690.7(A)(1) Voltage Temperature Calculation Method**. We can consider this optional method a shortcut; however, in some cases, we will have more options for more modules in series using the 690.7(A)(1) calculation method. The **690.7(A)(2) method using Table 690.7(a)** is **more conservative** and will come up with a slightly **higher module voltage** every time.

We use **Table 690.7(a)** by cross-referencing a temperature with a **temperature correction factor**. We then multiply the temperature correction factor by the module open-circuit voltage to get the module maximum voltage.

Let us use the **690.7(A)(2) method using Table 690.7(a),** using the same numbers that we just used in the **690.7(A)(1) calculation** example, however, this time we will not use the module manufacturer's temperature coefficient for open-circuit voltage.

Example:

1 Cold temp = −5°C
2 Voc = 40V
3 Number of modules in series = 10

*Table 2.1* NEC Table 690.7(a) voltage correction factors for crystalline and multicrystalline silicon modules. Correction factors for ambient temperatures below 25°C (77°F). (Multiply the rated open-circuit voltage by the appropriate correction factor shown below.)

| *Ambient temperature (°C)* | *Factor* | *Ambient temperature (°F)* |
|---|---|---|
| 24 to 20 | 1.02 | 76 to 68 |
| 19 to 15 | 1.04 | 67 to 59 |
| 14 to 10 | 1.06 | 58 to 50 |
| 9 to 5 | 1.08 | 49 to 41 |
| 4 to 0 | 1.10 | 40 to 32 |
| –1 to –5 | 1.12 | 31 to 23 |
| –6 to –10 | 1.14 | 22 to 14 |
| –11 to –15 | 1.16 | 13 to 5 |
| –16 to –20 | 1.18 | 4 to –4 |
| –21 to –25 | 1.20 | –5 to –13 |
| –26 to –30 | 1.21 | –14 to –22 |
| –31 to –35 | 1.23 | –23 to –31 |
| –36 to –40 | 1.25 | –32 to –40 |

*Source:* courtesy NFPA

Calculation using Table 690.7(a)

1. Looking at Table 690.7(a) at –5°C, we can see that –5°C corresponds with a temperature correction factor of 1.12 (12% increase in voltage)
2. Multiply 1.12 × 40V and get 44.8V
3. 10 in series × 44.8V = 448V maximum system voltage

We can see by the results of comparing the **690.7(A)(1) calculation method** to the **690.7(A)(2) table method**, that the **690.7(a) table method** resulted in a **higher voltage** that is very close to the 450V inverter maximum voltage.

If it were 1° colder at –6°C we would still be able to have 10 in series with the **690.7(A)(1) calculation method**, but we would have gone over voltage using the **690.7(A)(2) table method** using **Table 690.7(a)**.

We can see that at –6°C in **Table 690.7(a)** we have a temperature correction factor of 1.14.

40V × 1.14 = 45.6V
45.6V × 10 in series = 456V = over voltage for our 450V inverter example

690.7(A)(3) engineering supervision method for calculating maximum voltage for PV systems over 100kW generating capacity (ac system size)

Under engineering supervision, there can be alternative ways of doing things throughout the NEC. According to 690.7(A)(3), a **licensed professional electrical engineer** will have to stamp the system design. A professional engineer (PE) has gone to school, worked in the field and taken a difficult exam. The designation of PE is awarded on the state level. It is up to the AHJ to accept a stamp of a PE that is licensed in another state.

The 690.7(A)(3) Engineering Supervision Method requires that the PE uses an "industry standard method" for determining maximum voltage.

*690.7(A)(3) Informational Note*

There is an informational note that recommends an "**industry standard method**" for calculating maximum voltage of a PV system.

Industry Standard Method for Calculating Maximum Voltage:

Photovoltaic Array Performance Model
Sandia National Laboratory
SAND 2004–3535 http://prod.sandia.gov/techlib/access-control.cgi/2004/043535.pdf

To summarize the report: Taking the heating effects of irradiance into consideration, the temperature of the PV will be hotter than ambient and we can have a lower module voltage and perhaps another module in series.

***690.7(B) Dc-to-Dc Converter Source and Output Circuits***

Dc-to-dc converter source and output circuits shall be calculated in accordance with 690.7(B)(1) and 690.7(B)(2).

*690.7(B)(1) Single Dc-to-Dc Converter*

For a single dc-to-dc converter output, the maximum voltage is the maximum rated output of the dc-to-dc converter.

Maximum voltage is what it says on the label, installation instructions or datasheet for maximum output voltage.

**Dc-to-dc converters in modern PV and energy storage systems**

As electronics mature, we are seeing dc-to-dc conversion taking place throughout the industry. These are at the inputs of our multiple MPP inverters, MPP charge controllers and within our energy storage systems. One of the reasons that ac became our grid rather than dc, is because Tesla invented the technology to change voltages with transformers, which work for alternating current and not direct current. Now, with efficient modern dc conversion technology, we are seeing more applications for dc circuits. Watch out Nicolai Tesla, Thomas Edison is coming for you!

### *690.7(B)(2) Two or More Series Connected Dc-to-Dc Converters*

Maximum voltage is determined in accordance with instructions of the dc-to-dc converter.

If instructions are not included, sum up the voltage of the dc-to-dc converters connected in series.

Discussion: **Dc-to-dc converters can electronically limit voltage** when connected in series. There are, however, some dc-to-dc converters that, along with having the capability to convert voltages, also have the ability to bypass the converter internally and send PV voltage through the converter. Dc-to-dc converter installation instructions and help lines will be your best source of determining maximum voltage.

The most commonly used dc-to-dc converter as of the writing of this book has a maximum system voltage of 500V for all dc-to-dc converter source and output circuits connected to all inverters, except the 480/277 inverter which has a maximum system voltage of 980V and that is what is to be on the 690.53 Dc PV Circuits sticker that you put on that inverter.

### ***690.7(C) Bipolar Source and Output Circuits***

A bipolar circuit has a positive grounded monopole circuit and a negative grounded monopole circuit. Maximum voltage is considered voltage to ground.

If there is a ground-fault or an arc-fault, the inverter is required to isolate both circuits from each other and from ground.

Discussion: From a safety point of view, the voltage of your house is limited to 120V to ground, since voltage to ground relates to safety. In a similar way, a bipolar system with a maximum voltage of 1000V to ground can have a voltage of 2000V measured array to array! However, a 2000V bipolar system is allowed to use 1000V rated PV modules since the modules never see more than 1000V in this configuration.

## Outline of 690.8

- 690.8 Circuit Sizing and Current
  - 690.8(A) Calculation of Maximum Circuit Current
    - 690.8(A)(1) PV System Circuits
      - 690.8(A)(1)(a) PV Source Circuit Calculation by one of the following
        - 690.8(A)(1)(a)(1) 125 Percent of Short Circuit Current
        - 690.8(A)(1)(a)(2) Systems Over 100kWac Engineering Supervision
      - 690.8(A)(1)(b) Photovoltaic Output Circuits
      - 690.8(A)(1)(c) Dc-to-Dc Converter Source Circuit Current
      - 690.8(A)(1)(d) Dc-to-Dc Converter Output Circuit Current
      - 690.8(A)(1)(e) Inverter Output Circuit Current
    - 690.8(A)(2) Circuits Connected to the Input of Electronic Power Converters
  - 690.8(B) Conductor Ampacity
    - 690.8(B)(1) Without Adjustment and Correction Factors
    - 690.8(B)(2) With Adjustment and Correction Factors
  - 690.8(C) Systems with Multiple Direct-Current Voltages
  - 690.8(D) Sizing of Module Interconnection Conductors

## 690.8 Circuit Sizing and Current

This is how we define current and ampacity for **wire sizing** and equipment selection. Wire sizing is not simple, so pay close attention and come back often. 690.8(A) defines what current is and 690.8(B) defines the required ampacity of the wire.

### *690.8(A) and 690.8(B) Overview*

Reinforce in your synapses that **690.8(A) defines currents** used for wire sizing and **690.8(B)** gives us different checks to perform to make sure that the **wire can handle the current under different conditions,** such as heat and continuous current.

There are still **other checks** used for wire sizing regarding overcurrent protection found in Article 240 of the NEC. In **Article 240 Overcurrent Protection** we have to make sure that the **overcurrent protection** device is going to protect the wire. See wiring sizing examples in Chapter 12.

### *690.8(A) Calculation of Maximum Circuit Current*

We will **define currents** used for wire sizing for different circuits in a PV system. PV system currents are more complicated than currents in circuits most electricians are used to dealing with. This is because we have **some circuit currents that increase with the brightness** of light and **other** circuit currents that are **limited by smart electronics**.

#### *690.8(A)(1) PV System Circuits*

690.8(A)(1) says currents are determined by 690.8(A)(1)(a) through 690.8(A)(1)(e). Much of 690.8(A)(1) was rearranged in the 2020 NEC but is the same in theory and in electron flow (FPN: an amp is about 6 quintillion electrons passing by in a second). Stand-alone inverter input circuit current was moved to 710.12, since a stand-alone inverter is not part of a PV system.

##### 690.8(A)(1)(a)(1) 125% OF SHORT-CIRCUIT CURRENT METHOD

This is the typical way we define maximum circuit current for “wild” PV circuits and is the way we have always done it in the past:

125% of short-circuit current
Isc × 1.25 = maximum circuit current

Discussion: This is the definition of maximum circuit current for one module or a number of modules connected together in series. Some would argue that it is over-doing it to base your wire size on a short circuit. This is done because we are accounting for increased irradiance over STC (1000 w/m$^2$).

Also, it is unusual for electricians to see a short circuit that is about 7% greater than operating current, as it is with PV modules.

Let's look at some of the PV module circuit currents in order of increasing current:

Imp = current at maximum power
Isc = short-circuit current
Isc × 1.25 = Maximum circuit current from applying 690.8 (A)(1)(a)(1)
Isc × 1.56 = Required ampacity for continuous current from 690.8(B)(1)

Note: Maximum circuit current (Isc × 1.25) was used for the label on a dc disconnect in the 2017 NEC, however that 690.53 requirement was discontinued in the 2020 NEC.

It is considered by many smart people to be over-doing it by using 125% of short-circuit current in order to define maximum circuit

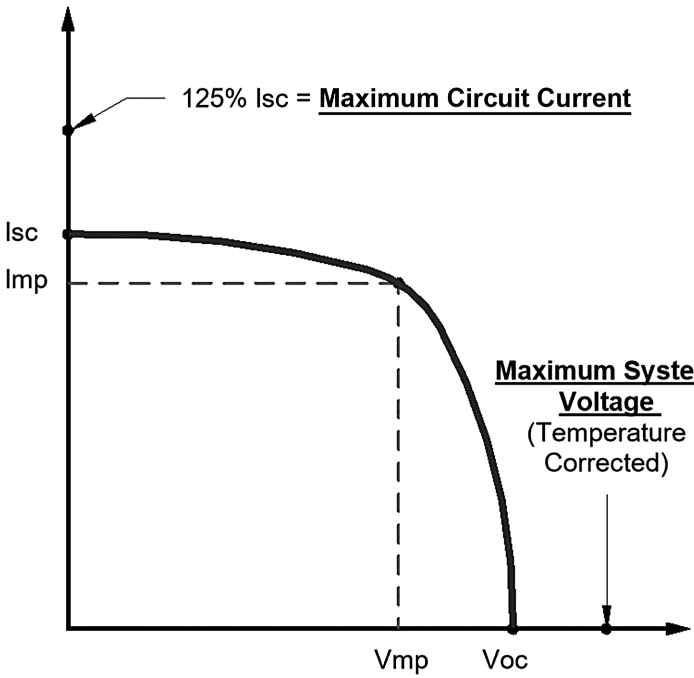


*Figure 2.1* IV curve with different currents plotted showing maximum circuit current, which is used for sizing wires, above and beyond short circuit current

*Source:* courtesy Robert Price AxisSolarDesign.com current. The reason it was not a big deal in the past is because PV was so expensive that oversizing wires was done in order to keep as much of our expensive energy as possible from being lost in the wires. Since we have entered the age of cheap PV energy, it makes more sense to use a smaller wire and this leads us to a new way to define current in **690.8(A)(1)(a)(2), the engineering supervision method**.

### Irradiance outside of Earth's atmosphere

It is interesting to note that Imp × irradiance in space at Earth's orbit, which is about 1366W per square meter, is about equal to Isc × 1.25.

$$\text{Imp} \times 1.366 = \text{Isc} \times 1.25$$

Coincidence or conspiracy? Clearly the Martians are planning to suck away our atmosphere and want to make sure our electrical code does not need to change after our atmosphere is gone …

690.8(A)(1)(a)(2) ENGINEERING SUPERVISION METHOD FOR CALCULATING MAXIMUM CIRCUIT CURRENT FOR PV SYSTEMS OVER 100kW GENERATING CAPACITY (AC SYSTEM SIZE)

As with 690.7(A)(3) for determining voltage, 690.8(A)(1)(a)(2) allows a licensed professional electrical engineer (**PE**) to use an **industry standard method**. This method is based on the **highest three-hour current average** from **simulated local irradiance accounting for elevation and orientation**.

This industry standard method **must also not be less than 70% of the 125% of Isc value used in 690.8(A)(1)(a)(1)**.

Since 690.8(A)(1)(a)(1) is Isc × 1.25 then the industry standard method cannot be less than 70% of 125% of Isc, so 0.7 × 1.25 = 0.875

This means that this **industry standard method cannot be less than 87.5% of Isc**.

We could call this the **not less than 87.5% Isc method**.

This does not mean that the PE does not have to do anything besides multiply Isc × 0.875. The PE will also have to analyze the PV system, including taking irradiance, elevation and orientation into consideration.

Higher elevation causes more current, due to less atmosphere filtering (closer to space).

The 690.8(A)(1)(a)(2) Informational Note

The Informational Note for 690.8(A)(1)(a)(2) points the professional electrical engineer in the same direction as 690.7(A)(3) and towards the same report mentioned earlier in 690.7 for voltage engineering supervision:

Industry Standard Method for Calculating Maximum Circuit Current:

Photovoltaic Array Performance Model
Sandia National Laboratory
SAND 2004–3535 http://prod.sandia.gov/techlib/access-control.cgi/2004/043535.pdf

**The 156 Factor**

Current and ampacity with PV source circuits has confused many prospective solar professionals. When both **690.8(A)(1)(a)(1)** and **690.8(B)(1)** are applied simultaneously, a **resulting multiplication factor of 156%** is used. Oftentimes people try to apply this **156%** factor to circuits besides PV source circuits. This multiplication factor is **only applied** to circuits that are **directly and proportionally influenced by sunlight** and ***not*** circuits that are limited by **electronics**. We can call this "**wild PV**" when PV is not limited by electronics.

156% comes from two different 125% correction factors. The **690.8(A)(1)(a)(1)** correction factor is for **natural irradiance beyond the standard testing conditions of 1000W per square meter**, which is how all PV modules are tested and rated. The other 125% in **690.8(B)(1)** is the **required ampacity for continuous current** that we have for all of our solar circuits. **Continuous current** as defined in the NEC is a current that can last over three hours. PV can last all day—particularly in tracking systems! Required ampacity for continuous current is not a current, it is more like a safety factor.

As a side note, did you know that most silicon solar cells are 156mm × 156mm? Coincidence or photovoltaic numerologist conspiracy?

This 156% of Isc factor was a 690.8(A) informational note that was removed in the 2020 NEC because everyone read the first edition of this book and no longer needed the information.

690.8(A)(1)(b) PHOTOVOLTAIC OUTPUT CIRCUIT CURRENTS

PV output circuit currents are the **sum of the parallel-connected PV source circuit currents.**

If you have 10 PV source circuits at the input of a dc combiner, then you will have 10 times the current coming out of the dc combiner through the PV output circuit. You just multiply the currents of the number of strings that are combined and send current through the PV output circuit by the current calculated for a PV source circuit in 690.8(A)(1)(a).

Most *non-utility scale* PV systems do not have PV output circuits and have PV source circuits that go directly to an inverter.

**String Inverters, Central Inverters and PV Output Circuit Combiners**

A "**string inverter**" is a vaguely defined non-NEC term that indicates that the PV source circuits go right to the inverter without being combined in parallel before going to the inverter. A "**central inverter**" is usually a very large inverter that has PV source circuits go to **dc combiners** and then to PV output circuits before reaching the inverter. In many utility scale systems, the PV output circuits will be combined again in "**PV output circuit combiners**," which are also called "**recombiners**." The IEC (International Electrotechnical Commission) calls what the NEC calls a "**dc combiner**" an "array junction box" if there is a single level of combining and if there are 2 levels of combining, then what we call the "**dc combiner**" in the NEC is called the "**sub-array junction box**" and the "**PV output circuit combiner**" is then called the "**array junction box.**" Perhaps we will get a "PV output circuit combiner" definition in the NEC someday, unless the string inverter folks pull off a coup.

690.8(A)(1)(c) DC-TO-DC CONVERTER SOURCE CIRCUIT CURRENT

The maximum current shall be the continuous output current rating.

Discussion: Dc-to-dc converters have the ability to electronically control current and voltage. In the instructions of the dc-to-dc converter there should be details on what the maximum current of the circuit can be. One of the benefits of the dc-to-dc converter is its smart ability to limit current, so that smaller wires can be used. For the most commonly used dc-to-dc converter (initials SE) at the time of this writing, the current of a dc-to-dc converter source circuit is 15A. It is also humorous that they tell us to use a wire size that is at least 11AWG. Has anyone ever seen an 11AWG wire? At least we don't need to have a greater-than or an equal-to sign there.

#### 690.8(A)(1)(d) DC-TO-DC CONVERTER OUTPUT CIRCUIT CURRENT

As dc-to-dc converter source circuits are connected together in parallel to make a dc-to-dc converter output circuit, the sum of all of the currents being combined at the ***dc combiner*** (see 690.2 definitions) shall be the dc-to-dc converter output circuit current.

Discussion: At the time of the writing of the 2020 NEC, the parallel combining of dc-to-dc converter source circuits is not common, however it does happen for sure in New Jersey.

#### 690.8(A)(1)(e) INVERTER OUTPUT CIRCUIT CURRENT

The maximum current shall be the inverter **continuous** current output **rating.**

Discussion: The current is often marked on the inverter. If current is not marked on the inverter, you can **calculate current by dividing power by operating voltage**. It is interesting to note that dividing power by voltage does not always get the exact same value for current as the inverter datasheet. This can be due to changes in power factor (current and voltage being out of phase with each other and causing a higher current than power divided by voltage would indicate).

### *680.8(A)(2) Circuits Connected to the Input of Electronic Power Converters*

**Pay attention to this big change in the 2020 NEC!**

NEC wording: Where a circuit is protected with an overcurrent device not exceeding the conductor ampacity, the maximum current shall be permitted to be the rated input current of the electronic power converter input to which it is connected.

What this means: We have always based the conductor size (current) of the PV dc circuits based on the rating of the currents coming from the direction of the PV (think Isc × 1.25). Now we are allowed another way to size these circuits based on the maximum current that the ***electronic power converter*** (see 690.2 definitions) can accept. An electronic power converter is usually the input of an interactive inverter.

This is very much like sizing the input of a battery inverter. We do not size a battery inverter input circuit based on the short circuit rating of the battery, which could be many thousands of amps. We will put an overcurrent device between the battery and the battery inverter and then size the wire based on the maximum current that the battery inverter will accept. This is also how many circuits are sized, such as loads on the grid. We do not size the loads based on the short circuit rating of the grid, we size load circuits based on how much current the load can take and then put an overcurrent device on the circuit, to protect from overcurrents and short circuits. As PV goes down in price, we are more likely to oversize the PV array and invoke 690.8(A)(2).

Summary: We can also size electronic power converter input circuits based on the maximum input current as long as the circuit is protected by an OCPD (overcurrent protection device).

### *690.8(B) Conductor Ampacity (ability to carry current)*

**Conductor Ampacity Code References (abbreviated and interpreted)**

690.8(B)(1) Before Application of Adjustment and Correction Factors

690.8(B)(2) After the Application of Adjustment Factors

690.8(A) PV Circuit Current Definitions

690.8(A)(1)(a)(1) PV Source Circuit Current Definition = Usually $I_{sc} \times 1.25$

Table 310.15(B)(1) Ambient Temp. Correction Factors Based on 30°C

Formerly Table 310.15(B)(2)(a) in 2017 NEC

Table 310.15(C)(1) Adjustment Factors for More Than Three Current-Carrying Conductors

Formerly Table 310.15(B)(3)(a) in 2017 NEC

Table 310.16 Ampacities of Insulated Conductors *not* in Free Air

Formerly Table 310.15(B)(16) in 2017 NEC

Table 310.17 Ampacities of Insulated Conductors in Free Air

Formerly Table 310.15(B)(17) in 2017 NEC

Note: See Chapter 12 "PV Wire Sizing Examples" for example calculations.

**Attention! The following is an important part of 690.8(B) that needs to be understood and is commonly misunderstood:**

Word-for-word NEC:

> 690.8(B) Conductor Ampacity: "***Circuit conductors shall be sized to carry not less than the larger ampacity calculated in accordance with 690.8(B)(1) or (B)(2)***"

The text in bold above needs to be properly understood before going further. We will do a check for 690.8(B)(1) and we will also do a check for 690.8(B)(2), and then we will choose the larger wire of the two checks. The wire will always be able to carry more current than the device it is connected to in order to be on the safe side. There will also be other checks. (See **Chapter 12 Wire Sizing** for examples).

Ampacity = Current-carrying ability

*690.8(B)(1) Without Adjustment and Correction Factors*

Here we account for **required ampacity for continuous current** by **multiplying the currents we defined in 690.8(A) by 1.25**.

Or said more simply:

690.8(A) current × 1.25 = 690.8(B)(1) required ampacity.

Some people call this 690.8(B)(1) value "current." **It is not really current;** it is a required ampacity that is more than the actual current in order to be extra safe due to current lasting three hours or more (continuous current).

690.8(B)(1) = Required Ampacity for Continuous Current

About continuous currents:

> PV system currents are continuous. Throughout the Code, we size wires much like we do in Article 690, and since our earth spins slowly (it takes a whole day!), the sunlight can last three hours or more, making PV currents subject to the 1.25 correction factor for continuous currents. This is where the 690.8(B)(1) correction factor comes from. In the 2017 NEC it used to say this in 690.8(B), but in the 2020 NEC ink was conserved.

**Terminal announcement regarding 690.8(B)(1) value!**

Terminal = what the end (terminal) of a wire is connected to. Example: screw terminal. Why do we take terminal temperature limits into consideration?

If a wire is connected to a terminal, there can be some resistance at the connection and the terminal can heat up. The wire can act as a heat sink absorbing heat from the terminal. Additionally, if the wire heats up and is connected to the terminal, the terminal will also become hot.

If you open up your NEC to Table 310.16 or 310.17, you will see values for ampacity for a particular wire that change as you go across the table, depending on the **temperature rating of the insulation** of the conductor. We see 60°C ampacity on the left next to 75°C ampacity and then 90°C ampacity. A conductor that has **an insulation rating that can be hotter will be able to carry more current.**

Terminals have temperature limits and **terminals that are 75°C rated and used with 90°C rated wires are most common in the solar industry**. In general, when doing the **690.8(B)(1)** check, we **use the 75°C column** in the **310.16 and 17** tables in this case.

If we were using 90°C rated terminals with 75°C rated wire, we would use the 75°C column, since it is less than 90°C. It is so uncommon to use 90°C terminals with 75°C wire that we have never seen it done. You can become the first and get mentioned in the next edition of this book. **90°C terminals are rare on both ends of a circuit**. Both ends of the circuit must have 90°C rated equipment to use the 90°C ampacity at the terminals.

On another note, the NEC tells us that if the terminal temperatures are not indicated, we should assume 60°C terminals if the terminals are rated for 100A or less. This situation of assuming 60°C terminals is probably only seen on a NABCEP exam. The vast majority of PV equipment has 75°C terminals.

This terminal temperature logic is only used for the 690.8(B)(1) check and not for the 690.8(B)(2) check.

Terminal Temperature NEC Reference:

Article 110 Requirements for Electrical Installations
110.14 Electrical Connections
110.14(C) Temperature Limitations

> 110.14(C) reads: "The temperature rating associated with the ampacity of a conductor shall be selected and coordinated so as **not to exceed the lowest temperature rating of any connected termination**, conductor, or device. Conductors with **temperature ratings higher than specified for terminations** shall be permitted to be used for **ampacity adjustment**, correction, or both."

Essentially, what this is saying is that the terminal is rated for a certain temperature (75°C for instance). The conductor can reach 75°C, but is not permitted to get hotter than 75°C. When we apply conditions of use, we are doing calculations that approximate how much current it takes to get the copper to 75°C. We don't do anything to the terminal. It's just reflecting the conductor temperature.

If we analyze the last sentence in 110.14(C):

> "Conductors with **temperature ratings higher than specified for terminations** shall be permitted to be used for **ampacity adjustment**, correction, or both."

We see that we do not need to apply the terminal temperature rating when we are **applying adjustment factors**, which we will read about next.

*690.8(B)(2) With Adjustment and Correction Factors*

The conductor ampacity should be able to handle the currents as defined in 690.8(A)(1) after the application of correction and **adjustment factors.**

Here are the correction and adjustment factors in the 2020 NEC:

1. Table 310.15(**B**)(**1**) Ambient Temp. Correction Factors Based on 30°C
2. Table 310.15(**C**)(**1**) Adjustment Factors for More Than Three Current-Carrying Conductors

Additional adjustment in 2014 NEC, but not in later NECs:

3. Table 310.15(B)(3)(c) Ambient Temperature Adjustment for Raceways or Cables Exposed to Sunlight on or Above Rooftops no longer exists
   - In 2020 NEC, if Raceway is 7/8 inch or less above the roof, we still add 33°C to ambient temperature.

These 690.8(B)(2) **adjustment factors** are also commonly called "**conditions of use**" since the adjustments have to do with wires put in areas where there will be more heat as with **Table 310.15(B)(1) Ambient Temp. Correction Factors Based on 30°C** or where the wires will have less of an ability to dissipate heat as with **Table 310.15(C)(1) Adjustment Factors for More Than Three Current-Carrying Conductors**.

Remember that when we apply these adjustment factors, we ***do not* apply the criteria in 690.8(B)(1) such as the 125% continuous current calculation** or the terminal temperature limits.

### TABLE 310.15(B)(1) AMBIENT TEMP. CORRECTION FACTORS BASED ON 30°C

This table is used to correct (some call derate) the ampacity of conductors in Tables 310.16 and 310.17 for temperatures that are different from 30°C. Tables 310.16 and 310.17 are based on temperatures of 30°C, which makes the tables all an electrician has to use if working inside of a building that is not a sauna. When we are working outside of a building in the sun, temperatures can get hotter than 30°C and we can compensate for this by multiplying the conductor ampacity by the derating factor in Table 310.15(B)(1).

> A good place to find high ambient temperatures to use for wire sizing is the www.solarabcs.org expedited permit process on the Expedited Permit Process, map of solar reference points web-page where we also found the cold temperatures that we used for calculating voltage in 690.7. It is recommended to use the temperature value given as the ASHRAE 2% high temperature for wire sizing (no need to use the higher 0.4% high temperature). This is not a record high temperature, but a temperature agreed on by many industry experts and copper barons.

### 310.15(C)(1) ADJUSTMENT FACTORS FOR MORE THAN THREE CURRENT-CARRYING CONDUCTORS

If there are more than three current-carrying wires together in a raceway or cable, then we shall use the derating factors in Table 310.15(C)(1). The reason we do this derating is that the extra conductors in a tight space will generate more heat that has to be dissipated.

We **do *not* count a neutral** that is only **carrying unbalanced currents** from other conductors in the same circuit as a current-carrying conductor. We also **do *not* count equipment grounding** conductors, since they do not carry current.

### TABLE 310.15(B)(3)(C) AMBIENT TEMPERATURE ADJUSTMENT FOR RACEWAYS OR CABLES EXPOSED TO SUNLIGHT ON OR ABOVE ROOFTOPS (LAST SEEN IN 2014 NEC)

In the 2014, 2011 and 2008 NEC according to Table 310.15(B)(3)(c), we had to add to the ambient temperature a temperature adder if there were conductors in a raceway exposed to sunlight over a rooftop. The reasoning behind this temperature adder is that a conduit in sunlight can act like a solar thermal heater for wires. Apparently, due to global cooling, it was not a serious enough consideration to leave the table in the 2017 and 2020 NECs.

**The 2020 NEC still tells us to add 33°C to raceways or cables that are less than 7/8 inch above the roof in sunlight**. We recommend installing all conductors more than 7/8 inch above a roof for other reasons besides heat. **Wiring methods close to the roof encourage debris build-up**, which can cause many other problems, such as **roof rot**.

To sum up these **application of adjustment factors**, we take the 690.8(A)(1) **or** 690.8(A)(2) defined currents and apply the adjustment factors to determine if the conductor fails to be able to carry the current. Oftentimes with rooftop PV it is this adjustment factor method that is the weak link and determines the wire size. Recall that the brand new **690.8(A)(2) currents are defined by the rated input current of electronic power converters**.

We will cover these tables in more detail in our wire-sizing example chapter at the end of the book in Chapter 12 on page 223.

### *690.8(B)(3) Adjustable Electronic Overcurrent Protective Device (new in 2017 NEC); Was Removed and Does Not Exist in the 2020 NEC*

### ***690.8(C) Systems with Multiple Direct-Current Voltages***

If a PV power source has **multiple output circuits** with **multiple output voltages** and employs a common return conductor, the ampacity of the **common return conductor** shall not be less than the sum of the ampere ratings of the overcurrent devices of the individual output circuits.

If we use a single common return wire for three circuits, the return wire must be capable of handling the current of all three circuits. We used to see this done with 48-volt PV systems connected to batteries.

690.8(C) is rarely if ever used.

### *690.8(D) Sizing of Module Interconnection Conductors*

Word-for-word NEC:

> "Where a **single overcurrent device** is used to protect a set of **two or more parallel-connected module circuits,** the **ampacity of each of the module interconnection conductors** shall **not be less than** the **sum** of the rating of the single **overcurrent device plus 125 percent of the short-circuit current** from the ***other*** **parallel-connected modules**."

Since this is confusing, lets also do word for word the blue colored commentary from the **2020 NEC Handbook** and recall that commentary is not the Code:

> "Normally, labels or module instructions require reverse overcurrent protection for each module or string of modules. In some cases, modules with low-rated short-circuit currents and high values of the required series protective fuse could allow the use of one overcurrent device to provide reverse-current protection for multiple modules or strings of modules and overcurrent protection for the conductors. The PV module manufacturer should be contacted for specific information allowing source circuit configurations."

The PV module parallel-connected circuit shown in Figure 2.2 is most often used with low current thin film PV modules in Utility Scale projects using central inverters.

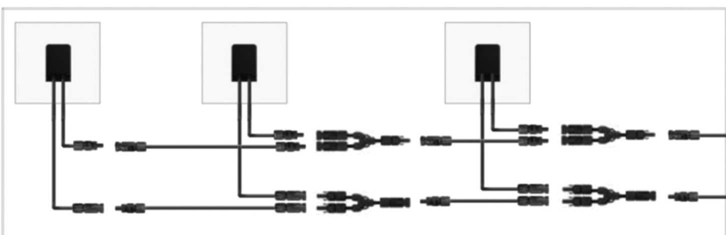

*Figure 2.2* Module interconnect for multiple parallel-connected module circuits
*Source:* courtesy Shoals

If we have 10 modules with an Isc rating of 1A each, we could imagine a short circuit or a fault on one of the modules, with the currents of all the other modules backfeeding through the fault or short circuit.

We will also figure that the maximum series fuse rating for this module and interconnect conductors is a minimum of 15A. The maximum series fuse rating of a module is like the ampacity of the module.

This would mean nine modules of backfeed current through the shorted or faulted module interconnect and the calculation and checks would be as follows:

**10 modules in parallel, Isc = 1A, Max series fuse = 15A**

Source Circuit Current = 1A × 1.25 × 10 = 12.5A and maximum module fuse is 15A

Fault current from parallel strings in source circuit = 1A × 1.25 × 9 (number of strings paralleled to the faulted string before the fuse) = 11.25A

Total current available to the module including reverse current through the fuse is 11.25A + 15A (fuse) = 26.25A ≥ 15A (fail)

- (15A fuse currents are from different part of array operating in parallel)

Reduce guess to six modules in parallel.

**6 modules in parallel, Isc = 1A, Max series fuse = 15A**

Current = 1A × 1.25 × 6 = 7.5A minimum fuse is 7.5A × 1.25 = 9.4A (10A fuse).

Total current available to module is 7.5A + 10A = 17.5A ≥ 15A (**fail**)

Check five in parallel

**5 modules in parallel, Isc = 1A, Max series fuse = 15A**

Current = 1A × 1.25 × 5 = 6.25A minimum fuse is 6.25 × 1.25 = 7.8A (8A fuse)

Total current available to module is 6.25A + 8A = 14.25A ≤ 15A (**Pass with 8A fuse and no more than five modules in parallel**)

Now wasn't that fun? With the new definitions of current we can use even lower numbers for module current based on simulations for systems over 100kW.

Discussion: Some PV systems have modules with low current and higher voltage. These modules are sometimes connected in parallel to a single overcurrent protection device. To some people, it would look like two (or more) PV source circuits combining at a single fuse. In fact, these two series connected groups of modules are considered a single PV source circuit. This is why in 690.8(A)(1) Photovoltaic **Source Circuit** Currents method (1), it says "the sum of **parallel-connected** PV module rated short-circuit currents multiplied by 125 percent."

Yes, that is right; **a PV source circuit can be made of two** or more **"strings" in effect** going to a single fuse as long as the module interconnection conductors can handle the currents from the number of strings minus one. We subtract one because the string being back fed on by the other strings in a short circuit condition does not need to be counted.

This logic is also used in the case that most designers know about in which two PV source circuits combining at a single MPP do not need a fuse.

If this 690.8(D) discussion was too much for you, join a large club and turn the page. This is only relevant to a small fraction of a percentage of people designing PV systems, such as First Solar Inc. engineers. For most of us, just remember that greater than two in parallel requires fusing.

## 690.9 Overcurrent Protection

### *Outline of 690.9*

- 690.9 Overcurrent Protection
  - 690.9(A) Circuits and Equipment
    - 690.9(A)(1) Circuits Where Overcurrent Protection Not Required
    - 690.9(A)(2) Circuits Where Overcurrent Protection is Required on One End
    - 690.9(A)(3) Other Circuits
      - 690.9(A)(3)(1) Conductors Less Than 10 ft Outside Protected on One End
      - 690.9(A)(3)(2) Conductors Less Than 10 ft Inside Protected on One End
      - 690.9(A)(3)(3) Conductors Protected on Both Ends
      - 690.9(A)(3)(4) Conductors Outside Protected at One End and a. Through e.
        - 690.9(A)(3)(1)(a) Installed in Metal, Underground or in Pad
        - 690.9(A)(3)(1)(b) Terminate on Single Breaker or Set of Fuses

690.9(A)(3)(1)(c) OCPD Within or Within 10 ft of Disconnect
690.9(A)(3)(1)(d) Installed Outside or Within 10 ft of Entrance Inside
690.9(B) Device Ratings
690.9(B)(1) Not less than 125% of Maximum Currents
690.9(B)(2) 100% of its Rating
690.9(C) Source and Output Circuits
690.9(D) Power Transformers
690.9(D) Exception: Permitted Without OCPD on Inverter Side

Article 690.9 **PV Overcurrent Protection** follows the line with **Article 240 Overcurrent Protection**, but with special provisions for PV that are different from most electricity, such as solar cells that produce current based on the brightness of light, the current-limited aspects of PV and current that can be flowing in different directions.

### *690.9(A) Circuits and Equipment*

PV system dc circuit and ac inverter output conductors and equipment shall be protected against overcurrent.

> Discussion regarding above sentence: Notice how the first sentence in 690.9(A) does not say conductors and equipment ***must*** be protected with overcurrent protection devices (OCPD). This is because with current-limited sources, such as with PV systems, it is simple to size the conductors for the highest continuous current. In fact, putting an overcurrent protective device in a circuit where it will not operate under a short circuit might fool people who associate a blown fuse with a short circuit and may be more dangerous than no OCPD at all.

Overcurrent devices are required for circuits sized based on the 690.8(B)(2). The current rating of the overcurrent device is based on the rated input current of the electronic power converter.

Overcurrent protective devices are not required for circuit conductors with sufficient ampacity for highest available currents when using 690.9(A)(1).

Examples of **current-limited supplies**:

- PV modules
- Dc-to-dc converters
- Interactive inverter output circuits

Circuits connected to current-limited supplies and also connected to sources with higher current availability shall be protected at the higher current source connection.

Examples of higher current availability:

- Parallel **strings** of modules
- Utility power

### Strings

690.9(A) was once the only place in Article 690 where it said string or strings rather than PV source circuit. This is no longer the case in the 2020 NEC. String is a term that is defined in the International Electrotechnical Commission (IEC) standard. We often call a PV source circuit a "string" and this can increase the use of slang.

The IEC is an international standard that is used to align Codes around the world. At the beginning of the NEC, on the first page of code, we can see:

***NEC 90.1(C) Relation to Other Standards***

The requirements of this Code address the fundamental principles of protection for safety contained in Section 131 of International Electrotechnical Standard 60364–1 Electrical Installations of Buildings

This means that the NEC follows the principles of the international standard that most places on Earth attempt to follow to a degree.

The NEC goes into much more detail regarding PV systems than the IEC.

IEC Definition:

PV string: a circuit of series connected modules

*690.9(A)(1) Circuits Where Overcurrent Protection Is Not Required*

Not required on both ends **where both of the following** (A)(1)(1) and (A)(1)(2) **are met.**

690.9(A)(1)(1) where conductors have sufficient ampacity for maximum current.

Overcurrent protection not required if circuit conductors "have sufficient ampacity for **maximum circuit current**."

690.9(A)(1)(2) Where the **currents from all sources** do not exceed the maximum overcurrent protective device rating specified for the PV module or electronic power converter.

The maximum circuit current of a PV module is analogous to the ampacity of the module (including the conductors that are part of the module, which is a listed unit).

**Just say no to OCPD (sometimes).**

There are instances where overcurrent protection, if used, would create a false sense of security and an unnecessary source of nuisance failures (fuses fail even when they don't get overcurrent at times). In these cases, overcurrent protection is not required.

Since PV itself is current-limited and we size fuses at a minimum of 156% of short-circuit current, in many cases a short circuit will not open a fuse.

If there are no external sources, such as parallel-connected PV source circuits, batteries or backfeed from inverters, we can often forgo the OCPD. (The following example does not include circuits sized based on the new 690.8(A)(2) Circuits Connected to the Input of Electronic Power Converters, where OCPD is required.)

Let's give an example: If there is a single string of PV connected to an inverter and there is a short circuit of the PV source circuit, the overcurrent device would never open the circuit. **PV source circuit fuses are sized based on 156% of short-circuit current and then rounded up to the next common overcurrent protection device.** If a PV module short-circuit current (Isc) is 9A, then the fuse size we would use would be calculated as:

$$9\text{A} \times 1.56 = 14\text{A then round up to } 15\text{A fuse}$$

We round up to the next common overcurrent protection device size. Common sizes are found in NEC 240.6. (800A and over we do not round up).

If we had a single string of 9A Isc PV modules short out, we would never get enough current to open a 15A fuse.

In fact, if we had a single PV output circuit short out where it was connected to an inverter, it still would not have enough current to open any properly sized overcurrent protection device on the PV output circuit. We could short circuit a MW of PV for 20 years and never blow a fuse!

This is the nature of current-limited PV. In some cases, it is safer, since we are not exposed to super high short circuits. The arc-flash danger is less, but it can be more dangerous in some aspects, since we cannot open up overcurrent protection devices with large enough currents in many cases.

If short-circuit currents from all sources do not exceed the ampacity of the conductors or the maximum overcurrent protective device size rating specified for the PV module or dc-to-dc converter, then we do not need to have overcurrent protection.

This is the example of not needing fuses when you have two PV source circuits going to a single inverter input. If we have one PV source circuit that is shorted out and the currents from the other PV source circuit are backfeeding to the shorted PV source circuit, then we would only have a maximum of the current from a single PV source circuit. We would not have the currents from both strings, since we would at most have currents from one PV source circuit feeding to another. In this case we do not need a fuse.

**Why do we even have PV source circuit fuses?**

If we had 50 PV source circuits combining at a dc combiner and a single string shorted, then we would get the current from 49 PV source circuits backfeeding a single PV source circuit. The fuse protecting the single PV source circuit would have currents going the reverse direction and would open up the fuse, even on a cloudy (low current) day. Dc combiner fuses are designed to open due to currents going in the reverse direction when the non-shorted PV source circuits send current back through a shorted PV source circuit. Once the fuse blows, the remaining 49 PV source circuits may just immediately go back to working without notifying anyone that anything happened if there is no monitoring or dc arc-fault protection did not turn off the inverter. It is possible that in a large array, that there may be many PV source circuits not contributing to power.

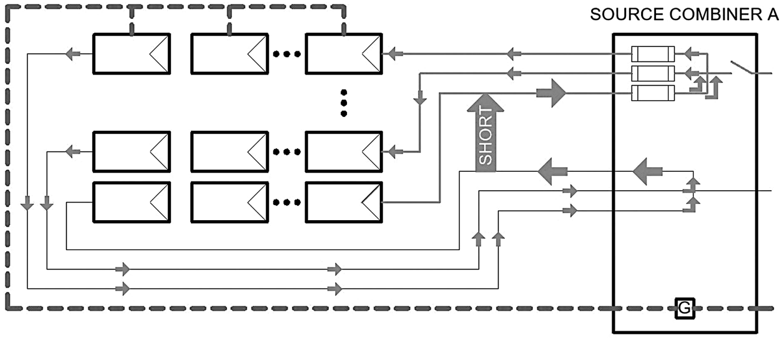


*Figure 2.3* Two PV source circuits backfeeding a short on another PV source circuit

*Source:* courtesy Robert Price AxisSolarDesign.com


*Figure 2.4* Fuses listed for PV

*Source:* courtesy Cooper Bussmann

**PV dc circuits are current-limited circuits** that only need overcurrent protection when connected in parallel to higher current sources. The overcurrent device is often installed at the higher current source end of the circuit.

Discussion: We install fuses at the source of the overcurrents at **dc combiners**. Some think it would be easier if there were fuses that came in the junction boxes of PV modules. The source of the overcurrents is not from the individual PV modules, but from the parallel-connected sources feeding back to the shorted PV source circuit. **Overcurrent protection should be installed at the source of the potential overcurrents**, which is where the PV source circuits are combined, at the dc source circuit combiner.

### *690.9(A)(2) Circuits Where Overcurrent Protection Is Required on One End*

If the conductor is sufficient for the current-limited supply it is connected to at one end, but the conductor is connected on the **other end to a supply that is greater than the ampacity of the conductor**, overcurrent protection is installed at the point of connection to the higher current source.

### *690.9(A)(2) Informational Note*

The informational note explains that the overcurrent protection device is **often put at the side of the circuit at the higher current source end**. An example where this may not be the case is covered in 690.9(A)(3) For Other Circuits.

### *690.9(A)(3) Other Circuits*

Circuits that do not comply with 690.9(A)(1) (OCPD not required on both ends) or 690.9(A)(2) (OCPD not required on one end), shall be protected by one of the following 690.9(A)(3)(1) through 690.9(A)(3)(4).

690.9(A)(3)(1)

Conductors ≤ 10 ft **not in buildings**
protected from overcurrent on one end

690.9(A)(3)(2)

Conductors ≤ 10 ft **in buildings**
protected from overcurrent on one end in raceway or MC cable

690.9(A)(3)(3)

Protected from overcurrent at both ends

690.9(A)(3)(4)

**Not in or on buildings** are permitted to be protected at one end if **all of the following** 690.9(A)(3)(4)(a) through 690.9(A)(3)(4)(b) **apply**.

690.9(A)(3)(4)(a): Installed in **either**:

- Metal raceway
- Metal-clad cable
- Enclosed metal-cable trays
- Underground

690.9(A)(3)(4)(b): The conductors for each circuit terminate on one end at a single circuit breaker or set of fuses that limit current to ampacity of conductors.

690.9(A)(3)(4)(c): The OCPD is part of disconnecting means or located within 10 ft of conductor length of disconnecting means.

690.9(A)(3)(4)(d): The disconnecting means is outside building or readily accessible location nearest the point of entrance of conductors inside building (including installations complying with 230.6).

### *690.9(B) Device Ratings*

Overcurrent protection devices used in PV dc circuits shall be **listed** for use in PV systems.

The requirement for a "listed" PV fuse was brought into the NEC in 2014.

Electronic devices listed to prevent backfeed current in PV system dc circuits are permitted to permit overcurrents on the array side of the device.

OCPDs are rounded up to the next higher device size in accordance with 240.4(B).

OCPDs shall be rated in accordance with 690.9(B)(1) or 690.9(B)(2).

(To see examples of OCPD sizing in action, read Chapter 12 Wire Sizing on Page 223)

#### *690.9(B)(1) Not Less Than 125% Of Maximum Currents*

Overcurrent protection devices must be **at least 125% of the currents defined in 690.8(A) Maximum Circuit Current**. You can review those currents defined in 690.8(A)(1) through 690.8(A)(2) starting on page 34 of this book.

*690.9(B)(2) 100% of its Rating*

If an assembly and its overcurrent protective device is rated for continuous use at **100% of its rating**, then it does *not* need to be at least 125% of its rating.

Invoking this "100% of its rating" section of the Code is rare, used for larger currents and not something most designers of smaller PV systems should concern themselves with.

***690.9(B) Informational Note: Some devices prevent backfeed current and sometimes the only source of overcurrent in a dc PV circuit is a backfeed current***

One-way diodes:

Back in the day, when most PV systems were stand-alone systems, we would insert blocking diodes between the PV and the battery to prevent the battery from backfeeding into the array at night (causing the array to heat up and the battery to discharge). Now that we have higher tech charge controllers, we are no longer using these blocking diodes. 10-years ago NABCEP would have a blocking diode question on their "Entry Level Exam" that compared a blocking diode to a one-way plumbing "check valve." In a way a solar cell is a diode, preferentially sending electrons to the N-side of the P-N junction.

Another more recent NABCEP Associate exam question is rumoured to ask about blocking and in that case, they mean attaching a block of wood between rafters which is used to attach a lag bolt to, which is roofing and not electrical.

***690.9(C) Source and Output Circuits***

When an overcurrent device is required, a single overcurrent protective device is permitted for each PV or dc-to-dc converter source circuit or each PV or dc-to-dc converter output circuit. This protected circuit includes the PV, dc-to-dc converters, and the conductors in these circuits.

When single overcurrent protection devices are used, they must all be in the same polarity.

Discussion: In the 2014 and earlier versions of the NEC, 690.35 required ungrounded systems to have overcurrent protection on both positive and negative polarities. The “transformerless” or “non-isolated” inverters that are the typical interactive inverter used today, were often called “ungrounded” inverters. Now the **NEC only requires overcurrent protection on a single polarity**, when overcurrent protection is required. The current codes only require overcurrent protection on one polarity for all PV source circuits and PV output circuits, regardless of how they are grounded. In places where the 2017 or 2020 NEC is not being used, such as jurisdictions that have not yet adopted the 2017 NEC or later, fuses on both positive and negative polarities may be required, whenever fusing is required on PV and dc-to-dc-converter source and output circuits. Fusing is usually required when there are greater than two circuits combined. Additionally, the new “690.8(A)(2) Circuits Connected to the Input of Electronic Power Converters” in the 2020 NEC also requires overcurrent protection. 690.8(A)(2) would not typically be invoked without a high PV to inverter ratio.

One of the reasons that we are allowing overcurrent protection on only one polarity of a new inverter, is that when an old, “formerly known as grounded inverter” needs to be replaced, we can replace it with a new inverter without adding fuses. The newer inverters are much safer and more able to detect ground faults. It would be stupid to incentivize people to replace old less-safe inverters with other less-safe inverters, because they did not want to go through the complicated and expensive process of adding fuses. We can also now use USE-2 wire in this case rather than PV wire for the same reason.

### *690.9(C) Informational Note: OCPD only in positive or negative*

Due to improved ground fault protection requirements, a **single overcurrent protection device** in either positive or negative in combination with ground-fault protection **provides adequate overcurrent protection**.

### *690.9(D) Power Transformers*

Overcurrent protection for a transformer with sources on both sides shall consider one side of the transformer, then the other side as primary to determine which way requires the most conservative overcurrent protection.

Discussion: Transformer overcurrent protection shall be done in accordance with 450.3. Section 450.3 has different values that overcurrent protection is based on, which are often more than 125% of current.

Article 450 is Transformers and Transformer Vaults and Section 450.3 is for Overcurrent Protection for transformers (not conductors).

Article 240 is what we refer to for overcurrent protection of conductors.

### *690.9(D) Exception: Side of transformer towards inverter*

If the current rating of the interactive inverter side of the transformer is at least the current rating of the inverter, then **overcurrent on the inverter side of the transformer is not required**.

Discussion: If the transformer can handle all of the current from the inverter, then overcurrent protection is not required between the inverter and the transformer.

This is due to the **current-limited characteristics of the inverter** not being able to hurt the transformer or overcurrent the conductors connected between the inverter and the transformer.

Often, when an inverter is connected to a transformer, there is no requirement for overcurrent protection on the current-limited inverter side of the transformer. The dangerous currents come from the big dangerous utility, not the safe PV side.

## 690.10 Stand-Alone Systems

Wiring of stand-alone systems shall be done in accordance with 710.15.

- Article 710 is Stand-Alone Systems.
- Section 710.15 General is 99% of Article 710.

Discussion: 690.10 Stand-Alone Systems was big in the earlier versions of the NEC, and the material had moved to Article 710 Stand-Alone Systems in the 2017 NEC and stayed there. No longer are energy storage and loads considered part of a PV system and this information has all moved to different locations in the NEC. Much of the requirements are the same, they are just found in a different location. We cover this material on page 195. This also means that 690.12 Rapid Shutdown for PV Systems on Buildings is not required for equipment in different articles, such as batteries, energy storage, and loads.

## 690.11 Arc-Fault Circuit Protection (direct current)

PV systems 80V or greater between any two conductors shall be protected by a listed PV arc-fault circuit interrupter or equivalent.

## 690.11 Arc-Fault Circuit Protection Exception

PV systems that are ***not* on or in buildings,** ***PV output circuits and dc-to-dc converter output circuits*** that are direct buried, in metallic raceways or metal clad cables or in enclosed metallic cable trays are **permitted *without* arc-fault circuit protection**.

Buildings that have the sole purpose of housing PV equipment are not required to be considered a building for this exception.

This exception only applies to PV and dc-to-dc converter **output** circuits. PV source circuits and dc-to-dc converter source circuits are still required to have dc arc-fault protection.

See pages 60 and 145 for exceptions for dc arc-fault protection under engineering supervision for large (greater than 5 MWac)

*Figure 2.5* Dangerous dc arc-fault (do not try this at home) Smoking kills
*Source:* Sean White's solar powered lighter company

systems in Article 691 Large-Scale Photovoltaic (PV) Electric Power Production Facility.

Discussion and history: **2011** NEC 690.11 **only applies to circuits penetrating or on a building** and was the first time 690.11 appeared in the NEC. **2014** NEC 690.11 **applies to all dc PV circuits,** even large ground mounts. This is a problem for large central inverter PV systems that would require dc arc-fault protection for PV source circuits and **PV output circuits**.

Engineering dc arc-fault protection is close to impossible for large PV output circuits. Some would say that utility scale PV using large central inverters does not comply with the 2014 NEC, since there is no way to perform dc arc-fault protection on the PV output circuits.

**2017 and 2020** NEC allows PV systems that are ***not*** **on or in buildings to not have dc arc-fault protection on PV output circuits when those circuits are either buried or in metal.** PV source circuits still require arc-fault detection if they are greater than 80V. This means combiner level dc arc-fault devices for PV source circuits are required in PV systems that cannot invoke Article 691 (over 5 MWac).

Part II of Article 690 is almost complete. The last section of Part II will be covered in the next chapter.

# 3 Section 690.12 Rapid Shutdown

Section 690.12 Rapid Shutdown is the hottest spot in PV education since it came out in the 2014 NEC. Chapter 3 of this book is dedicated to covering the evolution of 690.12. Not only were there changes from the 2014 NEC to the 2017 NEC to the 2020 NEC, there were even parts of the 2017 NEC that did not take effect until 2019. Therefore 690.12 deserves its own chapter. We will also cover 690.56(C) in this chapter, which are the labeling requirements for rapid shutdown.

**Rapid shutdown in popular culture**

At the Solar Battle of the Bands in San Francisco in 2018, during the last San Francisco Intersolar Conference, there was a band that called themselves the "Rapid Shutdowns" and was sponsored by Luminalt. Bill had to inform the Rapid Shutdowns that he was really the one who had named their band, so they took him backstage and whatever happened next was fortunately not on social media.

Grid Alternatives North Atlantic in DC also had a kickball team called the Rapid Shutdowns, and apparently they sucked and had a great time!

Please contribute to more of this behavior and let us know so your team, band, CCA or small government can also be featured in the next issue of this book!

## Overview

The rapid shutdown requirements of the NEC first appeared in the 2014 NEC and have changed quite a bit in the subsequent versions.

This evolution of the Code has a purpose: **to save firefighters' lives**. Additionally, in making houses with PV safer for firefighters, firefighters will be more inclined to save buildings that have PV on them. Having firefighters save buildings with PV on them has many benefits, including keeping insurance rates from going up for buildings sporting PV arrays. In talking to many firefighters, I find that many of them are less inclined to put out a fire on a building that has PV on it. It is up to us to educate the firefighters to look for the yellow sticker or other indications that the building has a PV system on it that cannot shock them once rapid shutdown has been initiated. We can also educate them on how to tell if rapid shutdown has been initiated, which most of the time means that there is no ac power from the grid connected to the inverter. **Rapid shutdown only applies to PV systems on buildings!**

## Outline of 2020 NEC 690.12

- 690.12 Rapid Shutdown of PV Systems on Buildings
  - 690.12 Exception
    - 690.12(A) Controlled Conductors
      - 690.12(A)(1) PV system dc circuits
      - 690.12(A)(2) Inverter output circuits originating in array boundary
    - 690.12(B) Controlled Limits
      - 690.12(B)(1) Outside the array boundary
      - 690.12(B)(2) Inside the array boundary
        - 690.12(B)(2)(1) Listed hazard control system
        - 690.12(B)(2)(2) 30 seconds, 80V
        - 690.12(B)(2)(3) No exposed wiring or metal
    - 690.12(C) Initiation Device
      - 690.12(C)(1) Service disconnecting means
      - 690.12(C)(2) PV system disconnecting means
      - 690.12(C)(3) Readily accessible switch
    - 690.12(D) Equipment

## 690.12 Rapid Shutdown of PV Systems on Buildings

PV systems in or on buildings shall have a rapid shutdown function system to reduce shock hazards for firefighters.

An interactive inverter is part of a PV system, so if you have a ground-mounted PV system, you might not want to mount the inverter on the side of a building if you do not want to have to comply with rapid shutdown. A battery inverter on the other hand is not part of a PV system and would not have to comply with rapid shutdown requirements.

## 690.12 Exception

If a building's sole purpose is to house PV system equipment, then it does not have to comply with 690.12.

Sometimes a large solar project will have a building that serves as an equipment enclosure, the only purpose of which is to house PV system equipment. Obviously, rapid shutdown requirements were not intended to require rapid shutdown on a large solar farm equipment enclosure.

### *690.12(A) Controlled Conductors*

The requirements for the controlled conductors shall be applied to **the following:**

690.12(A)(1) PV system dc circuits
690.12(A)(2) Inverter output circuits from inverters within the array boundary

Discussion: Controlled conductors are conductors that we can turn off or control with our rapid shutdown disconnect.

**Energy storage system and loads** are not PV systems. We can confirm this from the figures and images in NEC 690.1(b) and in Chapter 1 of this book, beginning on page 9. The **PV system disconnect in each figure is the boundary of the "PV system."** In the 2014 NEC, rapid shutdown requirements are applied to battery systems and stand-alone inverters. The 2017 and 2020 NEC's rapid shutdown requirements only apply to a PV system and not to energy storage systems. Some people would like to make rapid shutdown requirements apply to energy storage systems and anything that could be energized when the grid goes down—future Codes will decide. Some PV systems with rapid shutdown automatically de-energize when the grid goes down.

### *690.12(B) Controlled Limits*

We have different rules for inside vs. outside of the array boundary. The **array boundary** is **1 foot from the array**.

We can see the **690.2 definition of array**:

> **Array**. A mechanically integrated assembly of module(s) or panel(s) with a **support structure** and **foundation**, tracker and **other components**, as required, to form a dc or ac **power-producing unit**.

Discussion: The array boundary is usually going to be the edge of the PV, but if the rails, tracker or concrete foundation stick out more than the PV, then the array boundary can be 1 foot from the edge of it.

**A 20-foot-long conductor that is run 6 inches from the edge of the array would qualify as inside the array boundary**.

If you have 2 arrays that are 2 feet apart from each other and are running conductors between both arrays, your conductors would always be within an array boundary being 1 foot or less from each array.

We have different voltage limits within and outside of the array boundary, and the time to getting within these limits is always going to be within 30 seconds of rapid shutdown initiation.

*690.12(B)(1) Outside the Array Boundary*

Controlled conductors outside the array boundary, or **more than 3 feet from the point of entry inside a building**, shall be limited to no more than **30V within 30 seconds** of rapid shutdown initiation.

Voltage shall be measured between any two conductors and between any conductor and ground.

Discussion: First of all, we point out that besides having a limit of 1 foot from the array, **the NEC also gives us 3 feet from the point of entry inside the building** to have controlled conductors, which can be more than 1 foot from the array boundary if inside a building.

The reason that we need at least 3 feet inside the building is to allow enough space for the conductor to mount equipment inside an attic space or similar area. The roof thickness can take up much of that distance. Most of the time, the shutdown devices will be on the roof. Building-integrated PV systems are one example where this 3-foot rule will be important. Additionally, firefighters will probably not be cutting directly through the building under the PV while the PV system is energized.

**BIPV and microinverters Tony Diaz Style**

Tony Diaz installs BIPV (building-integrated PV) and puts microinverters under the ridgecap (ridge of the roof). This means that he would have greater than 30V and less than 80V going from the array 3 feet to the ridge to the roof. Since this could be interpreted as being inside of the building, perhaps it is Code compliant. The 3-foot pathway from the PV to the ridge is for firefighters to cut a hole and vent smoke out. This BIPV also has fewer solar cells, so he puts them in series before connecting them to a microinverter to get the equivalent of a 60- to 72-cell PV module.

Controlled conductors **outside of the array boundary** or **within 3 feet from the penetration** of a building must be limited to

- 30V
- Within 30 seconds

**Rapid Evolution 2014 NEC to the present**

In the **2014 NEC, 690.12** first stated that controlled conductors shall be limited to no more than **30V and 240 volt-amperes within 10 seconds**. The 2014 NEC was changed by an amendment in the year 2016 from **10 seconds to 30 seconds via a TIA (tentative interim amendment)**. The reason for this change was to allow product manufacturers **to address grid support requirements that may require that the PV array stay on for up to 20 seconds during utility grid problems**. It also **allows more time for the capacitors on the dc side of the inverter to discharge** in 30 seconds. The fire service also agreed that the danger to firefighters would not change significantly with the time increase.

The 2014 NEC 240 volt-ampere requirement was also taken out of the Code, since it is nearly impossible to verify in the field and needs to be verified by the laboratories that certify the equipment used for Rapid Shutdown.

*690.12(B)(2) Inside the Array Boundary*

The PV system shall comply with one of the following:

690.12(B)(2)(1) UL 3741 Listed PV Hazard Control System
690.12(B)(2)(2) 80V in 30 seconds (module level shutdown)
690.12(B)(2)(3) No exposed conductive parts or wiring methods

690.12(B)(2)(1) UL 3741 LISTED PV HAZARD CONTROL SYSTEM

At time of writing, there is no such thing as a UL 3741 Listed PV Hazard Control System. Products that do not meet 690.12(B)(2)(2) or (B)(2)(3) may be able to meet 690.12(B)(2)(1). Products meeting this new standard will also take time to come to market and, depending on what time you are experiencing, may already be a thing.

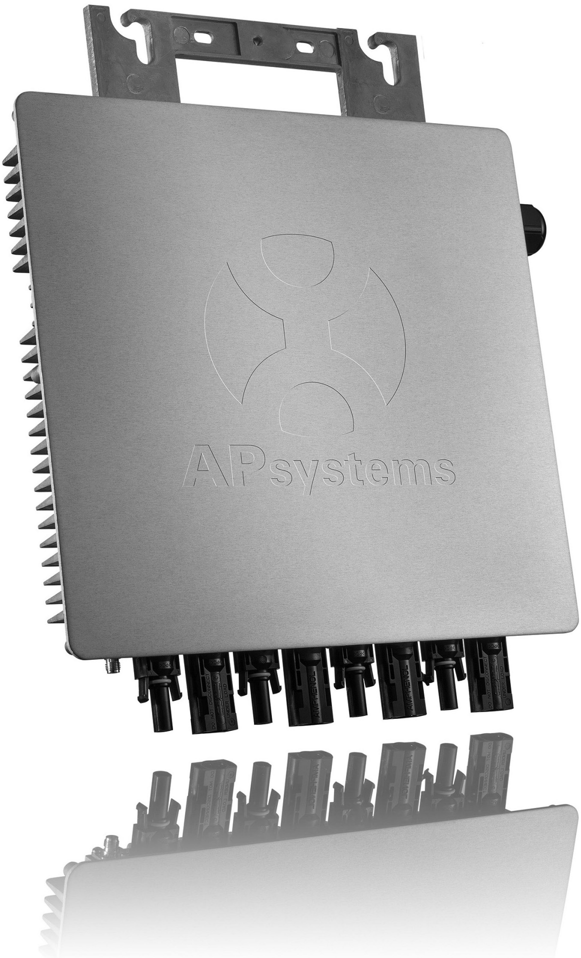


*Figure 3.1* AP system 4 module inverter
*Source:* courtesy AP Systems

690.12(B)(2)(2) 80V IN 30 SECONDS

*AKA module level shutdown*

690.12(B)(2)(2) is what everybody is talking about. It amounts to **module level shutdown**, which is already very common with **micro-inverters and dc-to-dc converters** (AKA power optimizers). There are products where the whole array operates below 80V, but these systems are far less common than power optimizers and microinverters.

The reason that 80V amounts to module level shutdown is because the maximum voltage of two 60- or 72-cell modules in series (temperature corrected) would be over 80V. It is uncommon to find a PV module for a building that would have a maximum voltage over 80V and one module under 40V. Even a rare 96-cell module will remain under 80V on a cold day in New Jersey. Some thin film modules are over 80V and may not be usable to meet this particular compliance option.

690.12(B)(2)(2) mentions that, besides conductors being inside the array boundary having to adhere by 690.12(B)(2)(2), conductors no more than 3 feet from penetration of the building have to comply. This is because the **690.12(B)(1) definition of outside the array boundary includes within 3 feet of penetration of the building**. Perhaps we could say that 3 feet from the penetration of a building qualifies as being inside of the array boundary for this purpose. The reason for this 3-foot rule was to make it clear that the wiring inside the building immediately under the array could not be counted as being within the 1-foot array boundary.

This 690.12(B)(2)(2) method is accomplished with electronics distributed throughout the array for the most part. However, this method can also be accomplished with parallel connections and special equipment that disconnect series-connected modules at the module level.

690.12(B)(2)(3) NO EXPOSED WIRING OR METAL

PV arrays with no exposed wiring methods, no exposed conductive parts and installed more than 8 feet from exposed grounded conductive parts are allowed. These systems can go up to 600V inside the array boundary on 1- and 2-family dwellings and up to 1000V on other buildings after the initiation of rapid shutdown. We are reducing the firefighters' ability to get shocked by limiting the conductive metal parts and exposed wiring methods.

Discussion: To meet the requirements of 690.12(B)(2)(3), we can envision a PV array that has **no exposed metal or conductors** and is **installed at least 8 feet from grounded metal on a roof**.

An example of a PV system that could comply with 690.12(B)(2)(3) would be a building-integrated PV (BIPV) system with no exposed metal parts, since many BIPV systems do not have metal racks or frames. Any grounded metal, such as combustion appliance vents, would need to be at least 8 feet from any point of the array.

### Building-integrated photovoltaics (BIPV)

The definition for BIPV was last seen in definition 690.2 in the 2014 NEC. This was not because of a conspiracy against BIPV, but because BIPV was not mentioned anywhere else in the NEC. The NEC is not supposed to have definitions that do not refer to anything else in the NEC. Microinverters were first mentioned in the NEC in the 2020 NEC in 690.33(D)(3) Informational Note. Perhaps it is time for a microinverter definition.

2014 NEC BIPV definition:

> ***Building-integrated photovoltaics.*** *Photovoltaic cells, devices, modules or modular materials that are integrated into the outer surface or structure of a building and serve as the outer protective surface of the building.*

It is interesting to note that **Building-integrated photovoltaics** were still in the index of the 2017 NEC and referred to 690.2 definitions because someone forgot to take them out of the index. This was also the only place in the NEC where the word “photovoltaics” was used, rather than “photovoltaic.”

Any PV system without exposed wiring or metal could comply with 690.12(B)(2)(3). Perhaps it is a good time to come up with your $158,000,000 idea. You would not be the first.

### *690.12(C) Initiation Device*

When in the **off position**, the rapid shutdown initiation device shall indicate that rapid shutdown has been initiated. This means that **off means that the PV system is off** and that rapid shutdown is activated.

For one- and two-family dwellings, at least one rapid shutdown initiation device must be outside in a readily accessible location.

**Following** are the **three methods** used for rapid shutdown initiation:

*690.12(C)(1) Service Disconnecting Means*

The service disconnecting means (main breaker) can be the rapid shutdown initiation device. This is an easy option, plus it shuts everything else down with one switch. This could be the fastest way to turn off a building in an emergency, PV system and everything.

*690.12(C)(2) PV System Disconnecting Means*

The PV system disconnecting means (usually a circuit breaker or fused disconnect) can be a rapid shutdown initiation device. In many places in America, the main service disconnect is in the basement, and the supply side fused disconnect is the PV system disconnecting means and the rapid shutdown initiation device.

*690.12(C)(3) Readily Accessible Switch*

A readily accessible switch (often a special rapid shutdown switch or inverter disconnect) can be the rapid shutdown initiation device, shown in Figure 3.2.


*Figure 3.2* Rapid shutdown initiation switch
*Source:* courtesy Bentek Solar

*690.12(C)(3) Informational Note*

One reason why a 690.12(C)(3) readily accessible switch type initiation device is used is for systems that operate in island mode to keep operating upon loss of utility voltage.

Discussion: Many rapid shutdown systems shut down whenever the utility shuts down. For systems with backup, there needs to be a way to initiate rapid shutdown independent of utility outages. Otherwise, the rapid shutdown function would negate the benefit of the backup power system. As more batteries go on the grid, we will see more systems require a rapid shutdown initiation device independent of just cutting ac power to the inverter interactive output circuit.

Where multiple PV systems with rapid shutdown are installed on a **single service**, the initiation device(s) shall consist of no more than six switches or circuit breakers in a single enclosure or group of enclosures.

### *690.12(D) Equipment*

Equipment that performs rapid shutdown, **other than initiation devices, such as disconnect switches, circuit breakers or control switches**, shall be listed for providing rapid shutdown protection.

Discussion: The 2014 NEC did not require special listed rapid shutdown equipment. When disconnecting conductors on a roof, using the 2014 NEC, we could use equipment such as listed contactors for PV systems (remote-controlled switches) to turn off a system on the roof, which we also used for other purposes besides rapid shutdown of PV systems. Now, according to the 2017 and 2020 NEC, our special rapid shutdown equipment needs to be specially listed for rapid shutdown. Generally we do not use special "rapid shutdown listed" devices for the initiation devices, since we use switches such as circuit breakers and other devices with an "off" and "on" position.

We can still use regular switches and breakers to provide rapid shutdown initiation, such as the main breaker or a breaker in a subpanel. The Code recognizes that it would be ridiculous to get a special listing for a switch when it is just being used as a switch. However, some switches may have special communications functions like the Midnite Solar "birdhouse." Specialized switches like this product may require a special listing for rapid shutdown. The Midnite Solar "birdhouse" switch can also shut down battery connections, which would be a good idea for safety, but has not been required since the 2014 NEC.

### *Rapid Shutdown Labeling from 690.56(C)*

This chapter is going to include the labeling requirements for rapid shutdown systems which are found in **690 Part VI Marking / 690.56 Identification of Power Sources.** The other question here is as follows: Is this book going out of order, or is the NEC out of order? For discussion purposes, it is a good idea to put all of the rapid shutdown material together.

## Outline of 690.56(C)

690.56(C) Buildings with Rapid Shutdown
Figure 690.56(C) Label for Roof-Mounted PV Systems With Rapid Shutdown
690.56(C)(1) Buildings With More Than One Rapid Shutdown Type
690.56(C)(2) Rapid Shutdown Switch

### *690.56(C) Buildings with Rapid Shutdown*

Buildings with PV Systems shall have a permanent label at each service entrance location.

- The label shall indicate where rapid shutdown initiation device(s) is located
- The label shall have a simple diagram of the building
- The label shall include the following words:

SOLAR PV SYSTEM IS EQUIPPED WITH RAPID SHUTDOWN
TURN RAPID SHUTDOWN SWITCH TO THE “OFF” POSITION
TO SHUT DOWN
PV SYSTEM AND REDUCE SHOCK HAZARD IN ARRAY

The yellow accented 690.56(C) sign is now required for all 3 methods of rapid shutdown.

There are specific requirements for a sign that includes specific colors and words. As a note, the NEC does not have the colors in the example of the sign and neither do the pages of this book.

The scheme for the 690.56(C) rapid shutdown sign is:

Title wording:

Solar PV System is Equipped with Rapid Shutdown

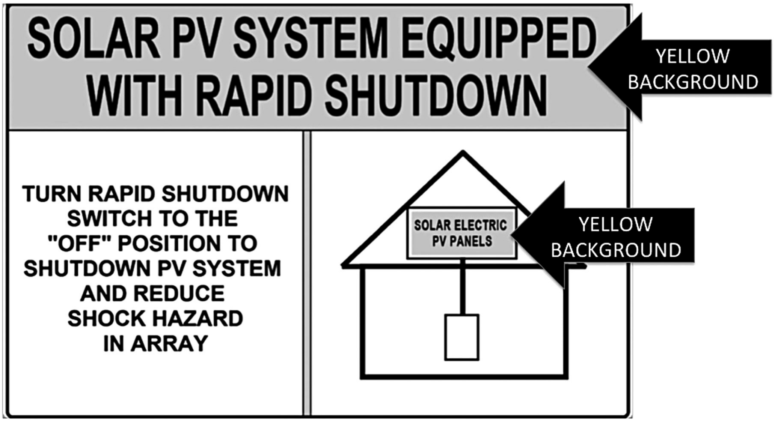


*Figure 3.3* NEC Figure 690.56(C) Label for Roof-Mounted PV Systems with Rapid Shutdown

*Source:* courtesy NFPA

Title characters:

Capitalized black 3/8 inch minimum height

Title background color:

Yellow (yellow is the ANSI caution color)

Remaining characters wording:

Turn Rapid Shutdown Switch to the “OFF” Position to Shut Down PV System and Reduce Shock Hazard in Array

Remaining characters:

Capitalized black 3/16 inch minimum height

Remaining characters background color:

White

The area on the sign where it says “SOLAR ELECTRIC PV PANELS” in the image is intended to be in black letters on a yellow background. **The reason it says PV PANELS rather than PV MODULES** is because only solar professionals call solar modules “solar modules,” while most people, including **firefighters, refer to solar modules as solar panels.**

**The Array Level Shutdown Sign and the 2019 Requirements that were in the 2017 NEC.**

In the 2017 NEC we had another, similar sign, which was used for systems that did not reduce hazards inside the array but had array level shutdown. There was a red color on the sign. The 2017 NEC allowed energized conductors within the array until January 1, 2019. The 2020 NEC does not have this red sign, although we still have a method for array level rapid shutdown, which is the 690.12(B)(2)(3) "no exposed metal parts or wiring methods" method. In this case, we can just use the 690.56(C) sign.

*690.56(C)(1) Buildings with More Than One Rapid Shutdown Type*

If a building has more than one type of PV system with different rapid shutdown types or a PV system installed without rapid shutdown and another system installed later with a rapid shutdown system, then we need a sign that will indicate the different rapid shutdown type scenarios and where the PV system will remain energized after rapid shutdown is initiated.

Figure 3.4 is an example of a sign to be used for a rectangular-shaped building with two different types of rapid shutdown arrays. In this example, the **color scheme** is:

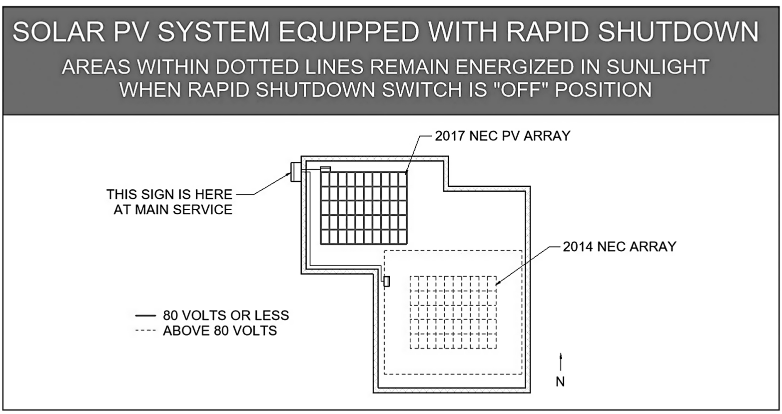


*Figure 3.4* Buildings with more than one rapid shutdown type
*Source:* example courtesy Robert Price www.axissolardesign.com

- Red with white background: title box on top
- Yellow: 2020 NEC PV array, 80V or less
- Red: 2014 NEC PV array (over 80V)
- Dotted line: within energized

Your building and PV systems will probably look different than the sign in the image, so this sign is customized to the installation. Your sign should plainly indicate to firefighters which areas of the roof will be energized after rapid shutdown is initiated. **A dotted line shall be around areas that remain energized after the rapid shutdown switch is operated**.

*690.56(C)(2) Rapid Shutdown Switch*

Within 3 feet of a rapid shutdown switch, there shall be a label with the following words:

Rapid Shutdown Switch for Solar PV System

Criteria for rapid shutdown switch label:

- Reflective
- All letters capitalized
- Letters at least 3/8 inch height
- White on red background


*Figure 3.5* Rapid shutdown sign
*Source:* Sean White

# 4 Article 690 Part III Disconnecting Means

Article 690 Part III includes two sections:

690.13 Photovoltaic System Disconnecting Means
690.15 Disconnecting Means for **Isolating** Photovoltaic Equipment

Let us first define **disconnecting means** in general with the **Article 100 Definition:**

> Disconnecting Means. A device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply.

In this definition, we can have a variety of different devices or means that can disconnect sources from supply. These devices are **not required to be load-break rated** devices or big expensive switches that can disconnect a service.

Here are a few examples of disconnecting means:

- Load-break rated dc disconnect
- PV inter-module connectors
- Non-load-break rated disconnect
- Touch safe, tilt-out fuseholders

Even a light switch is a disconnecting means and, for that matter, even unscrewing a light bulb can be considered operating a disconnecting means, no matter how many licensed professional electrical engineers it takes.

## Outline of 690.13

690.13 Photovoltaic System Disconnecting Means
- 690.13(A) Location
- 690.13(B) Marking
- 690.13(C) Maximum Number of Disconnects
- 690.13(D) Ratings
- 690.13(E) Type of Disconnect
  - 690.13(E)(1) Manually Operated Switch or Circuit Breaker
  - 690.13(E)(2) Connector
  - 690.13(E)(3) Pull-Out Switch
  - 690.13(E)(4) Remote-Controlled Switch or Breaker
  - 690.13(E)(5) Listed or Approved for Intended Application

## 690.13 Photovoltaic System Disconnecting Means

Here we are not going to be using a light switch to disconnect an entire PV system; however, we do need to provide a way to disconnect the PV system from all other systems.

### *690.13(A) Location*

Disconnecting means shall be installed in a **readily accessible location**.

Article 100's definition of "readily accessible":

> **Accessible, Readily** (**Readily Accessible**). Capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to take actions such as tools (other than keys) to climb over (or under to remove obstacles), or to resort to portable ladders and so forth.

Discussion: A readily accessible disconnecting means can be locked in a room or building but cannot require access with tools. This means that the PV system disconnecting means can be inside a building.

**Think of the PV system disconnecting means as the last thing that separates the PV system from any other system.**

Here are some examples of common PV system disconnecting means:

- Grid tied inverter backfeed breaker
- Stand-alone system dc disconnect between PV and battery
- Breaker feeding panelboard that is used exclusively for PV inverters


*Figure 4.1* PV system disconnect sign
*Source:* Sean White

Recall the disconnecting means in the diagrams in NEC Figure 690.1(b) shown in Chapter 1 of this book, beginning on page 9, **separates the PV system from other systems**.

### *690.13(B) Marking*

690.13(B) Marking requires a sign that says, **"PV SYSTEM DISCONNECT" or equivalent.** It is interesting to note that most label companies go with the "equivalent clause" and add words and make the sign say more words than required, such as "main photovoltaic system dc disconnect." Perhaps label companies get paid per character, unlike the characters who wrote this book.

Other markings are required for some disconnecting means which do not completely de-energize on both sides of the switch when the switch is opened (off). The sign shall say the following or equivalent:

WARNING
ELECTRIC SHOCK HAZARD
TERMINALS ON THE LINE AND LOAD SIDES
MAY BE ENERGIZED IN THE OPEN POSITION

Interestingly, label makers do not use the equivalent used here for the "line and load" sign. If we may suggest: "Warning, this switch can have electricity on both sides when off". This has fewer letters and is easier for non-electrician firefighters and installers to understand. We could also put the time it takes after turning off before it is safe on the inverter side. This is usually anywhere from 30 seconds to 5 minutes.

The NEC does not require a particular color or letter size for the PV SYSTEM DISCONNECT sign or the LINE AND LOAD ENERGIZED sign; usually this sign is in capital white letters on a contrasting background. However, **690.13(B) requires that signs or labels do comply with 110.21(B).**

**110.21(B) Field-Applied Hazard Markings are required by 690.13(B)**

110.21(B) Field-Applied Hazard Markings. Where caution, warning or danger signs are required by the Code, the labels shall meet the following requirements:

> 110.21(B)(1) The marking shall warn of the hazards using effective words, colors, symbols or any combination thereof.

110.21(B)(1) *Informational Note* (recommended but not required): **ANSI (American National Standards Institute) ANSI Z535.4–2011 is recommended**.

According to this 48 Page **American National Standard for Product Safety Signs and Labels**, there are requirements for the design and use of safety signs and labels.

Here are some examples:

Danger = white triangle, red exclamation mark, red background
Warning = black triangle, orange exclamation mark
Caution = black triangle, yellow exclamation mark
Danger, Warning or Caution = yellow triangle, black border and exclamation mark

Since our 690.13(B) sign has the word WARNING in it, we can say that according to ANSI, **WARNING indicates**:

> "a hazardous situation which, if not avoided, could result in death or serious injury"

In addition, warning signs such as the "line and load" sign should have a black triangle with an orange exclamation mark if you follow the informational note.

When we have an inverter that has capacitors that discharge within 30 seconds to comply with rapid shutdown requirements, we still need the 690.13(B) LINE AND LOAD ENERGIZED sign because a switch cover can be opened immediately and be hazardous to an electrical worker that is unaware of the hazard. Some electricians can get their fingers inside a disconnect within 30 seconds.

**The Old 2017 NEC 690.13(C) Suitable for Use as Service Equipment**

In the 2017 NEC, 690.13(C) was a different concept and the 2020 NEC 690.13(C) is now something else. 2017 NEC 690.13(C) told us that supply side disconnecting means should be listed as suitable for use as a service disconnecting means. We will study this further in 705.11 Supply-Side Connections on page 151, where it sends us to 230.82(6) and still **requires disconnecting means listed as suitable for service equipment**.

Discussion: A **supply side connection** (often and perhaps incorrectly referred to as a **line side tap**) is **not a separate service**; however, it is subject to unprotected currents from the service. In other past versions of the NEC, including the **2014 NEC, this was not a requirement**, but was **recommended** by solar professionals. As battery systems become more commonplace, these parallel generator connections will often be converted into services to accommodate backup loads and EV chargers.

### *690.13(C) Maximum Number of Disconnects*

Each PV system disconnecting means shall not consist of more than six switches mounted in a single enclosure or group of enclosures. It is uncommon to have more than one disconnect for a PV system. An example of where you might have several disconnects to make up a PV system disconnect is with dc coupled systems where more than one dc PV circuit is connected to a battery storage system. Remember that the NEC does not limit the number of PV systems that could be connected to a building [690.4(D) Multiple PV Systems].

A single PV system disconnecting means shall be permitted for the combined ac output of one or more inverters or ac modules in an interactive system. Examples of this may be a microinverter circuit with 15 microinverters or an ac panel main breaker that can disconnect 150 microinverters.

Discussion: If a building has multiple sources of power, then we can have no more than six disconnects per source. This means a building that has 1 PV system and is connected to the utility can have 12 disconnects. If there were 2 PV systems, then we could have up to $6 \times 3 = 18$ of these disconnects.

If the PV system disconnect(s) were grouped together on one side of the building and the utility disconnect(s) were grouped together on the other side, that is not a problem. However, a directory is required at each location to inform about the other sources to the building. Recall that 690.4(D) requires a directory if there are PV system disconnects located in different locations.

### *690.13(D) Ratings*

The PV system disconnecting means shall have ratings sufficient for the maximum circuit current, available fault current and voltage that is available at the terminals of the PV system disconnect.

Discussion: We do not just look at the trip rating of an overcurrent protection device. We also look at the maximum available current that can be interrupted. If we are performing a **supply side connection**, we would be on the utility side of all overcurrent protection devices and the overcurrent protection would often need to have a higher **ampere interrupting rating** than a load side connected PV system would. This is one reason why service rated equipment is often used for a supply side connection because it often has a higher available fault current. Service rated switches also have a means to connect the neutral to ground in the enclosure, which is often done, depending on the local AHJ requirements.

Overcurrent protection devices have a high-end **ampere interrupting rating** for fault currents and a low-end overload **amp rating**. Often the high-end current is overlooked or ignored, since usually we are focused on the overcurrent protection device protecting conductors with the overload **amp rating**. The overcurrent protection device also needs to protect itself. On your house, the main service disconnect may have a higher **ampere interrupting rating** than the load breakers in the service panel, since it is the first line of defense for utility fault currents. Ampere interrupting ratings are often in the tens of thousands of amps.

### *690.13(E) Type of Disconnect*

PV system disconnecting means **shall**:

- Simultaneously disconnect all non-solidly grounded conductors
- Be capable of being locked
- Be one of the following types of disconnects 690.13(E)(1) through (5):
  1. Manually operated switch or circuit breaker
  2. Connector as in 690.33(D)(2) of (D)(3) (see page 108)

3. Pull-out switch (with required interrupt rating)
4. Remote switch that is operated locally and opens when control power is cut
5. Device listed or approved for intended operation

Discussion: Recall that a PV system disconnecting means is the borderline between the PV system and other wiring systems. This means that a **dc disconnect in an interactive PV system is not a PV system disconnecting means**. It is merely an equipment disconnect for the inverter. Since the interactive inverter is part of the PV system (only processes PV power), the **PV system disconnect would be an ac disconnect for an interactive system.**

**PV system disconnects need to open all non-solidly conductors simultaneously**. A PV module connector is an example of a disconnect or isolating device that does not simultaneously disconnect all conductors. It could not be used as a PV system disconnect, but a connector can be used as an isolation device [690.15].

690.13(E) Informational Note: **"Circuit breakers marked "line" and "load" may not be suitable for backfeed or reverse current.**

This informational note has a big change. Before, in the 2017 NEC and earlier, it was a **shall**, where now it is a **may** in an informational note. There is a big difference between "shall" and "may." The 2017 "shall" means that there is no way you can backfeed something marked "line" and "load," but "may" in this context means that there is a chance that you may not be able to backfeed something marked "line" and "load." Thermally operated circuit breakers and fuses cannot tell which way the power is flowing and are generally suitable for backfeed.

Many people are in jail right now, because they did not know the difference between "shall" and "may," so be sure to read this book carefully and stay safe!

## Outline of 690.15

690.15 Disconnecting Means for Isolating Photovoltaic Equipment
- 690.15(A) Location
- 690.15(B) Isolating Device
  - 690.15(B)(1) Connector
  - 690.15(B)(2) Finger-Safe Fuseholder
  - 690.15(B)(3) Isolating Switch Requiring Tool
  - 690.15(B)(4) Isolating Device Listed for Application
- 690.15(C) Equipment Disconnecting Means
- 690.15(D) Type of Disconnecting Means

## 690.15 Disconnection of Photovoltaic Equipment

First of all, let's discuss the difference between **690.13 PV System Disconnecting Means** and **690.15 Disconnection of Photovoltaic Equipment.**

**690.13 PV System Disconnecting Means** applies to how to separate a PV system from what is not a PV system. You could also consider this the borderline between the NEC definition of a PV system and some other system or special equipment covered outside of Article 690, such as loads in a panelboard, an energy storage system or a dc coupled battery bank on a 10MW PV system.

**690.15 Disconnection Means for Isolating Photovoltaic Equipment** applies to the disconnection of equipment inside the depths of the PV system. Here we can have non-load-break rated equipment, and **non-simultaneous circuit opening, as with module connectors and fuse-holders**. We also have equipment disconnecting means, which can be load-break rated and can simultaneously disconnect.

Although Article 690 does not have a definition for "**isolating device**" and perhaps it should, there is an **Article 100 Definition for Isolating Switch**, which can give us some clues. Article 100 is titled Definitions.

> **Switch, Isolating.** A switch intended for isolating an electrical circuit from the source of power. **It has no interrupting rating**, and is **intended to be operated only after the circuit has been opened by some other means.**

The above definition relates to what is often called a **non-load-break disconnect.**

To sum it up, PV equipment disconnecting means are always allowed to be **load-break rated** and other times ***not* required to be load-break rated.**

**Another term for load-break rated** that we may see on equipment is **current interrupting.**

Some inverters or charge controllers have multiple inputs with a single disconnect; this single disconnect with multiple inputs is acceptable.

The purpose of isolating devices is for the safe ability to work on equipment without being exposed to energized conductors. **Isolating devices are not intended to be operated in an emergency condition** since they require that the technician makes sure that the circuit being interrupted does not have current flowing. **It is essentially a maintenance disconnect.**

690.15 states that a disconnect as described in 690.15(D) (page 88) shall be provided to disconnect the following equipment from all not-solidly grounded conductors:

- Ac PV modules
- Fuses
- Dc-to-dc converters
- Inverters
- Charge controllers

***690.15(A) Location***

The following are acceptable locations for **isolating devices or equipment disconnecting means:**

- Within equipment
- Within **site and** within **10 feet** of equipment

Equipment disconnecting means **can be operated remotely** from the disconnect if:

- There is a remote means to **operate the disconnect within 10 feet of equipment**

Discussion: **Equipment disconnects and isolating devices must be within 10 feet of equipment or remotely operated within 10 feet of equipment.**

**Turning off an inverter with your phone**

Many devices, such as inverters and PV modules come with isolating devices or disconnecting means. It is also quite possible that an inverter could be designed with the ability to turn off with the use of a smartphone app. In this case, the smartphone could be used to turn off the inverter and then the connections to the inverter could be unplugged (isolating device) to remove or service the inverter.

### *690.15(B) Isolating Device*

Isolating devices are not required to have an interrupting rating. If the isolating device is not rated for interrupting the circuit current, then it shall be marked with one of the following:

- Do Not Disconnect Under Load
- Not for Current Interrupting (this phrase is made up of fewer characters and saves label ink).

An isolating device is not required to simultaneously disconnect all current-carrying conductors of a circuit.

For example, if someone is removing or installing a PV module, they will not disconnect or connect positive and negative at exactly the same instant. If they were that quick, they would be making millions playing baseball.

Discussion: PV systems are current-limited and the equipment of a PV system will have short-circuit currents available that are not much more than operating currents. We have to be sure that the terminals of the equipment side of the disconnect can handle these short-circuit currents.

It is the PV system disconnecting means covered by 690.13 that has to have the ability to interrupt higher fault currents coming from batteries and the utility, which are outside of the PV system.

Equipment disconnecting means have to be able to open circuits that have current flowing through them.

Isolating devices are not made to interrupt current. Isolating devices should not be opened when there is current flowing. If they were opened under load, it could catch fire in rare circumstances, such as in an Article 691 compliant solar farm with no dc arc-fault protection or an old PV system that is pre-2011 NEC without dc arc-fault protection.

#### *690.15(B)(1) Through (4)*

Following are the only types of isolating devices we can use.

#### *690.15(B)(1) Connector Meeting the Requirements of 690.33*

Must be **listed and identified** for use with specific equipment. The primary purpose for this statement was to make it clear that a connector could be used as a disconnect when the application is clearly defined. For instance, consider an MC-4 connector that is rated up to 50A and can be installed on circuits up to 1000Vdc. However, on a 1000Vdc series string, if you were to take it apart under even a 5A load, it could start a fire. Take that same connector and put it on the input of a lower dc voltage microinverter and that same connector can easily break the 5A load without damage to the connector or the operator.

Examples are:

- PV module connectors, such as an MC-4 or Amphenol connector
- Dc-to-dc converter connector
- Some inverters come with ac cable connectors (more often in other countries)

690.33 Connectors are covered on page 106 of this book.

### *690.15(B)(2) Finger-Safe Fuseholder*

Finger-safe fuseholders are most often used in combiner boxes.

Discussion: When doing voltage or IV curve testing on strings of modules at a dc combiner, we often open the finger-safe fuseholders to **isolate the circuit**. This should only be done after the PV output circuit disconnect is opened and there is no current going through the circuit. Many solar installers have witnessed an arc show when opening touch-safe fuseholders under load on a system without dc arc-fault protection.

As we can see in Figure 4.2, the finger-safe fuseholder can be opened without touching the fuse. After the fuseholder is opened, both sides of the fuse are de-energized.

*Figure 4.2* Finger-safe fuseholder

*Source:* courtesy Schurter, Inc.

### *690.15(B)(3) Isolating Device Requiring Tool to Turn Off*

For isolating devices that are accessible to non-qualified personnel, these switches require the use of a tool to move the switch to the open position so that it is impossible for someone without the tool to walk by and open the switch under load. Opening one of these switches under load could be extremely dangerous to the operator. Laypeople usually think that turning something off is safe, but when you turn off a non-load-break rated switch under load, it is not safe. This is kind of the opposite of Lockout Tagout. Here we want to keep the isolating device on instead of off to prevent arcs.

### *690.15(B)(4) Isolating Device Listed for Application*

This option is a catch-all that allows products that have been tested and evaluated for a specific purpose to be used according to how they were evaluated. It may be a combination of several of the options above, but configured in a special way that makes it easier to work on the equipment.

### ***690.15(C) Equipment Disconnecting Means***

Requirements for PV Equipment Disconnecting Means:

- Have rating for:
    - Maximum circuit current
    - Available fault current
    - Voltage
- Externally operable
- Will not expose operator to contact with energized parts
- Shall indicate if on or off (you can see that it is on or off)
- Shall be lockable (in accordance with 110.25)
- Will simultaneously open current-carrying conductors that are **not solidly grounded**
    - Discussion: It is an important distinction to note that, in the 2020 (and 2017) NEC, we are required to open all **not-solidly grounded conductors**. Inverters that were previously called grounded inverters in the 2014 NEC that were fuse grounded and were the typical US inverter of the 2000s decade are now called grounded functionally and are *not* solidly grounded. These formerly "grounded" inverters will have their formerly "grounded conductor" opened in the disconnect in the 2020 NEC. *Not* disconnecting this former "white

wire" that was referenced to ground through a fuse was a requirement of the 2014 NEC and the opposite is true in the 2017 and 2020 NECs.

- If load terminals can be energized in the open (off) position, then the 690.13(B) "line and load energized sign" shall be used **unless 690.33 connectors are used.**
    - Connectors between modules and from modules to other equipment are equipment disconnecting means. Fortunately, **we do not need the "line and load energized" label at every solar module.**

### 2014 NEC and earlier vs. 2020 NEC (2017 and later) NEC inverter/array grounding

Comparing NEC requirements for formerly known as "grounded" (fuse grounded) inverters:

≤ 2014 NEC

- White grounded conductor
- Opened only single ungrounded conductor per circuit
- Fuses when required only on ungrounded conductor

≥ 2017 NEC

- Positive and negative must not be white unless one is solidly grounded
- Both positive and negative must be opened at disconnect
- Fuses only required on one polarity (positive or negative)

While we are at it, we might as well give the 2020 NEC (2017 and later) and 2014 NEC (and earlier) differences of the formerly known as **ungrounded, transformerless or non-isolated inverters**, which are also now known as functionally grounded inverters and have the **same rules as all other interactive inverters in the 2020 NEC**.

Formerly known as "ungrounded" inverters:

≤ 2014 NEC

- Positive and negative must not be white
- Both positive and negative opened at disconnect

- **Fuses required on positive and negative** when fuses required
- **Must use PV wire**, no USE-2 wire for PV circuits outside of conduit

≥ 2017 NEC

- Positive and negative must not be white
- Both positive and negative opened at disconnect
- **Fuses only required on one polarity** (positive or negative)
- **USE-2 or PV wire both acceptable** for PV circuits outside of conduit

Now that we know about functionally grounded inverters, perhaps we can say that the 2014 and earlier versions of the Code were instigating dysfunctional grounding.

### *690.15(C) Informational Note:*

For PV dc disconnects, it is common to put the line side toward the PV. This is more likely to de-energize the load side terminals, blades and fuses when the disconnect is open.

In addition to the information in this informational note, with a utility interactive system, if you look at the dc and ac disconnects, it is always going to be the inverter side that is safer, so a good idea is to put the line side of the disconnect or other equipment toward the more dangerous side and the load side of the ac or dc disconnect toward the interactive inverter.

### *690.15(D) Type of Disconnecting Means*

Disconnects to isolate solar equipment shall be one of the following two types:

#### *690.15(D)(1)*

If the circuit is over **30A**, then a 690.15(C) style (**load-break rated**) dc disconnect is required.

*690.15(D)(2)*

If the circuit is **30A** or less, then any **non-load-break rated** 690.15(B) style isolating device, like a connector, finger-safe fuseholder, etc. is acceptable.

End of chapter breakdown:

Let us break down the different types of disconnecting means as related to PV systems and Article 690 Part III of the NEC.

- Disconnecting means
  - Device(s) that disconnect conductors from supply
  - The three below are all disconnecting means
    - PV system disconnecting means
      - Separates PV system from *not* a PV system
    - Isolating device
      - Non-load-break rated (load-break rated not required)
    - PV equipment disconnecting means
      - Load-break rated

In other countries that do not abide by the super-safe NEC, it is common for the only load-break rated disconnect in an interactive PV system to be a backfed circuit breaker in a load center. The rest of the system is connected together with connectors so we can say it is "connectorized." These systems are turned off by the backfed breaker and then taken apart while not under load. It appears that the cowboys have gone foreign.

It has been said (although not yet in the NEC) that a well-trained firefighter wielding a fiberglass-handled axe is an exceptional disconnecting means.

# 5 Article 690 Part IV Wiring Methods and Materials

**Article 690 Part IV Wiring Methods and Materials** covers the methods and materials specific to wiring PV systems. Much of this material refers to and works with other articles of the NEC, especially the NEC articles within **Chapter 3 Wiring Methods and Materials**, such as **Article 310 Conductors for General Wiring**.

> **Chapters 5–7 modify the first four chapters of the NEC.**
>
> This means that if there is a difference between regular wiring methods and Article 690, when we are dealing with a PV system, we will go with Article 690. Same would also go for Articles in Chapter 7, such as 706 Energy Storage systems, which modifies the first 4 chapters, including Article 480 Storage Batteries.

Although there are PV-specific wiring methods in 690 Part IV Wiring Methods, all other parts of the 2020 NEC apply to the wiring of PV systems.

690 Part IV Wiring Methods and Materials sections

690.31 Wiring Methods
690.32 Component Interconnections
690.33 Mating Connectors
690.34 Access to Boxes

Part IV Detail:

690.31 Wiring Methods
- 690.31(A) Wiring Systems
  - Table 690.31(A)(a) Correction Factors
  - Table 690.31(A)(b) Ampacities 105°C to 125°C
- 690.31(B) Identification and Grouping
  - 690.31(B)(1) Identification
  - 690.31(B)(2) Grouping
- 690.31(C) Cables
  - 690.31(C)(1) Single Conductor Cable
  - 690.31(C)(2) Cable Tray
  - 690.31(C)(3) Multiconductor Jacketed Cables
  - 690.31(C)(4) Flexible Chords and Cables Connected to Tracking PV Arrays
  - Table 690.31(C)(4) Minimum PV Wire Strands (for Flexible Chords and Cables)
  - 690.31(C)(5) Flexible, Fine-Stranded Cables
  - 690.31(C)(6) Small-Conductor Cables
- 690.31(D) Direct-Current Circuits on Buildings
  - 690.31(D)(1) Flexible Wiring Methods
  - 690.31(D)(2) Marking and Labeling Required
- 690.31(E) Bipolar Photovoltaic Systems
- 690.31(F) Wiring Methods and Mounting Systems

690.32 Component Interconnections

690.33 Mating Connectors
- 690.33(A) Configuration
- 690.33(B) Guarding
- 690.33(C) Type
- 690.33(D) Type Interruption of Circuit
  - 690.33(D)(1) Rated for Interrupting
  - 690.33(D)(2) Requires Tool to Open
  - 690.33(D)(3) Connectors can be MLPE Disconnects

690.34 Access to Boxes

## 690.31 Wiring Methods

It is amusing when we see 690 Part IV **Wiring Methods and Materials**/690.31 Wiring **Methods/Wiring Systems.** That is the order of things and how we emphasize the **importance** of our **wiring method and materials systems!**

### *690.31(A) Wiring Systems*

The following are all permitted wiring methods:

- Raceway wiring methods in the NEC
- Cable wiring methods in the NEC
- Other wiring systems specifically **listed for PV arrays**
- Wiring that is part of a **listed system**

The following are comments on different wiring systems:

- Raceway wiring methods in the NEC
  - Raceway wiring methods are found primarily throughout Chapter 3 of the NEC. Chapter 3 is titled **Wiring Methods and Materials**
  - EMT is often the raceway method of choice and is covered in **Article 358 Electrical Metallic Tubing: Type EMT**
- Cable wiring methods in the NEC
  - Cable wiring methods are also found in Chapter 3 of the NEC
  - USE-2 a popular cable is covered in Article 338, Service-Entrance Cable: Types SE and USE. The -2 of USE denotes that it is 90°C rated
  - PV wire is another wiring method that was specifically required in the 2014 NEC, but is an option along with USE-2 in the 2017 and 2020 NEC
- Other wiring systems specifically **listed for PV arrays**
  - A cable manufacturer could design a cable that was superior to PV wire, get a certifying agency to list it, and now we have another cable listed for PV arrays
- Wiring that is part of a **listed system**
  - While this listed system could be a wiring system for rapid shutdown, it could be any special cable used as part of a listed system. The Enphase microinverter cable fits under this category
- Enclosures:
  - Where wiring systems with integral enclosures are used, there must be enough extra wire length to facilitate replacement

**300.14 Length of free conductors at outlets, junctions and switch points** says that we need **6 inches of free conductor**. It also says that, for boxes measuring fewer than 8 inches in any dimension, we only need the wire to be able to extend 3 inches outside an opening. Additionally, if the wires are not spliced in the box, then this requirement does not apply.

PV source and PV output circuits (does not say dc-to-dc converter circuits) over 30V in **readily accessible locations** shall be one of the following:

- Guarded
- In MC cable (Article 330 Metal-Clad Cable: Type MC)
- In raceway (does not require metal raceway)

**Table 690.31(A)(a)** shall be used for correcting ambient temperatures over 30°C for conductors with 105°C and 125°C rated insulation. The temperature rating of the insulation is theoretically how hot the wire can get after running the current in the ampacity table through it under given conditions. At this point, nobody is using 105°C and 125°C wire; however, Bill put this in the NEC, since he is an NEC futurist. For proper wire sizing, see Chapter 12 Wire Sizing.

Table 690.31(A)(a) is adapted from 690.31(A) in the 2017 NEC. In the 2017 NEC, the temperature rating of the wires included temperatures covered in the 310 Tables. In the 2020 NEC, this Table 690.31(A)(a) covers 105°C and 125°C insulation temperatures only, which are very hot! Perhaps we are preparing for a Venus-like climate.

> Table 310.15(B)(2)(a) Ambient Temperature Correction Factors Based on 30°C in the 2017 NEC was renamed Table 310.15(B)(1) in the 2020 NEC. **The 310.15(B) Tables were renamed in the 2020 NEC**. See page 213 for details. In the 2017 NEC, we were not supposed to use 2017 NEC Table 310.15(B)(2)(a) for PV systems, however we had "almost" exactly the same information in 2017 NEC Table 690.31(A). Now there is no overlapping since 2020 NEC 690.31(A)(a) is for higher conductor temperature ratings than 2020 NEC 310.15(B)(1).

*Table 5.1* 690.31(A)(a) correction factors for 105°C and 125°C rated wire (ambient temperature correction factors for temperatures over 30°C)

| *Ambient temperature (°C)* | *Temperature rating of conductor* | |
|---|---|---|
| | *105°C(221°F)* | *125°C(257°F)* |
| 30 | 1.00 | 1.00 |
| 31–35 | 0.91 | 0.94 |
| 36–40 | 0.82 | 0.88 |
| 41–45 | 0.71 | 0.82 |

*this table goes up to 120°C (248°F) ambient temperatures in the NEC
*Source:* courtesy NFPA

*Table 5.2* 690.31(A)(b) Ampacities of 105°C and 125°C rated wire not in free air

| | *Ampacities* | |
|---|---|---|
| *AWG* | *105°C(221°F)* | *125°C(257°F)* |
| 14 | 29A | 31A |
| 12 | 36A | 39A |
| 10 | 46A | 50A |
| 8 | 64A | 69A |
| 6 | 81A | 87A |
| 4 | 109A | 118A |
| 3 | 129A | 139A |
| 2 | 143A | 154A |
| 1 | 168A | 181A |
| 1/0 | 193A | 208A |
| 2/0 | 229A | 247A |

*Source:* courtesy NFPA

690.31(A) continued:

**Table 690.31(A)(b)** shall be used for determining ampacities of conductors rated for 105°C and 125°C. This table can be viewed as an extension of the table formerly known as 2017 NEC 310.15(B)(16), now known as Table 310.16 in the 2020 NEC as it was in the 2008 NEC.

The NEC went 12 years retro! At least the 2008 NEC had an offline PDF version you could buy. Unfortunately, the NFPA now requires an internet connection to view the digital version.

Although conductors with a higher temperature rating can carry more current, they will still have the same voltage drop as conductors with a lower temperature rating. Since PV prices are getting so low, at this rate, they will pay us to take it in a few more code cycles, so why not save money on smaller wire?

### *690.31(B) Identification and Grouping*

- **Dc circuits can go in the same location as signaling types of circuits**
  - **This means that there is no question that we can put a communication conductor that goes to the array for rapid shutdown or monitoring in the same raceway as the dc conductors**

PV System dc circuits, **unless separated by a barrier or partition**, shall not be in the same:

- Wiring enclosure
- Cable
- Raceway

**as other conductors** from other non-PV systems or inverter output circuits.

If **separated by a partition**, then we have a work around and can put PV source and PV output circuits with other conductors in the same wireway. Partitions are available with some enclosure products such as gutters. **Most jurisdictions will require a partition to be an accessory included in the listing of the enclosure.**

690.31(B) Exception:

> You do **not** need a partition or barrier to comply with 690.31(B) if you are using either:
>
> - Multiconductor jacketed cable
> - Metal-clad assemblies
> - Listed wiring harness identified for the purpose
>
> And all conductors must have a voltage rating of the highest voltage, so if there is a 600V circuit and a 24V circuit in the same jacketed cable, then the insulation around the 24V circuit has to be rated for 600V.

690.31(B) also tells us we need to comply with both 690.31(B)(1) Identification and Grouping and 690.31(B)(2) Grouping

*690.31(B)(1) Identification*

**PV system circuit conductors** shall be **identified** at accessible points of

- Termination
- Connection
- Splices
- Exception: evident by spacing or arrangement

**Means of identifying** PV system circuit conductors:

- Color coding
- Marking tape
- Tagging
- Other approved means
- Spacing or arrangement (690.31(B)(1) Exception)

Only **solidly grounded** conductors in accordance with **690.41(A)(5)** shall be marked in accordance with **200.6 Means of Identifying Grounded Conductors**.

Discussion: **Solidly grounded systems** in the 2020 NEC are rare systems that are ***not* fuse grounded**. An example of a solidly grounded PV system according to the 2020 NEC is a **direct PV well pump**, where the negative conductor is solidly connected to a grounding system that includes a grounding electrode (often the well casing). Grounding through a fuse is not solidly grounding.

These rare and solidly grounded conductors will most likely be marked white according to 200.6 (the marking could be grey, three white stripes or three grey stripes). **Fuse-grounded current-carrying conductors** that operate at zero volts to ground **are not considered to be meeting the requirements of 200.6** and **should *not* be identified as white, as they were in the 2014 NEC and earlier versions**. The ac side of an inverter is most often solidly grounded, just like anything else ac.

The **690.31(B)(1) Identification Exception** tells us that if the identification of conductors is evident by spacing or arrangement, then we do not need other forms of identification.

### *690.31(B)(2) Grouping*

If the conductors of more than one PV system occupy the same

- **Junction box** or
- Raceway with removable cover

then the conductors of each system shall be grouped separately by **cable ties** or similar every **6 ft**.

The **690.31(B)(2) Grouping Exception** tells us that the grouping **does *not* apply** if the circuit **enters from a cable or raceway that is unique and obvious**.

### *690.31(C) Cables*

PV wire and distributed generation (DG) cable shall be listed

PV Wire listing is UL 4703 and DG cable is UL 3003

**UL listing numbers in this industry are related**

The UL **listing for PV is UL 1703**. If you change the 03 to 41, then you have the **inverter, charge controller and dc-to-dc converter**

**UL listing 1741**. If you change the first digit to UL 1703 from a 1 to a 2, then you get the **racking listing of UL 2703**. If you change the first digit in UL 1703 from a 1 to a 4, then you get the listing for **PV wire, which is UL 4703**. If you change the first digit in UL 1703 from a 1 to a 6, then you get the listing for **PV connectors, which is UL 6703**. For DG cable, you change the 17 in UL 1703 to a 30, then you get the listing for **DG cable, which is UL 3003**. Everything that we mentioned here, except for UL 1741, ends with 03.

*690.31(C)(1) Single-Conductor Cable*

**Single conductor cable** types permitted in **exposed outdoor** locations in **PV source circuits:**

(1) PV wire or PV cable
(2) USE-2 / RHW-2 dual listed wire that is sunlight resistant

Note: This is a new thing requiring the USE-2 wire to be dual listed as RHW-2, however most USE-2 wire already is dual listed, so it would be more difficult to find USE-2 wire that was not also RHW-2 wire. USE-2 wire on its own cannot go inside of conduit inside a building, but when it is dual listed it can go inside of buildings on the coattails of RHW-2. The RHW designation includes the building wire fire ratings required for conductors in buildings. PV wire also has this same fire designation and is usually also marked RHW-2.

Exposed cables (PV wire and USE-2) need to be secured every 24 inches.

This is a new requirement in the 2020 NEC.

In earlier versions we looked to 338.10(B)(4)(b) and 334.30 which let us support the conductors every 4.5 ft. Some installers would like to have the distance be at least the width of the module, which is about 40 inches.

### USE-2 and PV Wire

USE-2 cable and PV wire are the two most common wiring methods for connecting PV modules to each other and to connecting

PV modules to anything else. These wiring methods are commonly installed under PV modules and do get exposed to sunlight. It is interesting that USE stands for Underground Service Entrance, has properties and has been tested for exposure to sunlight. Not usually much sunlight underground.

In previous versions of the NEC, PV wire was specifically required for what was formerly known as “ungrounded” PV arrays, but now there is no specific requirement to use PV wire. PV wire may be better than USE-2 wire and has been tested with more UV light, but USE-2 cable may be less expensive.

When the PV industry was originally trying to get the code making panel to accept “ungrounded” inverters, they used similar wiring methods to systems with double insulation in Europe. PV wire is often the wire of choice of PV module manufacturers, since it is acceptable everywhere in the world and with every version of the NEC.

USE-2 cable and PV wire is often colored black and works better when colored black, since black is the color of carbon black, which is a pigment that helps with UV resistance by preventing UV light from penetrating. This is also why black cable ties are more UV resistant (and why light skin can lead to melanomas). When sourcing black cable ties, use Nylon 6 cable ties when contacting everything except galvanized steel. Nylon 12 is necessary for any cable ties contacting galvanized steel. One last item for cable ties, the NEC and UL standards require that the cable ties be rated “Type 21C” where used for cable support. This Type 21C designation will typically be printed on the package enclosing the ties.

There was a time when some inspectors did not read **200.6 Means of Identifying Grounded Conductors** and they believed that white USE-2 cable was required.

Some installers have used red USE-2 cable to indicate a positive conductor and as the red faded, people would see white, and think that the formerly red wire was a white grounded conductor.

Most, if not all PV wire is also marked RHW-2 since it has to pass all the same tests as RHW-2. This rating of RHW-2 also allows the conductor to be installed inside buildings. USE-2 if RHW-2 is not permitted because it may not have been tested for fire and sunlight ratings.

### *690.31(C)(2) Cable Tray*

PV wire, PV Cable or Distributed Generation (DG) cable with or without a cable tray rating shall be permitted in cable trays outdoors and shall be supported in cable trays every 12 inches and secured every 4½ ft.

This is because PV and DG Wire/Cable is not listed for cable trays, but we can do it because it says so right here.

690.31(C)(2) Informational Note:

> PV and DG Wire/Cable has a non-standard diameter (it can vary from one manufacturer to the next), so we cannot use Annex C and we have to get the wire diameter from the manufacturer and use that along with Chapter 9 Tables 1, 4 and 5 for determining how many wires fit in conduit.

### ***690.31(D) Multiconductor Jacketed Cables***

If these cables are part of a listed assembly, then install them according to the instructions. You always follow instructions for listed equipment, because that is how it was tested to be safe. Also, if something bad happens in the system and instructions are not followed, the lawyers will make a lot of money.

A microinverter cable is an example of this kind of cable.

If the cables are not part of a listed assembly, then you can still install these **multiconductor jacketed cables** in accordance with the cable's listing and in accordance with the following (1) through (2) a to f.

- 690.31(C)(3)(1) If on or in buildings then in raceway
- 690.31(C)(3)(2) If not in raceways then a to f
    - 690.31(C)(3)(2)(a) Marked sunlight resistant if exposed outdoors
    - 690.31(C)(3)(2)(b) Protected or guarded when exposed to damage
    - 690.31(C)(3)(2)(c) Closely follow the surface or support structure
    - 690.31(C)(3)(2)(d) Secured no less than every **6 ft**
    - 690.31(C)(3)(2)(e) Secured every 24 inches of connectors or entering enclosures
    - 690.31(C)(3)(2)(f) Marked direct burial if buried

To sum up multiconductor jacketed cables: If it is inside, it needs to be in a raceway and if it is outside, then it needs to be in a raceway **or** meet all 6 things above a through f.

### *690.31(C)(4) Flexible Chords and Cables Connected to Tracking PV Arrays*

The following shall apply to flexible chords and cables connected to tracking PV arrays:

- Identified as **hard service chord** or **portable power cable**
- Suitable for extra-hard usage
- Listed for outdoor use
- Water resistant
- Sunlight resistant
- Stranded copper permitted to be connected to moving parts of tracking PV arrays in accordance with **Table 690.31(C)(4)** see below
- Comply with **Article 400 Flexible Chords and Cables**
- Allowable ampacities in accordance with **400.5 Ampacities for Flexible Chords and Cables**

Article **400 Flexible Chords and Cables** Discussion:

> There are different tables to be used for flexible chords and cables, which are used for stationary conductors.

Table **690.31(C)(4) (Formerly 690.31(E)) Minimum PV Wire Strands** Discussion:

> Tracking arrays have moving parts that may bend wires back and forth 365 times per year, which can be 10,000 times or more in the life of a 30-year-old PV system. Wire with not enough strands will strain-harden and break.
>
> Table **690.31(C)(4) Minimum PV Wire Strands** does not have in its title that it is specific for tracking arrays and, if taken out of context, someone might think that it would apply with all PV

*Table 5.3* 690.31(C)(4) minimum **PV wire** strands

| *PV wire AWG* | *Minimum strands* |
|---|---|
| 18 | 17 |
| 16–10 | 19 |
| 8–4 | 49 |
| 2 | 130 |

*Source:* courtesy NFPA

wire or all PV system wiring. **This table is only required for PV wire connected to moving parts of PV tracking arrays.** For other types of wire connected to tracking systems, you would look in Article 400 Flexible Chords and Cables, where PV wire is not covered.

The **ampacities in 400.5 and Tables 400.5(A)(1) and 400.5(A)(2) differ from the ampacities typically used for conductors in free air** in Table 310.17 (formerly 310.15(B)(17). These cables also have different ampacities depending on how many conductors are contained within the cable.

The ambient temperature correction factors in Table 310.15(B)(1) (formerly 310.15(B)(2)(a)) do apply.

### *690.31(C)(5) Flexible, Fine-Stranded Cables*

Flexible, fine-stranded cables shall only be terminated with lugs, devices or connectors in accordance with 110.14.

**110.14 Electrical Connections** includes information on (A) Terminals, (B) Splices and (C) Temperature Limitations.

In 110.14(C) it says that **conductors with temperature ratings higher than specified for terminations may be used for** ampacity adjustment, correction or both. This is something that is more of the complicated part of wire sizing. You can read more about wire sizing in Chapter 12 of this book beginning on page 223.

### *690.31(C)(6) Small Conductor Cables*

**16 American Wire Gauge (AWG) and 18 AWG single-conductor cables** are **permitted for module interconnections** if they:

- Meet ampacity requirements of **400.5 Ampacities for Flexible Chords and Cables**
- Comply with correction and adjustment factors from **Section 310.14 Ampacities for Conductors Rated 0–2000 Volts**
    - **310.14 does point to the famous tables used for wire sizing in 310.15 among other things**

Discussion: It may have been **unthinkable to use 16 AWG or 18 AWG wire for PV systems** when PV was more expensive; however, with the advent of falling prices, it is now thinkable and more likely in large projects using thin film modules with lower than typical crystalline silicon PV module current ratings. 310.10(A) Minimum Size of

Conductors says that we cannot use any copper conductor smaller than 14AWG unless stated elsewhere in the Code. 690.31(C)(6) is officially elsewhere in the Code.

### *690.31(D) Direct Current Circuits on or in Buildings*

**PV dc circuits inside** a building **that exceed 30V or 8A** shall be inside of:

- Metal raceway (like EMT Article 358)
- MC cable (Article 330, Metal-Clad Cable: Type MC). We are also directed to 250.118(10), which tells us how MC cable can be also used as an equipment grounding conductor.
- Metal enclosures

This "inside of metal" requirement **used to be** in the 2017 NEC and earlier, **only applied up to the first readily accessible dc disconnect**. This is no longer the case. Dc parts of a PV system in a building require metal.

690.31(D) Exception:

> With a listed PV **hazard control system** (formerly known as listed rapid shutdown array), wiring methods shall be permitted to be non-metallic from the first penetration into the building to the PV hazard control actuator (this would be in the listing of the listed PV hazard control system).
>
> Take note that the special requirements that were in the 2017 NEC regarding PV circuits embedded in building surfaces have been removed from the NEC. Perhaps due to 690.12, the roof is safer and these requirements are no longer needed.

**Wiring methods on or in buildings shall also comply with 690.31(D)(1) and (2) below.**

### *690.31(D)(1) Flexible Wiring Methods*

690.31(D)(1) Applies to:

- Flexible Metal Conduit (FMC) smaller than 3/4 inch
- MC cable smaller than 1 inch

Either FMC smaller than 3/4 inch or MC cable smaller than 1 inch shall be **protected by substantial guard strips**.

When FMC smaller than 3/4 inch or MC cable smaller than 1 inch is run exposed more than 6 ft from connection to equipment, ***either*** of the following apply:

- Follow the building surface
- Protected by approved means

Typically, runner boards are an approved means used to protect flexible wiring methods.

Reminder: 690.31(D)(1) only applies to dc conductors.

*690.31(D)(2) Marking and Labeling Required*

**PHOTOVOLTAIC POWER SOURCE** or **SOLAR PV DC CIRCUIT**

Unless located and arranged so the purpose is evident, this wording above **shall be marked** on the following wiring methods and enclosures that contain PV system **dc** circuits **on or in buildings** (**not ac! Only on or in buildings!**):

1 Exposed raceways, cable trays and other wiring methods
2 Covers or enclosures of pull and junction boxes
3 Conduit bodies if there are unused conduit openings on the conduit bodies

Label shall be:

- Every 10 ft;
- Every section separated by:
  - Enclosures
  - Walls
  - Partitions
  - Ceilings
  - Floors

The **label specifications** shall be:

- Capitalized
- 3/8-inch height minimum
- White letters
- Red background
- Label shall be suitable for the environment used

Changes in wording from 2017 NEC to 2020 NEC:

| | |
|---|---|
| Wording used to be: | WARNING: PHOTOVOLTAIC POWER SOURCE |
| Now wording is either: | PHOTOVOLTAIC POWER SOURCE |
| or: | SOLAR PV DC CIRCUIT |

Note: SOLAR PV DC CIRCUIT is made up of fewer letters and takes up less space and resources. Getting rid of the WARNING would make people less afraid of solar and it is safer because of rapid shutdown requirements.

**Flexible, Fine-Stranded Cables, Formerly Known as 690.31(H)**

Although 690.31(H) was moved to the cable section as 690.31(C)(5). The NEC already has provisions for using proper terminations for the application in **110.14 Electrical Connections**, but we are reminded about it here since many installers tend to forget this part of the Code.

***Flexible, fine-stranded cables shall be terminated only with terminals, lugs, devices or connectors in accordance with 110.14.***

Flexible, fine-stranded cables are easy to bend, but are more difficult to terminate. Inexperienced installers in the past have used typical screw terminals that are not meant for flexible, fine-stranded cables. In these cases, the connection will often become loose, resistance will rise and heat will be generated, which can be a fire hazard.

PV installers in the past used batteries and liked to use flexible, fine-stranded cables, since they would not overstress battery terminals. Most battery cables now use fine-stranded cables with the proper terminations. Batteries are no longer part of a PV system as of the 2017 NEC.

PV arrays that track the sun do require flexible cables and installers of these cables should be aware of the requirements for using proper terminal procedures and equipment.

### *690.31(E) Bipolar Photovoltaic Systems*

Discussion: Bipolar PV systems have a benefit of being able to be considered the voltage for the purposes of the Code as being voltage to ground rather than the maximum voltage between any two conductors.

Analogy:

> Your house in the US is wired at 120/240V split phase. This means that you will not have more than 120V to ground in your house; however, you can have an electric dryer that gets all of the benefits of 240V. This is because your house is bipolar in a way and is grounded and has a grounded conductor right in the middle of that 240V.
>
> A bipolar system has two **monopole circuits** (typically groups of strings), one which is positively grounded and the other negatively grounded. This type of system can potentially give the array 25% of the power losses due to voltage drop at double the voltage and half the current than it otherwise would have.
>
> The wiring rules with these systems state that we cannot have conductors next to each other that could have voltages greater than the wiring method the conductors and the Code are rated for. If these conductors are in the same location, they need to be able to handle these bipolar hot-to-hot voltages that are double of what the voltage to ground can be.
>
> In other words, going bipolar does not give a designer the right to have two wires next to each other that have voltages greater than that for which they are rated.
>
> At the time of the writing of the 2020 NEC, we did not see much in the way of bipolar systems. It is invigorating to think that we could have a “1500V to ground” ground-mounted system that would have conductors that could measure 3000V to each other and still be NEC compliant! That could be efficient with the low relative currents.
>
> Bipolar systems were more popular a decade ago when the maximum system voltage for all PV systems was 600V rather than 1500V.

### *690.31(F) Wiring Methods and Mounting Systems*

Roof mounting of PV systems does not need to comply with 110.13.

**110.13 Mounting and Cooling includes 110.13(A) Mounting** and 110.13(A) says that equipment shall be "firmly secured in place." Since many PV systems are ballasted and held in place by weight and aerodynamics, **690.31(F) is formally allowing ballasted systems.**

We are required by 690.31(F) to use an approved method to hold the PV and wiring methods in place and to design the wiring methods to allow for any expected movement.

690.31(F) Informational Note explains that expected movement is often included in structural calculations.

After this **690.31 Methods Permitted** marathon comes the brief …

## 690.32 Component Interconnections

This section is **specific to building-integrated systems.**

**Fittings and connectors** that are **concealed** at the time of **on-site assembly** and **listed** for such use shall be:

- Permitted for **interconnection of modules**
- Permitted for **interconnection of array components**

**Fittings and connectors** shall be **at least equal to wiring method** in:

- Insulation
- **Temperature** rise
- **Short-circuit current rating**

These fittings and connectors shall also be able to **withstand the environment** in which they are used.

To repeat, section **690.32 Component Interconnections** was designed specifically for building-integrated PV systems.

## 690.33 Mating Connectors

Connectors other than those covered by 690.32 Component Interconnections go here. These connectors are the primary connecters known to solar installers, including your typical **MC4 connector or your microinverter cable.**

These connectors **shall comply with all of 690.33(A) through (D)**

**The word "mating" was added to the title of this section in 2020. In the 2017 NEC, it was titled "Connectors." This was to indicate what**

**kind of connectors this section is specifying since there are many other types of connectors in the electrical world (e.g., spade connectors).**

### *690.33(A) Configuration*

Mating connectors shall be:

- **Polarized** (Example: positive or negative, but not both)
- **Non-interchangeable** (with other receptacles of other systems)

### *690.33(B) Guarding*

Mating connectors shall **guard persons** against inadvertent contact with

- Live parts

As you can see from playing with a typical MC4 connector, you could not get your finger or tongue into the connector to touch metal.

### *690.33(C) Type*

Mating connectors shall be **latching or locking**
***if* readily accessible** and over 30Vdc or 15Vac

- **Then** they shall **require a tool for opening**.

**If mating connectors are not of the identical type and brand,** then they shall be listed and identified for **intermatability**, as described in the manufacturer's instructions.

Discussion: We are not allowed to use MC4 connectors with Amphenol H4 connectors since they are not listed as "intermateable," although it was a common practice. Here we see there is a pathway for these different connectors to be used together. The process of intermateability is covered in UL6703. Only two mating connectors currently used in the PV industry are intermateable. They are the Amphenol H4 and the Amphenol UTX. No other combination is officially intermateable. Any salesperson claim that is not backed up by an official UL6703 certification is simply not true. Incidentally, how can you tell whether a salesman is lying?—their lips are moving.

### *690.33(D) Interruption of Circuit*

Connectors shall be either one of the three following:

(1) Rated for interrupting current
(2) Require a tool for opening and marked either
- "Do Not Disconnect Under Load"
- "Not For Current Interrupting"

(3) Supplied as part of listed equipment

690.34(D)(3) Informational Note: Equipment, such as module level power electronics are often listed so that the connectors can be a load-break rated disconnect, even when the connectors say "Do Not Disconnect Under Load" on the PV module connectors themselves.

## 690.34 Access to Boxes

Junction, pull and outlet boxes (used for wiring) located behind PV modules shall be installed, so that removing the module can make the wiring accessible.

# 6 Article 690 Part V Grounding and Bonding

Bonding is electrically connecting metal together and grounding is connecting to earth. The term grounding is used often to indicate bonding, as with an equipment grounding conductor, which is used for both bonding metal together and connecting the metal to ground.

## 690.41 System Grounding

System grounding is connecting a current-carrying conductor to ground potential at one place in a system. Not all systems have system grounding, but all metal equipment that could be exposed to a fault will have equipment grounding (AKA bonding).

Here are some simple Article 100 Definitions to get us grounded on grounding:

**Grounding Electrode.** A conducting object through which a direct connection to earth is established.

**Grounding Electrode Conductor (GEC).** A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system.

**Equipment Grounding Conductor (EGC).** The conductive path(s) that provides a ground-fault current path and connects normally non-current-carrying metal parts of equipment together to the system grounded conductor, or to the grounding electrode conductor or both. (Also performs bonding.)

**Ground.** The earth.

**Grounded Conductor**. A system or circuit conductor that is intentionally grounded.

**Solidly Grounded**. Connected to ground without inserting any resistor or impedance device.

**Ground Fault.** An unintentional, electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment or earth.

**Ground-Fault Circuit Interrupter (GFCI)**. A device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds the values established for a Class A device. (Class A will trip between 4 and 6 mA).

## Outline of 690.41

- 690.41 System Grounding
  - 690.41(A) PV System Grounding Configurations
    - 690.41(A)(1) 2-Wire PV Arrays with One Functionally Grounded Conductor
    - 690.41(A)(2) Bipolar PV Arrays with a Functionally Grounded Center Tap 690.7(C)
    - 690.41(A)(3) Arrays Not Isolated from the Grounded Inverter Output Circuit
    - 690.41(A)(4) Ungrounded PV Arrays
    - 690.41(A)(5) Solidly Grounded PV Arrays 690.41(B)
    - 690.41(A)(6) PV Systems Using Other Listed and Approved Methods 250.4(A)
  - 690.41(B) Ground-Fault Protection
  - 690.41(B) Ground-Fault Protection Exception
    - 690.41(B)(1) Ground-Fault Detection
    - 690.41(B)(2) Faulted Circuits
      - 690.41(B)(2)(1) Current-Carrying Conductors Auto-Disconnect
      - 690.41(B)(2)(2) Power Off, Isolate Circuits in Functionally Ground System
      - 690.41(B)(2)(3) Indication of Faults

## 690.41 System Grounding

System grounding is done by electrically connecting a current-carrying conductor to earth via bonding neutral to ground in a single place. The grounded conductor is generally colored white for grounded systems. However, new in the 2017 NEC, when system grounding is not solid, such as through a fuse, we no longer color the grounded conductor white. Since the conductor can be at higher voltages during a fault, coloring it white can be misleading to an electrician.

### *690.41(A) PV System Grounding Configurations*

Most of the six configurations are unusual and not worth paying much attention to for most solar professionals. **Paying close attention to 690.41(A)(3)** is a good idea, since well over **90% of the inverters installed these days are of the non-isolated type**.

#### *690.41(A)(1) 2-Wire PV Arrays with One Functional Grounded Conductor*

This is our old-style **fuse grounded** solar inverter and was **formerly known as a grounded inverter when applying the 2014 NEC** and earlier. This type of inverter is still common in the large-scale MW inverter realm and seen often when doing maintenance on an old array. This was the most popular inverter in the US until 2013.

The term often used for this type of inverter's ground-fault detection system is **ground-fault detection and interruption (GFDI)**. This inverter bonds a grounded conductor to the inverter internal grounding busbar through an overcurrent protection device (fuse). When there is a ground fault on the ungrounded conductor, currents will flow through

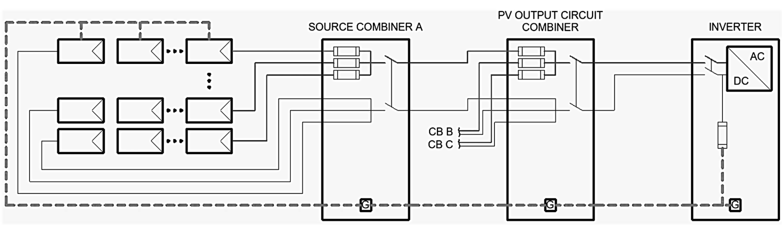


*Figure 6.1* Fuse grounded PV array with one functional grounded conductor

*Source:* courtesy Robert Price (2017; modified from Bill Brooks, 2014) www.axissolardesign.com the grounding pathway to the GFDI fuse and open the fuse. The inverter will detect that the grounded conductor is no longer grounded, proceed to turn off the inverter and then disconnect positive and negative at the inverter in order to prevent fires (you can still get shocked).

One of the reasons that this type of inverter has gone out of style is that there is a blind spot for detecting ground faults. With all PV modules and conductors, things such as glass and conductor insulation are not perfect insulators, and some current will leak through the glass and insulation and complete the circuit through the GFDI fuse. On a small residential system, there is never enough leakage current to cause a problem, but, on larger systems, the milliamps add up, and the current can be great enough to require the inverter to use a larger GFDI fuse. As the fuse gets larger for these leakage currents, it also inhibits the inverter's ability to detect ground faults. Once there is a ground fault that is unseen (blind spot), another ground fault can short circuit the whole PV array and fires can occur. There are ways that these older systems can be modified by monitoring the current to make them safer, but the easiest thing to do is install a newer, non-isolated inverter, which is cheaper, safer and more efficient.

### *690.41(A)(2) Bipolar PV Arrays with a Functionally Grounded Center Tap*

We have mentioned bipolar arrays a number of times in this book and you can look in the index to read about bipolar arrays at every mention. Bipolar arrays are usually only seen in large utility-scale PV systems.

690.41(A)(2) applies to these bipolar arrays with a functional ground reference (center tap).

A few people think of bipolar arrays as a way to sneak around the requirement for maximum voltage and double the system voltage. Bipolar arrays will give you double voltage benefits, so there is truth; however, now that we have ground-mounted PV arrays of 1500V to ground, there is less of an incentive to double the voltage, since 1500V is a lot and jumping to 3000V for efficiency gains may not be worth doing.

### *690.41(A)(3) Arrays Not Isolated from the Grounded Inverter Output Circuit*

This is the **most popular inverter today**, representing over 90% of inverters installed. **Formerly and commonly (though somewhat**

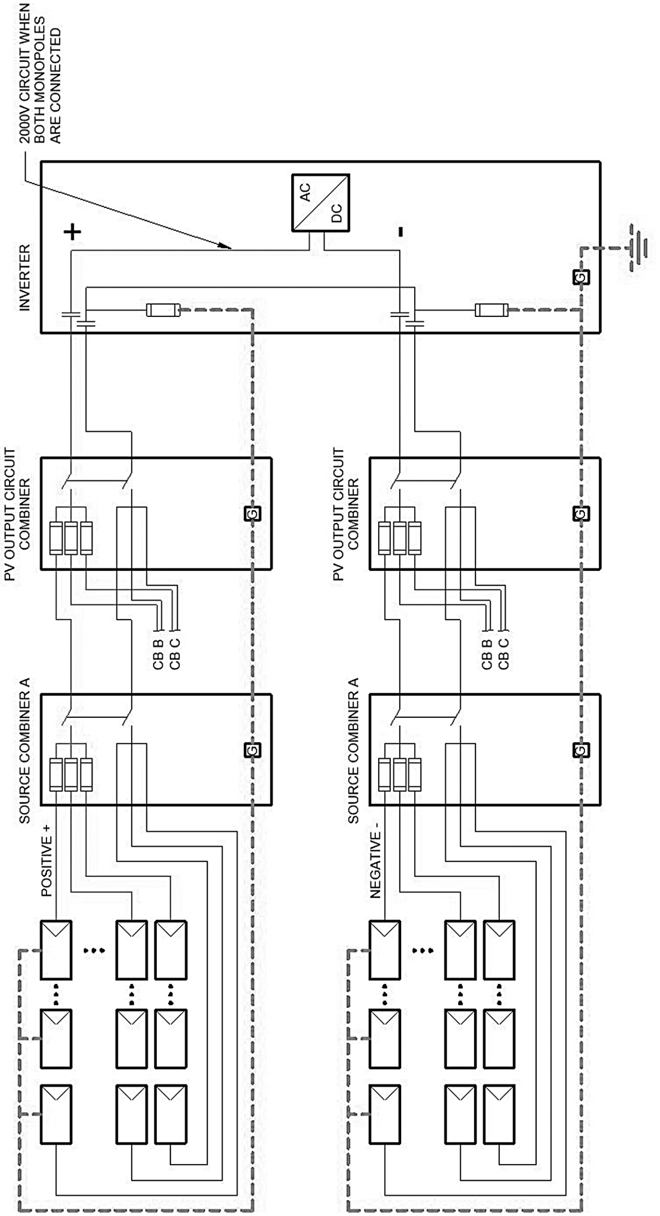


*Figure 6.2* Bipolar PV array

*Source:* courtesy Robert Price (2017; modified from Bill Brooks, 2014) www.axissolardesign.com

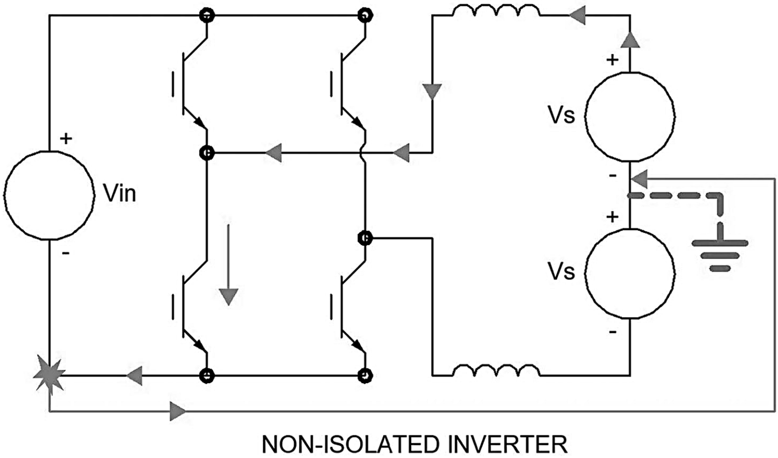


*Figure 6.3* Non-isolated inverter showing ground-fault pathway

*Source:* courtesy Robert Price (2017; modified from Bill Brooks, 2014) www.axissolardesign.com

**inaccurately) known as an "ungrounded inverter"** in the 2014 NEC, this inverter is now called a **functionally grounded inverter** and, according to 690.41(A)(3) text, we can officially call this inverter a **not-isolated** inverter or, as we prefer, a **non-isolated inverter**.

In Figure 6.3 Vin would be input voltage to the inverter. Vs is the source voltage (center-tap split-phase ac transformer).

The **non-isolated** gets its name because the inverter is not isolated from the grounded ac transformer. The reason that it was formerly thought of as ungrounded is because the PV array is ungrounded when the system is offline and grounded when operating. When this inverter is operating at 400V, we could expect the positive conductor to measure 200V to ground and the negative to measure –200V to ground. This array is referenced to ground and does not have a voltage that is randomly floating around or isolated by a transformer when the inverter is operating.

These inverters are:

- Cheaper
- Safer
- Lighter
- More efficient

Than your old style, 690.41(A)(1) 2-wire PV arrays with one functional grounded conductor, inverters.

**Cheaper** because no transformer to manufacture.
**Safer** because more sensitive ground-fault protection.
**Lighter and More efficient** since no isolation transformer.

Non-isolated inverter ground-fault detection:

Non-isolated inverters can detect ground faults much more sensitively than fuse grounded inverters.
Fuse grounded inverters have to have an allowance for leakage currents and the fuse must be upsized as more PV is added to the system.

Non-isolated inverters have different methods of detecting dc ground faults, such as:

- Insulation testing
  - As the inverter wakes up in the morning, a quick pulse of voltage will be sent out along the current-carrying conductors into the array. If there is lower than expected resistance to ground, then there is a failed insulation test and signs of a ground fault. The inverter will not be allowed to start.
- Comparing positive and negative currents (residual current monitor)
  - While operating, if positive does not equal negative, then the electrons must be taking an alternate path, otherwise known as a ground fault (or Martians are feeding on the electrons).

> Using non-isolated inverters prevents fires since it can be up to 3000 times more sensitive to ground faults than old-school fuse grounded inverters!

*690.41(A)(4) Ungrounded PV Arrays*

The 2020/2017 NEC definition of an ungrounded array is different from the 2014 and earlier editions of the NEC. This truly ungrounded PV array is not the "*now known as non-isolated array" (formerly known as ungrounded)*, but is an array that has no functional reference to ground.

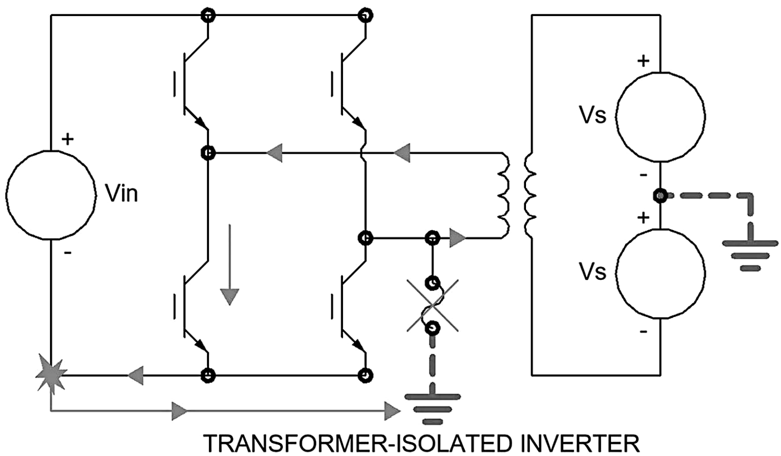


*Figure 6.4* 2017 NEC ungrounded PV array AKA transformer-isolated inverter

*Source:* courtesy Robert Price (2017; modified from Bill Brooks, 2014) www.axissolardesign.com

Now the only way to have an ungrounded array on an inverter connected to a grounded utility transformer is where the inverter has an isolation transformer, but with no fuse or connection between a current-carrying conductor and ground as in Figure 6.4. This array would be considered floating, since the voltage could change with reference to ground. This inverter is uncommon and only currently used with some large utility-scale inverters. The array is monitored with a sensitive insulation tester on a continuous basis. This is a very simple and effective method of ground-fault detection.

There is no way to look at an inverter and know whether it is an ungrounded inverter unless you look at the listing label. We are unaware of any ungrounded inverters currently listed in the United States. All the units currently running in the US are in large-scale plants and have been certified to IEC (International Electrotechnical Commission) standards.

### *690.41(A)(5) Solidly Grounded PV Arrays*

A solidly grounded PV array is one where there is a connection between a current-carrying conductor and ground that is not a fuse and is solid!

Many old-style stand-alone systems, as well as some more modern stand-alone systems, are solidly grounded. Many dc PV systems are also solidly grounded.

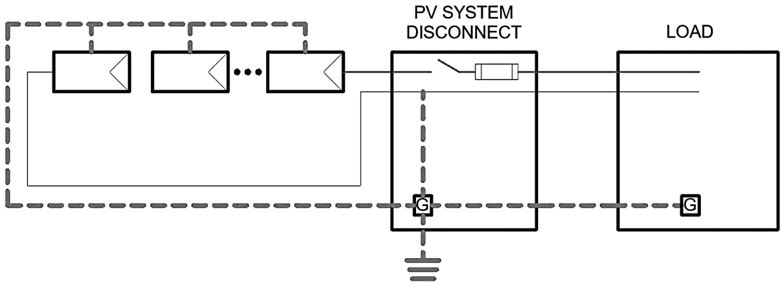


*Figure 6.5* Solidly grounded PV array

*Source:* courtesy Robert Price (2017; modified from Bill Brooks, 2014) www.axissolardesign.com

Coming up soon in a 690.41(B) exception, we will mention that if an array is solidly grounded, has one or two PV source circuits and is not on a building, then ground-fault protection is not required. This way we can solidly ground the system.

As we can see in Figure 6.5, the grounding busbar is connected solidly to a grounded conductor. This is also an example of a dc direct-coupled PV system, which is common for water pumping systems in the California foothills.

### *690.41(A)(6) PV Systems Using Other Listed and Approved Methods*

PV technology is fast-moving, and the Code has left open a way for newer inventions to be Code compliant if they are listed and approved. Over the years, several inverters have been certified to this option. One key example in recent history was the Advanced Energy Inverters that had an array configured in a bipolar-ish fashion.

These larger inverters were configured similar to bipolar PV systems, but had several features that were very different from bipolar arrays. Those inverters were among the safest inverters back when they were manufactured. 690.41(A)(6) makes sure the NEC does not disrupt inverter innovation for your next genius inverter idea.

**690.41(B) Ground-Fault Protection** (**Direct Current** requirement) **Dc PV arrays** shall be provided ground-fault protection in accordance with **both** 690.41(B)(1) **Ground-Fault Detection** and 690.41(B)(2) **Isolating Faulted Circuits**.

**690.41(B) ground-fault protection exception**

A PV array is not required to have ground-fault protection if it meets all of the following requirements:

- One or two PV source circuits
- Not in or on building
- Solidly grounded

Additionally, an array that is both less than 30 volts and less than 8 amps is not required to have dc ground-fault protection.

We are used to solidly grounded systems with typical electrical systems. The reason it is uncommon with PV systems is because of the lack of high short-circuit currents, due to the current-limited characteristics of PV. With low short-circuit currents, we cannot rely on standard overcurrent devices to clear faults. We can only detect faults and shut down the system as a result of the fault.

*690.41(B)(1) Ground-Fault Detection*

Ground-fault detection must meet all of the following requirements:

- Detect ground faults in PV array dc current-carrying conductors
- Detect ground faults in functionally grounded conductors
- Performed by ground-fault protection device or system
- Listed for PV ground-fault protection

**Dc-to-dc Converters:**

Dc-to-dc converters sometimes do not provide ground-fault protection and must work with listed ground-fault protection equipment.

Informational Note: Some dc-to-dc converters without ground-fault protection on their source (PV) side may prevent other ground-fault protection equipment from working properly.

*690.41(B)(2) Faulted Circuits*

Faulted circuits shall be **controlled** by **either one** of the following of 690.41(B)(2)(1) or 690.41(B)(2)(2):

**690.41(B)(2)(1) Current-carrying conductors auto-disconnect** Current-carrying faulted conductors of the circuit will automatically disconnect.

690.41(B)(2)(2) Power off, interrupt faulted PV dc circuits from the ground reference in functionally grounded systems.

Inverter or charge controller fed by faulted circuit will **automatically do both**

- Stop supplying power to output circuits
- Interrupt PV system dc circuits from ground reference in functionally grounded system

Discussion: A properly UL 1741 listed inverter will have been tested and listed for ground-fault protection.

**Equipment certification, UL and ANSI**

Equipment certification is a de facto requirement of the NEC because it requires all equipment to be evaluated for the intended use in Section 90.7 Examination of Equipment for Safety. Underwriter's Laboratories (UL) has been tasked by the ANSI (American National Standards Institute) to establish certification standards for the safety of PV equipment. There are numerous UL standards that are used for PV equipment. UL1741 is the standard used for certifying inverters.

## 690.42 Point of System Grounding Connection

Dc PV arrays that are not solidly grounded shall have any current-carrying conductor to ground connection (or reference) made by a ground-fault protection device.

For solidly grounded systems, there may only be a single point of system grounding.

Discussion: Ground-fault protection is, in essence, determining if there is a connection to ground by a current-carrying conductor that was not meant to be. In order to determine if there is an extra connection (ground fault), then a ground-fault protection device must be keeping tabs on the state of the current-carrying conductor vs. ground.

In any electrical system, more than one point of system grounding is called a ground fault. If there were two points of system grounding, then there would be a parallel pathway for current to flow along the grounding system or through equipment.

## 690.43 Equipment Grounding and Bonding

Exposed metal parts that do not intentionally carry current need to be grounded.

## Outline of 690.43

690.43 Equipment Grounding and Bonding
- 690.43(A) Photovoltaic Module Mounting Systems and Devices
- 690.43(B) Equipment Secured to Grounded Metal Supports
- 690.43(C) With Circuit Conductors

Grounding shall comply with **250.134 Equipment Fastened in Place or Connected by Permanent Wiring Methods (Fixed)** and **250.136(A) Equipment Secured to Grounded Metal Supports**.

Equipment grounding of PV systems is theoretically the same as equipment grounding of other systems; hence we refer to and take the rules from Article 250 when applying the Code to our PV system grounding systems.

For instance, 690.43 directs us to 250.134, which directs us to 250.32, which directs us to 250.118 and so on and so forth.

Since equipment grounding of a PV system is similar to and takes much of its requirements from Article 250 Bonding and Grounding, inspectors who are not as familiar with PV systems as they are with other systems will often put a lot of effort into inspecting what they know, which is how to inspect grounding and bonding.

### Why equipment grounding?

A good reason for equipment grounding is to protect people. If a hot wire got loose and touched a piece of metal that was not grounded, then someone could touch that piece of metal and get shocked. Another good reason for grounding is a pathway for ground-fault protection to signal the inverter when there is a ground fault. Without an equipment grounding conductor, ground-fault protection would not work properly.

### *690.43(A) Photovoltaic Module Mounting Systems and Devices*

Equipment that is listed, labeled and identified for bonding PV modules is permitted for equipment grounding and bonding of PV modules. Also, this equipment may be used to bond adjacent modules to each other.

Discussion:

> UL 2703 Standard:
>
> Standard for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels.

When we think of UL 2703 listed racking systems, we often think of a clamping device that holds a PV module or piece of equipment in place and has a sharp point that will pierce the anodized coating of a piece of aluminum and make a Code-compliant equipment grounding pathway.

A big benefit to PV installers for using UL 2703 listed racking is the reduction in time and materials required by not having to undertake time consuming grounding methods of the past, such as using lugs on each PV module with a collection of washers, antioxidant chemicals and using emery cloth to rub off the anodized coating of a module frame to get a good connection.

### *690.43(B) Equipment Secured to Grounded Metal Supports*

Grounded metal supports are support structures that PV modules are mounted on that are already connected to ground by any means permitted in Article 250. In order to bond PV equipment to grounded metal supports, the grounding devices must be:

- Listed = On a National Recognized Testing Lab (NRTL) list
- Labeled = Has a label from the NRTL
- Identified = For specific use (no off-label usage)

Metallic support structure sections shall be either:

- Connected via identified bonding jumpers
- Connected to equipment grounding conductor (EGC) and support structure shall be identified

### *690.43(C) With Circuit Conductors*

Equipment grounding conductors for array and support structure shall be run together with the circuit conductors by one of the following means:

- In same raceway
- In same cable
- Run with PV system conductors where leaving array vicinity

While it is common for the equipment grounding conductor (EGC) to be run in the same raceway as the current-carrying conductors, the **NEC allows the EGC to be run next to the conduit for the current-carrying conductors**. For instance, a bare 6 AWG copper conductor could be run in the same trench as a PVC conduit with the current-carrying conductors. The benefit of this buried copper conductor will be lower ground resistance for the whole grounding system.

### *690.43(D) Bonding over 250 Volts*

For solidly grounded systems over 250V (rare), **250.97 Bonding for Over 250** Volts shall apply.

Here we see requirements about continuity of metal raceways and metal sheathed cables for systems over 250V to ground.

Where concentric or eccentric knockouts are encountered, there may not be sufficient continuity to clear large circuit breakers in a fault. This is more commonly referenced for ac systems over 250V to ground, since solidly grounded PV systems, especially those over 250V to ground are rare. **Sensitive ground-fault equipment required in functionally grounded systems can effectively use concentric and eccentric box connections without failing in a fault and therefore don't need to follow 250.97.**

## 690.45 Size of Equipment Grounding Conductors

PV system circuit equipment grounding conductors are sized in accordance with **Table 250.122 Minimum Size of Equipment Grounding Conductors**, which bases the EGC off of the size of the overcurrent protection device.

If there is no overcurrent protection device (such as with one or two PV source circuits) then the value calculated in **690.9(B) Overcurrent Device Ratings (Isc × 1.56)** for an assumed overcurrent protection device will be used in place of an overcurrent protective device value.

*Table 6.1* NEC Table 250.122 EGC based on OCPD

| *Rating or setting of automatic overcurrent device in circuit ahead of equipment, conduit, etc., not exceeding (amperes)* | *Size (AWG or kcmil)* | |
|---|---|---|
| | *Copper* | *Aluminum or copper-clad aluminum* |
| 15 | 14 | 12 |
| 20 | 12 | 10 |
| 60 | 10 | 8 |
| 100 | 8 | 6 |

*Source:* courtesy NFPA

Recall that 690.9(B) (covered on page 123) calculates an overcurrent protection device based on either

- 125% of maximum current calculated in 690.8(A)
- Maximum circuit current × 1.25
- Isc × 1.56 for PV source circuits
- Maximum current and application of adjustment and correction factors
- Electronic overcurrent protection device listed to prevent backfeed on PV side of device

Equipment grounding conductor size shall not be smaller than 14 AWG.

Discussion: It is interesting to note that, in many cases, multiple PV output circuits are not required to have more than a single 14 AWG equipment grounding conductor when protected in a raceway. Many solar installers will size the equipment grounding conductor to be the same size as the current-carrying conductor for conductors up to 10 AWG. This is to decrease the possibility of a well-intentioned inspector questioning a Code compliant 14 AWG equipment grounding conductor.

Just to make a point here, it would be Code compliant to have 8 PV source circuits come off a rooftop in a raceway with 16 different 10 AWG current-carrying conductors along with a single 14 AWG equipment grounding conductor.

Since the smallest equipment grounding conductor is a 14 AWG, which is sized based on a 15A overcurrent device, then we can calculate the highest short-circuit current value that will fit on a 15A fuse and use a 14 AWG equipment grounding conductor as follows:

Isc × 1.56 = 15A
Isc = 15A/1.56 = 9.6A

Therefore, if a PV module has an Isc value of over 9.6A, then it would need greater than a 15A fuse and greater than a 14 AWG equipment grounding conductor. And a PV module with an Isc over 9.6A would have a maximum series fuse rating of 20A (unless you could find a future module that had an Isc greater than 20A/1.56 = 12.8A).

We do not have to increase EGC size for voltage drop considerations on either the dc or ac side of a PV system. Since PV is the opposite of a load, current does not increase because of voltage drop. There are no NEC or safety requirements for PV systems regarding voltage drop. A 50% voltage drop would be illogical and very wasteful, but not necessarily a Code violation.

**Exposed to physical damage = 6 AWG minimum bare copper**

Oftentimes the equipment grounding conductors (EGCs) under the array are considered to be **exposed to physical damage** and, if that is the case, the bare copper equipment grounding conductor would need to be a **6 AWG** size minimum. Oftentimes in places with significant weather, such as snow and ice, the AHJ will require a 6 AWG bare copper equipment grounding conductor if exposed bare copper is used.

If you are trying to talk your inspector into agreeing that you do not require a 6 AWG EGC, you can reference 250.120(C) Equipment Grounding Conductors Smaller Than 6 AWG, where it says that you need to be protected from physical damage in a raceway or cable armor, unless it is **installed within** the hollow spaces of framing members of buildings or **structures** and where it is not subject to physical damage. Since a PV array is a structure, you would have a good point. We are not saying that you would win the debate, but you would have an intelligent point to make. The unanswered question is, "what is considered subject to physical damage?" and the answer is regional and subjective.

It is interesting to note that, in the Chicago area, according to at least 10 people whose jobs it is to meet with inspectors every day, they require more heavy-duty intermediate metal conduit (IMC) or rigid metal conduit (RMC) instead of EMT. This is due to the extreme weather, but they allow 10AWG EGCs under the array (because Bill told them it was okay 20 years ago).

In other locations, installers are allowed to use green 10AWG USE-2 wire under the array.

## 690.47 Grounding Electrode System

Are you one of the top PV experts in the country? Lace up your boxing gloves and welcome to 690.47, the section of 690 where there are heated debates on how to interpret how grounding electrode systems are meant to be interpreted in the Code. Try not to take it personally if you have a different idea than your colleagues. Good debate can be fun! Especially when you are right and everyone else is wrong.

There are many factors to deal with here and grounding electrode systems outside of PV are also hard to understand because the way they are implemented differs regionally. Factors such as wet earth, dry earth, lightning vortexes, corrosion, living on a rock, stray currents, proximity to large power production systems and more will influence people's opinions on how to properly connect to earth.

## Outline of 690.47

- 690.47 Grounding Electrode System
  - 690.47(A) Buildings or Structures Supporting a PV System
    - 690.47(A)(1) ECG Only Connection to Ground if Not Solidly Grounded
    - 690.47(A)(2) Solidly Grounded Systems Dc Grounding Electrode Conductor (GEC)
  - 690.47(B) Grounding Electrodes and Grounding Electrode Conductors

**690.47 Grounding Electrode System** was once again dramatically reorganized in the 2020 NEC.

### *690.47(A) Buildings or Structures Supporting a PV System*

Buildings or Structures Supporting a PV System shall utilize a grounding electrode system installed in accordance with:

- **Article 250 Part III Grounding Electrode System and Grounding Electrode Conductor**

> - **Part III of Article 250** is 5½ pages of Code and is where we find the rules for grounding electrodes and grounding electrode conductors.
> - Here are some hot spots in 250 Part III:
> - Common types of grounding electrodes:
>     - 250.52(A)(1) Metal Underground Water Pipe
>     - 250.52(A)(2) Metal In-Ground Support Structure
>     - 250.52(A)(3) Concrete-Encased Electrode
>     - 250.52(A)(4) Ground Ring
>     - 250.52(A)(5) Rod and Pipe Electrodes (ground rods)
>     - 250.52(A)(6) Other Listed Electrodes
>     - 250.52(A)(7) Plate Electrodes
>     - 250.52(A)(8) Other Local Metal Underground Systems or Structures
> - 250.53 Grounding Electrode System Installation
> - 250.54 Auxiliary Grounding Electrodes
> - **Additional Electrodes** referenced in 690.47(B) are electrodes that are **attached to the equipment grounding system** and do not follow the rules of typical electrodes.
> - 250.64 Grounding Electrode Conductor Installation
> - Table 250.66 Size of Alternating-Current Grounding Electrode Conductor
>     - The ac grounding electrode conductor is based on the size of the largest ungrounded service entrance conductor.
>     - Often with PV on a building, the ac electrode is a pre-existing condition. Minimum size is 8 AWG and the dc GEC is found in 250.166 (sounds like 250.66 where we find ac GEC sizes).

**And back to 2020 NEC 690.47(A) Buildings or Structures Supporting a PV System:**

PV array equipment grounding conductors (EGC) shall be connected to a grounding electrode system in accordance with:

- **Article 250 Part VII Methods of Equipment Grounding Conductor Connections**
- Connection is in addition to **690.43(C) With Circuit Conductors** which tells us to run the EGC with the circuit conductors (can be on the outside of conduit).

Also building and structure array EGCs shall be sized in accordance with **690.45 Size of Equipment Grounding Conductors**, which directs us to **Table 250.122 Minimum Size of Equipment Grounding Conductors**

One of the two following will apply. 690.47(A)(1) is for systems that are not solidly grounded, which is the majority of everything and 690.47(A)(2) will apply to the extremely rare solidly grounded PV system on a building or structure.

**690.47(A)(1) Not-Solidly Grounded Systems** on buildings are allowed to have the EGC be the only connection to ground. This definitely means that for most systems installed today, we do not need a dc GEC like the old days. Dc grounding electrode conductors are just out of style.

**690.47(A)(2) Solidly Grounded Systems** on structures would have to comply with 690.41(A)(5) on page 126 and we size the dc GEC based on Table 250.166 Size of Direct-Current Grounding Electrode Conductor. This is rare, especially on buildings and structures, so we will not go too deep and waste your extremely valuable time.

### *690.47(B) Grounding Electrodes and Grounding Electrode Conductors*

A grounding electrode system includes pieces of metal connected to earth and other pieces of metal connecting those pieces together and then to the grounding system via a grounding electrode conductor (GEC).

690.47(B) has been the controversial "back and forth" over the years. The conflict was this: should we have an additional auxiliary electrode (or electrodes) or not? In the 2014 NEC, it was often interpreted as required, which upset people, and many did not install them. In the 2017 NEC, this section was reworded to make it clear that the additional auxiliary electrode was optional. Once again, in the 2020 NEC it is optional, but no longer called auxiliary. Now it is just termed **additional electrode**(s).

> **Auxiliary Electrodes** are electrodes that are **attached to the equipment grounding system** and do not follow the rules of typical electrodes. Now, apparently, we have to follow the typical rules.

In the **2014 NEC** 690.47(D), Additional Auxiliary Electrodes for Array Grounding said that these electrodes **shall** be installed and made a few people irate. This is now a low-key **optional** thing in the **2020 (and 2017) NEC** that someone can do if they want. One of the reasons for this being controversial was because lightning strikes to the earth can send a wave of voltage. If the wave hits an electrode and causes different voltages at different electrodes that are attached through equipment, then the equipment can sizzle and pop.

What they are:

> If you have an array on your roof, you are permitted to go from the array straight to a ground rod. This would also go for a ground mount; however, one way you can look at it is if your array is put in concrete or earth with metal, every post is electrically an additional electrode. You can connect the 690.47(B) electrodes to the PV arrays on buildings to the metal structural frame of the building if you want. Keep in mind that this connection does not substitute for the EGC connection to the inverter. Without that EGC connection at the inverter, the ground-fault detectors will not work properly.

Get grounded! At least functionally.

# 7 Article 690 Part VI to the End of 690

This chapter of PV and the NEC includes:

690 Part VI Marking
690 Part VII Connection to Other Sources
690 Part VIII Energy Storage Systems
Other Material no longer in 690 as of 2017 NEC

## 690 Part VI Marking

Not all of the requirements for marking PV systems reside within Article 690 Part VI. We also included part of Article 690 Part VI within Chapter 3 of this book in our Section 690.12 Rapid Shutdown chapter.

Here is a list of the common—and some less common—marking requirements, and where to find them in the NEC and this book, which are **not covered in this chapter in detail.**

- 690.13(B) PV SYSTEM DISCONNECT label and ELECTRIC SHOCK HAZARD, TERMINALS ON THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION
    - Page 77 of this book
- 690.31(D)(2) PHOTOVOLTAIC POWER SOURCE or SOLAR PV DC CIRCUIT label
    - Page 103 of this book
- 690.56(C) Rapid Shutdown Labels

SOLAR PV SYSTEM IS EQUIPED WITH RAPID SHUTDOWN, TURN RAPID SHUTDOWN SWITCH TO THE "OFF" POSITION TO SHUT DOWN PV SYSTEM AND REDUCE SHOCK HAZARD IN ARRAY

SOLAR PV SYSTEM IS EQUIPPED WITH RAPID SHUTDOWN

- Page 71 of this book

- 705.10 Plaque or Directory at Power Source Disconnecting Means
  Including location of power sources and the words:

  CAUTION: MULTIPLE SOURCES OF POWER

  - Page 150 of this book
- 705.12(B)(2)(3)(2) 120% rule label

  WARNING: PV POWER SOURCE OUTPUT CONNECTION—
  DO NOT RELOCATE THIS OVERCURRENT DEVICE

  - Page 165 of this book
- 705.12(B)(2)(3)(3) the **sum rule** label

  WARNING: THIS EQUIPMENT FED BY MULTIPLE SOURCES.
  TOTAL RATING OF ALL OVERCURRENT
  PROTECTION DEVICES EXCLUDING THE MAIN SUPPLY
  OVERCURRENT DEVICE
  SHALL NOT EXCEED THE AMPACITY OF THE BUSBAR.

  - Page 167 of this book
- 705.12(C) Supplied by Multiple Sources Label
  No specific wording required
  - Page 171 of this book

Now we will cover, in detail, the markings required in 690 Part VI, with the exception of the markings covered in the Rapid Shutdown chapter earlier in this book, since we covered the rapid shutdown labeling in Chapter 3 of this book on page 71.

## Outline of 690 part VI

690 Part VI Marking
- 690.51 Modules
- 690.52 Alternating-Current Photovoltaic Modules
- 690.53 Direct-Current Photovoltaic Power Source
- 690.54 Interactive Source of Interconnection
- 690.55 Photovoltaic Systems Connected to Energy Storage Systems
- 690.56 Identification of Power Sources
  - 690.56(A) Facilities with Stand-Alone Systems
  - 690.56(B) Facilities with Utility Services and Photovoltaic Systems
  - 690.56(C) Buildings with Rapid Shutdown [See Chapter 3 of this book.]

The marking and labeling requirements for PV systems are included in this book. There are also other marking systems required for energy storage systems in Article 706 Energy Storage Systems and in Article 480 Battery Storage Systems.

## 690.51 Modules and Ac Modules

Modules and ac modules shall be marked in accordance with their listing.

It is difficult to get a copy of the listing without paying a lot, so we have to trust the manufacturers.

In previous versions of the Code, we had the following labeling requirements for **dc modules**, which should align with what is in the listing:

- Polarity of terminals
- Maximum overcurrent device ratings (usually 15A or 20A)
- The following ratings:
  - Open-circuit voltage = Voc
  - Operating voltage = Vmp (maximum power voltage)
  - Maximum permissible system voltage = maximum system voltage (often 1000V)
  - Operating current = Imp = current at maximum power
  - Short-circuit current = Isc
  - Maximum power = Pmax = power rating of module

Discussion: A few years ago, Sean bought 12 used Arco solar modules that were originally installed in California in the 1980s and have been making power in San Francisco for most of the time since. It is interesting that there were no data written on the modules. These modules would not be Code compliant to install, unless perhaps a label was made for them in the 21st century. They still work great by the way!

In previous versions of the Code, we had the following labeling requirements for **ac modules**, which should align with what is in the listing:

**690.52(1)** Nominal Operating Ac **Voltage** [usually 240V, 208V, 277V or 480V.]
**690.52(2)** Nominal Operating Ac **Frequency** [60Hz in the US.]
**690.52(3)** Maximum **Ac Power** [inverter output power.]
**690.52(4)** Maximum **Ac Current**

**690.52(5) Maximum Overcurrent Device** Rating for Ac Module Protection [Typically circuit breaker.]

Discussion: If an ac module had a PV module that would be 100W when tested dc at STC and contained a 300W inverter, then the ac module would be considered to be a 300W module, although it would never put out even 100W. Hopefully nobody would make such a thing, unless it was trifacial and made 3 × the power.

Recall that an ac module is, in effect, a microinverter and PV module combined together before testing as a complete ac power-producing unit. The dc wiring, however, is considered as part of the listing and is not subject to the requirements of the NEC. That is the primary difference between an ac module and a PV module connected to a microinverter.

## 690.53 Dc PV Circuits

Dc PV circuits require a label at one of the following locations:

(1) Dc PV system disconnecting means
(2) PV system electronic power conversion equipment
(3) Distribution equipment associated with PV system

**All this sign requires now is the maximum dc voltage from 690.7**.

In previous versions of the Code we had requirements for maximum circuit current in 2017 NEC, along with operating voltage (Vmp) and current (Imp) in 2014 and earlier versions of the NEC.

There are no color, size or reflective requirements in the NEC for the 690.53 Dc PV Circuits sign, so get creative! All it has to be is permanent and readily visible.

## 690.54 Interactive System Point of Interconnection

The interactive source of interconnection sign at the disconnecting means shall have the following:

- Ac nominal voltage [usually 240V, 208V, 277V or 480V.]
- Ac rated current [usually inverter power/inverter ac voltage.]

Note: ac rated output current can be slightly different than power divided by voltage, due to power factor and if operating voltage is less than nominal. It is best to determine inverter rated current by reading the inverter label, datasheet or installation manual.

This sign shall be at an accessible location at the disconnecting means.

## 690.55 Photovoltaic Systems Connected to Energy Storage Systems

PV system output circuit conductors shall have the polarity marked when connected to energy storage systems.

Positive and negative shall be marked on the conductors coming from PV, so that the energy storage system is not connected backward, which could cause exciting safety problems.

**Common positive/negative mix-up**

Be careful when using PV connectors. A negative connector will only connect to a positive connector. When you are connecting a wire to the negative connector of a module, you have to use a positive marked connector, which will not be positive since it is an extension of the negative output of a PV module. Many times, installers get this backward and are grateful when inverters have reverse polarity protection. It is best to always test voltages before connecting PV to an inverter, charge controller or energy storage system.

## 690.56 Identification of Power Sources

With PV systems, energy storage systems and the grid, we can have power pushing in all directions, therefore it is prudent to identify what is going on for those who will be puzzled in the future. As the future happens, we will see more things connected, and with power control systems we will discover that more things will be networked to work in harmony for a better grid experience.

### *690.56(A) Facilities with Stand-Alone Systems*

Stand-Alone Systems shall be installed in accordance with 710.10
Article 710 is Stand-Alone Systems

In 710.10 it says that stand-alone (off-grid) PV systems shall have a permanent plaque or directory on the exterior of the building or structure that is in a readily visible location.

The plaque or directory shall indicate that there is a stand-alone system and the location of the stand-alone system disconnecting means.

If there are multiple source of power, then the plaque or directory should state:

CAUTION: MULTIPLE SOURCES OF POWER

### *690.56(B) Facilities with Utility Services and Photovoltaic Systems*

Plaques or directories shall be installed in accordance with 705.10 and 712.10 when PV systems are installed at facilities with utility services.

Article 705 is Interconnected Electric Power Production Sources
Article 712 is Direct-Current Microgrids

When there are different power sources at a facility, there shall be a plaque or directory indicating each location for each source of power. This means that, at the utility service and the PV system disconnecting means, there shall be plaques or directories indicating the different locations of equipment, so that all systems on or in the building may be properly turned off in an emergency situation.

705.10 says a plaque or directory shall be installed at each service equipment location, or at an approved, readily visible location. It shall read:

CAUTION: MULTIPLE SOURCES OF POWER

712.10 says that there should be a source directory denoting all power source locations at each power source capable of being a primary power source. There should also be a building directory installed outside the building at each service equipment location or at an approved readily visible disconnect location. This directory shall denote each power source disconnecting means location that is on or in a building.

### *690.56(C) Buildings with Rapid Shutdown (see Chapter 3 of this book)*

The many required signs for a rapid shutdown system are covered in Chapter 3 of this book on page 71. Including signs for module level and array level rapid shutdown requirements. Since the NEC is black and white, it can only describe color.

## Part VII Connection to Other Sources

Part VII of 690 is short, containing one section that sends us to other articles.

**690.59 Connection to Other Sources**

Shall be installed in accordance with **Article 705 Parts I and II and Article 712**, which are:

- 705 Part I General (most of 705)
- 705 Part II Microgrid Systems (1 page of 705)
- Article 712 is Direct-Current Microgrids

Not included is: 2017 NEC 705 Part II Interactive Inverters and III Generators. The Interactive Inverter Part was merged back into Part I to reduce confusion and because it was no longer necessary to differentiate among different power sources.

The majority of Article 705, including the interconnection requirements in 705.11, 705.12 and 705.13, are in Part I of 705.

## Part VIII Energy Storage Systems

There are two sections in Part VIII. One tells us to go to the new Energy Storage Systems Article 706 and the other is regarding an obscure PV battery combination that has no charge controller.

## Outline of 690 part VIII

690.71 General
690.72 Self-Regulated PV Charge Control
    690.72(1) Matching PV to battery 690.72
    690.72(2) No greater than 3% per hour

## 690.71 General

Energy Storage Systems connected to PV shall be **installed in accordance with** the new to the **Article 706 Energy Storage Systems**.

Notice how it does not mention Article 480 Storage Batteries—keeping this article in the NEC is confusing and causes a problem with two articles having overlapping scopes (editorial opinion).

Energy Storage was taken out of Article 690 in the 2017 NEC and is no longer considered part of a PV system. Only the section on self-regulated PV charge control [690.72] remains as it is unique to PV systems.

## 690.72 Self-Regulated PV Charge Control

Self-regulated PV systems have the benefit of not needing a charge controller but have the drawback of not being able to work at the optimal part of the IV curve. These systems are often designed so that they will operate toward the Voc end of the IV curve, so that an overcharge will not occur, or they can be designed so that the PV is undersized relative to the battery, yet so is the load. With the advent of less expensive and more reliable PV electronics, self-regulating systems are less common. An example often used for a self-regulating system is a buoy in the ocean with 35 solar cells, charging a 12V battery to operate a flashing light that takes very little energy. Another example is my small solar module that keeps my car battery topped off when I go away for extended periods of time. No charge controller is needed.

690.72 says: "A PV source circuit shall be considered to comply with the requirements of 706.33 if: … and the 'if' is 690.72(1) and 690.72(2) below. It is like we have a PV source circuit that is a silicon-based charge controller."

### *690.72(1) Matching PV to battery 690.72*

The voltage of the PV should match the voltage of the battery(s) paying attention to the IV curve

### *690.72(2) No greater than 3% per hour*

The current of the PV should not overcharge the battery(s)

We do not recommend self-regulating charge control of lithium batteries on Boeing 787s.

This is the End of 690!

# 8 Article 691 Large-Scale Photovoltaic (PV) Electric Supply Stations

Article 691 was new in the 2017 NEC and there is not a whole lot to it (about one page in the NEC). There are certain things that can be done with these larger systems, under the supervision of an engineer, which cannot be done with smaller systems.

In the past, our excuse for changing the rules on these large "utility-scale" solar farms was that we decided to call them utilities, and utilities are not subject to the requirements of the NEC. Utilities typically use engineering standards and the **National Electrical Safety Code (NESC)** for designing their systems. The question has always been: Is it really a utility? Now, we can use the NEC and no longer have to look for a utility loophole when installing large PV. Also, many jurisdictions did not buy that a large-scale PV system was like utility-owned properties and would enforce Article 690.

## Outline of Article 691

691 Large-Scale PV
- 691.1 Scope (≥5MW ac)
- 691.1 Informational Note 1: purpose to supply utility
- 691.1 Informational Note 2: refers to 90.2(B)(5) and NESC
- 691.1 Informational Note 3: refers to figure 691.1
- 691.2 Definitions
- 691.4 Special Requirements for Large-Scale Electric Supply Stations
  - 691.4(1) Qualified Personnel
  - 691.4(2) Restricted Access
  - 691.4(3) Medium or High Voltage Connection
  - 691.4(4) Loads Only for PV Equipment
  - 691.4(5) Not Installed on Buildings

691.5 Equipment
691.5(1) Listing and Labeling
691.5(2) Field Labeling
691.5(3) Engineering Review
691.6 Engineered Design
691.7 Conformance of Construction to Engineered Design
691.8 Direct-Current Operating Voltage
691.9 Disconnecting Means for Isolating Photovoltaic Equipment
691.10 Arc-Fault Mitigation
691.11 Fence Bonding and Grounding

## 691 Large-Scale Photovoltaic (PV) Electric Supply Stations

A 5+MW PV system can be installed outside of the scope of 691; for instance, on a building. Just because a PV system is larger than 5MW does not automatically make it compliant with 691. It has to meet all of 691.4's special requirements as well.

### *691.1 Scope (≥5MW Ac)*

Requirements for PV systems covered in Article 691

- Generating capacity (ac) of no less than 5000kW (5MW)
- Not under exclusive utility control

Generating capacity definition title was revised to be specific to inverters and moved from 691.2 Definitions to Article 100 Definitions in the 2020 NEC.

Article 100 Definition Generating Capacity, Inverter:

> "The sum of the parallel-connected inverter maximum continuous output power at 40°C in watts or kilowatts."

Essentially this is the ac output of the inverter.

Oftentimes the dc PV portion of a PV system is sized between 1.2 and 1.5 times greater than the inverter generating capacity for large-scale PV projects. We have seen as high as a 2:1 ratio!

If the PV system were under **utility control, then it would not need to comply with the NEC** at all. However, most utility-owned PV supply stations look just like every other PV power plant that uses Article 691.

### *691.1 Informational Note 1*

Large-scale PV covered in this article is producing electricity for the **sole purpose of supplying electricity to a regulated utility**.

### *691.1 Informational Note 2*

Section 90.2(B)(5) includes information about utility-owned properties not covered by the NEC.

There is a reference to the **National Electrical Safety Code**, which is also known as **ANSI Standard C2** and is published by IEEE.

- ANSI is the American National Standards Institute. ANSI accredits standards that are developed by of other standards organizations, government agencies, consumer groups, companies and others.
- IEEE is the Institute of Electrical and Electronics Engineers. World's largest association of technical professionals with more than 423,000 members in over 160 countries.

Section 90.2(B)(5) tells us that **installations that are under the exclusive control of a utility are not covered by the NEC.**

### *690.1 Informational Note 3*

New in the 2020 NEC is Informational Note 3 figure 691.1, Identification of Large-Scale PV Electric Supply Station Components.

This image shows a simple single line diagram with PV going to an inverter, to an inverter output circuit, through a transformer, up to

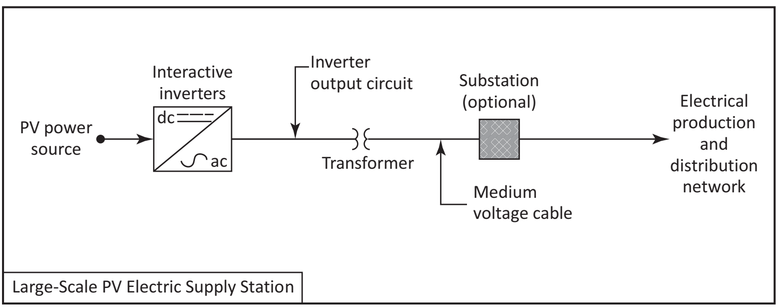


*Figure 8.1* Informational Note figure 691.1 Identification of large-scale PV electric supply station components

*Source:* courtesy NFPA

medium voltage (thousands of volts), to a medium voltage cable and then optionally to a substation and up to the electrical production and distribution network.

Oftentimes the utility-scale solar plant will have medium voltage connections inside the plant and then all of the medium voltage cables will combine at a substation where the voltage will be boosted to high voltage. An example would be medium voltage of 34.5kV and high voltage of 115kV. At 115kV a MW would be 1000kW/115kV/1.732 = 5A. As you can see with higher voltage, the current goes way down!

## *691.2 Definitions*

The definitions in 691 only apply to 691.

*Electric Supply Stations*

Locations containing:

- Generating stations
- Substations
- Generator
- Storage battery
- Transformer
- Switchgear areas

*Generating Station*

A generating station is a plant where electric energy is converted from another source.

Typical sources:

- Solar
- Nuclear
- Chemical
- Wind
- Mechanical
- Hydraulic

## *691.4 Special Requirements*

Large-scale PV electric supply stations shall be accessible only by authorized personnel.

Large-scale PV electric supply stations shall comply with 691.4(1) to 691.4(5)

### *691.4(1) Qualified Personnel*

Electrical circuits and equipment shall be maintained and operated only by qualified personnel.

Discussion: Qualified person as defined in NEC Article 100 Definitions is:

> "One who has skills and knowledge related to construction and operation of electrical equipment and installations and has received safety training to recognize and avoid the hazards involved."

This means that there is no hard definition of qualified personnel; however, common sense should prevail. Some people consider NABCEP Certification as a way of showing that someone is qualified, and others believe that an electrician is qualified personnel. Perhaps only people reading this book are truly qualified. It would also depend on the job someone is doing. The average person who is qualified to install solar racking systems at a large solar plant is likely not qualified to work on medium voltage or high voltage equipment.

It is interesting that 691.4(1) Informational Note directs us to **NFPA 70E Standard for Electrical Safety in the Workplace** for the qualified personnel definition and that it is the same exact definition that we find in NFPA 70, the NEC. Perhaps NFPA is doing a good job at trying to sell more books. We should learn from them!

### *691.4(2) Restricted Access*

Access to PV electric supply stations shall be restricted by fencing or other means in accordance with 110.31. Additionally, field-applied hazard markings shall be applied in accordance with 110.21(B).

**110.31 Enclosure for Electrical Installations** is in Article 110 Requirements for Electrical Installations **Part III Over 1000V**, Nominal and this section of Code goes into the details of how to keep unqualified people out of the electrical installation.

Some of the other means besides fencing for keeping the PV area restricted to qualified people according to 110.31 are:

- Vaults
- Rooms
- Closets

- Walls
- Roofs
- Floors
- Doors
- Locks

691.4(2) also directs us to **110.31 Enclosure for Electrical Installations** and here we find **Table 8.1 110.31 Minimum Distance from Fence to Live Parts**.

*691.4(3) Medium or High Voltage Connection*

The connection between the PV electric supply station and the utility shall be made through a **medium voltage or high voltage method,** such as the following:

- Switchgear
- Substation
- Switchyard
- Similar method

There are different definitions of medium and high voltage, but a general consensus is that medium voltage is over 1000V, so here we are typically talking about connections that are **between 4000 and 500,000V**.

> That means no 480V 5MW projects here. That would be a lot of current.
> 5MW / 480V / 1.732 for 3-phase = Over 6,000A!

*691.4(4) Loads Only for PV Equipment*

The only loads allowed in a PV electric supply station are those to power the auxiliary equipment used in the process of generating power.

*Table 8.1* Table 110.31 Minimum distance from fence to live parts

| | *Minimum distance to live parts* | |
|---|---|---|
| *Nominal Voltage* | *m* | *ft* |
| 1001–13,799 | 3.05 | 10 |
| 13,800–230,000 | 4.57 | 15 |
| Over 230,000 | 5.49 | 18 |

*Source:* courtesy NFPA

Examples of loads would include monitoring equipment, weather stations, lights, controls and PV maintenance equipment.

### *691.4(5) Not Installed on Buildings*

Article 691 will not apply to PV systems installed on buildings. This does not mean that PV systems larger than 5MW cannot be on a building; it means that the special rules in Article 691 will not apply to any PV system installed on a building. Article 690 applies in all cases where Article 691 does not apply for PV and the NEC.

Question: If you had 5MW over an underground Y2K bunker, would it be "on a building"?—I don't think so, Tim.

## ***691.5 Equipment Approval***

Equipment shall be approved by one of the following methods:

### *691.5(1) Listing and Labeling*

A listed PV module tested to UL 1703 and labeled would be an example.

### *691.5(2) Field Labeling and Identified for Application*

Typically, field labeling would be having a Nationally Recognized Testing Lab (NRTL), such as UL, TUV or Intertek send someone out to approve of the product and give it the lab's label while it is in the field. These field labels may represent a subset of the tests that are conducted on factory labeled equipment since all tests are not feasible in the field. Added in the 2020 NEC was that the equipment also had to be identified for the application.

### *691.5(3) Engineering Review*

When listing and labeling or field labeling are not available, an engineering review can take place to validate that the equipment is evaluated and tested to an industry standard or practice. Keep in mind **this method is only available if the other two methods are *not* available**. It is up to the AHJ whether to approve of this process.

## ***691.6 Engineered Design***

Documentation stamped by a licensed professional engineer shall be made available at the request of the AHJ.

The engineer shall be independent and retained by the system owner.

Additional stamped engineering reports shall be made available upon request of the AHJ documenting:

- Compliance with Article 690
- Alternative methods used not in compliance with Article 690
- Alternative methods used not in compliance with the NEC
- Compliance with industry practice

Discussion: What this means is that under engineering supervision, we are allowed to stray from Article 690 when we meet the requirements of Article 691. Section 691.6 is a documented version of what is commonly performed during the plan check phase of a construction project. Several examples of typical areas where a large-scale PV system is likely to take exception to Article 690, or the rest of the NEC, are listed in 691.8 through 691.11.

### *691.7 Conformance of Construction to Engineered Design*

Documentation that **construction of the project followed** the electrical engineered **design** shall be made available to the AHJ upon request.

Additional licensed professional electrical engineer stamped reports detailing that **construction conforms with the NEC, standards and industry practice** shall be provided to the AHJ upon request.

The engineer shall be independent and retained by the system owner. Discussion: Section 691.7 is a documented version of what is commonly performed during the field inspection phase of a construction project.

### *691.8 Direct-Current Operating Voltage*

Included in the documentation required by 691.6 Engineered Design shall be voltage calculations.

### *691.9 Disconnecting Means for Isolating Photovoltaic Equipment*

Isolating devices (non-load-break rated disconnecting means) shall be **permitted to be remote from the equipment**.

Requirements of isolating devices remote from equipment (690.15 Disconnecting Means for Isolating Photovoltaic Equipment requires isolating devices to be 10 ft from equipment):

- Written safety procedures ensure only qualified persons service equipment
- Maintenance conditions ensure only qualified persons service equipment
- Supervision ensures only qualified persons service equipment

Informational note: Lockout-Tagout procedures are in NFPA 70E Standard for Electrical Safety in the Workplace. For maintenance information, see NFPA 70B Recommended Practice for Electrical Equipment Maintenance.

Adherence to **690.12 Rapid Shutdown is not required** for buildings whose sole purpose is to protect PV supply station equipment.

Written standard operating procedures detailing shutdown procedures in case of emergency shall be available on site.

### *691.10 Arc-Fault Mitigation*

**If PV system does not comply with 690.11 Dc arc-fault protection,** then included in the documentation in 691.6 Engineered Design shall be **fire mitigation plans to address dc arc-faults**.

Here is an example of fire mitigation plans:

- Fire Mitigation Plans
  - Include specific details for firefighting within the PV plant
  - Include access in and around the PV plant for fire department equipment
  - May provide on-site suppression capabilities including extinguishers at each inverter pad and tanker trucks with fire hoses for early response
  - May include personnel on site during operating hours that can see fires as they get started
  - "Hot Work" practices followed for cutting and welding within the facility
    - ("Hot Work" is the main cause of fires in a large-scale PV facility)

### *691.11 Fence Grounding*

Fence grounding requirements and details shall be included in the documentation in **691.6 Engineered Design**.

***690.11 Informational Note: directs us to 250.194***

**250.194 Grounding and Bonding of Fences and Other Metal Structures**

250.194 relates bonding and grounding of fences to substations and the informational note does not mean we are required to follow 250.194; however, it is a good reference. We are looking out here for things such as step voltages, which means that in certain instances you could take a step and the voltage could be different one foot to the next if a power line hit the ground. Ouch!

**250.194(A) Metal Fences** goes on to say that we need to bond fences that are within 16 ft of exposed electrical conductors or equipment

- **250.194(A)(1)** Bonding jumpers are supposed to be every 160 ft
- **250.194(A)(2)** When bare overhead connectors cross over a fence, bonding jumpers shall be on each side of the crossing
- **250.194(A)(3)** Gates shall be bonded to gate post which shall be connected to electrode system
- **250.194(A)(4)** Gate or opening in fence shall be bonded by buried bonding jumper
- **250.194(A)(5)** Grounding grid or electrode systems shall cover the swing of gates
- **250.194(A)(6)** Barbed wire strands above the fence bonded to the electrode system

Question: Why ground the barbed wire? To protect the criminals? How about a medium voltage electric fence to keep out the riffraff?

## Article 691 Overview

When installing a large-scale PV system in the past, PV companies were often forced to pretend that they were a utility. Using Article 690 for compliance with a 100MW power plant was never the intended use of the article. These large systems are unlike smaller systems, in that they are not accessible to people, as are PV systems on buildings and in back yards. With the ability to do things under engineering supervision that stray from the requirements of Article 690, we are no longer put into a position where we have to pretend that we are a utility and that the system is behind a utility fence.

Utilities may still build and operate PV systems that are not required to be compliant with the NEC; however, it is now Code compliant to build a large PV system that does not comply 100% with Article 690. This flexibility can actually improve operation, maintenance, and safety for these large power plants.

# 9 Article 705 Interconnected Electric Power Production Sources

Article 705 was first introduced into the NEC in 1987. As both Articles 690 and 705 developed over time, the requirements in 690.64 were incorporated into Article 705 in the 2011 NEC. With the advent of much more distributed generation coming onto the grid from solar PV, wind and other sources, Article 705 has grown in size and importance.

In this chapter, we will not cover everything in as much detail as we did when we covered Articles 690 Solar Photovoltaic (PV) Systems and 691 Large-Scale Photovoltaic (PV) Electric Power Production Facility. Instead, we will focus on the most important solar PV and energy storage related material in Article 705.

For our purposes, Article 705 Interconnected Electric Power Production Sources includes the requirements for connecting utility interactive inverters to the grid.

Many of the requirements of Article 705 are satisfied by the listing of the interactive inverters.

Reviewing an outline of an Article before studying the article helps us get properly situated and our minds organized to study the article. There was a bit more organizing of 705 in the 2020 NEC than the 2017 NEC, but most of what we actually do stays the same.

## Outline of Article 705

705 Part I. General
- 705.1 Scope
- 705.2 Definitions
- 705.6 Equipment Approval
- 705.8 System Installation
- 705.10 Identification of Power Sources
- 705.11 Supply-Side Source Connections
    - 705.11(A) Output Rating
    - 705.11(B) Conductors

705.11(C) Overcurrent Protection
705.11(D) Connections
705.11(E) Ground-Fault Protection
705.12 Load-Side Connections
705.12 Load-Side Source Connections (half of our 705 focus is here)
705.12(A) Dedicated Overcurrent and Disconnect
705.12(B) Bus or Conductor Ampere Rating
705.12(B)(1) Feeders
705.12(B)(1)(A) Feeder Ampacity Protection
705.12(B)(1)(B) Feeder Overcurrent Device
705.12(B)(2) Taps
705.12(B)(3) Busbars
705.12(B)(3)(1) 100% Rule
705.12(B)(3)(2) 120% Rule
705.12(B)(3)(3) Sum Rule
705.12(B)(3)(4) Center-fed 120% rule
705.12(B)(3)(5) Switchgear, Switchboards and busbars with Engineering Supervision
705.12(B)(3)(6) Feed-Through Conductors
705.12(C) Marking
705.12(D) Suitable for Backfeed
705.12(E) Fastening
705.13 Power Control Systems
705.13(A) Monitoring
705.13(B) Settings
705.13(C) Overcurrent Protection
705.13(D) Single Power Source Rating
705.13(E) Access to Settings
705.14 Output Characteristics
705.16 Interrupting and Short-Circuit Current Rating
705.20 Disconnecting Means, Source
705.25 Wiring Methods
705.25(A) General
705.25(B) Flexible Chords and Cables
705.25(C) Multiconductor Cable Assemblies
705.28 Circuit Sizing and Current
705.28(A) Calculation of Maximum Circuit Current
705.28(B) Conductor Ampacity
705.28(C) Neutral Conductors
705.28(C)(1) Single-Phase Line-to-Neutral Power Sources
705.28(C)(2) Neutral Conductor Used Solely for Instrumentation, Voltage, Detection or Phase Detection

705.30 Overcurrent Protection
705.30(A) Circuit and Equipment
705.30(B) Overcurrent Device Ratings
705.30(C) Power Transformers
705.30(D) Generators
705.32 Ground-Fault Protection
705.40 Loss of Primary Source
705.45 Unbalanced Interconnections
705.45(A) Single Phase
705.45(B) Three Phase

Part II. Microgrid Systems

705.50 System Operation
705.60 Primary Power Source Connection
705.65 Reconnection to Primary Power Source
705.70 Microgrid Interconnection Devices (MID)

## 705.1 Scope

Article 705 covers the installation of **multiple power sources connecting in parallel,** such as from a renewable energy source and the utility. One of the power sources must be a primary power source.

## 705.2 Definitions

Definitions in this article only apply to this article. We have seen this new statement in the 2020 NEC in many different Articles.

**Microgrid Interconnect Device (MID).** A device that will allow the microgrid to work in parallel with and separation from the grid (primary power source), such as anti-islanding, which means separating from the grid when the grid is down. Often with ac coupling of PV systems a battery inverter/charger will perform this function. The MID definition has an informational note that refers to IEEE standards and tells us that microgrid controllers are typically used to measure and evaluate parameters.

**Microgrid System.** A premises wiring system that can perform all or some of the following:

- Generation
- Energy storage
- Loads

A microgrid also can disconnect and reconnect to the primary power source (grid).

There is an informational note with the microgrid system definition that sends us to 90.2(B)(5) Not Covered, which tells us that installations that are utility controlled are not covered by the NEC.

**Power Source Output Circuit**. Conductors between power production equipment and the service or distribution equipment. This sounds like an inverter output circuit and is a new definition in the 2020 NEC.

## 705.3 Other Articles—removed from the NEC in 2020

## 705.6 Equipment Approval

Equipment shall be **approved for intended use**. We need to use equipment that is approved for interconnection to the grid.

Equipment that should be listed interactive or field labeled and evaluated interactive includes:

- Interactive inverters
- Engine generators with special controls
- Energy storage equipment
- Wind turbines

Recall that the UL listing for an inverter is UL 1741

## 705.8 System Installation

Installations only to be performed by qualified person (see pages 22 and 141 of this book for discussion on qualified person). Or see Article 100 Definition of Qualified Person.

## 705.10 Identification of Power Sources

A permanent plaque or directory shall be placed at each service equipment location of approved readily visible location. At each location, the plaque or directory shall tell us where all other power source disconnecting means are located. The plaque or directory shall be a 110.21(B) compliant label that says: "CAUTION: MULTIPLE SOURCES OF POWER."

Discussion: If there is an emergency, the firefighters would like to know the location of every power source disconnecting means, so they can know when they turn everything off. This plaque or directory will show at every location where all of the other locations' disconnecting means are located. Firefighters do not want to think they have turned off the building only to find out that they missed a power source disconnect hidden in the backyard.

705.10 has been referenced earlier in section 690.56(B) and has been an important theme in the NEC throughout the years. We do not want people turning something off and thinking they turned off the whole building, when they did not.

## Interconnections 705.11 and 705.12

Part of the magic of PV systems is connecting inverters to the grid and sending power backward.

In the 2020 NEC, some of the rearranging was taking **supply-side connections** (AKA line-side taps) out of 705.12 and giving **supply-side connections, its own section 705.11** and making a few more rules for these between the meter and main service disconnect connections. Supply-side connections went from 705.12(A) and five lines of code to 705.11(A) through (E) and way more lines of code. Time to dive in!

## 705.11 Supply-Side Source Connections

Supply-side connections shall be permitted as is in 230.82(6) and 705.11(A) through (E)! 230.82(6) is not worth looking up, it just says that interconnected power production sources, including PV, can be connected on the supply side of the service disconnect.

A supply-side connection is the connecting of a parallel power source, such as a solar interactive inverter, on the **supply side of all overcurrent protection** on a service. **If the inverter is on the load side of any over-current protection, then it is not a supply-side connection.** Typically, supply-side connections are **between the main breaker and the meter.** A feed-in tariff PV system (rarer in the US) would also be connected on the supply side of both the main breaker and the service meter. This type of installation could also be covered by 705.11.

### *705.11(A) Output Rating (Supply-Side)*

The **sum of the power source continuous currents cannot exceed the ampacity of the service conductors.** This is different than the 2017 NEC, where we would only sum up the power source supply-side overcurrent devices. The 2020 gives us more potential to add PV, since we are not penalized for the 125% and rounding up to the next breaker size. We do not take loads or the size of the main breaker into consideration when determining the maximum amount of inverter rated power that we can connect with a supply-side connection. Typically, with a supply-side connection, you can connect as much PV as you will ever need. However, some large commercial facilities may want to install PV systems even larger than their service ratings to zero out their relatively high day and night electricity consumption over the year. These large systems typically require a significant service upgrade, including a larger service transformer.

Another sort of exception we have here, new and improved in the 2020 NEC, is **705.13 Power Control Systems.** We will learn about these power control systems soon on page 173 and how they **can control the power direction and quantity, just like we need it**. With the power control systems, in theory, we can connect as much PV as we want, as long as our artificial intelligence (AI) pays attention to the current on the service conductors and makes sure there are not dangerous situations.

### *705.11(B) Conductors (Supply-Side)*

The **power source output circuit (inverter output circuit)** conductors from the point of interconnection to the first overcurrent device shall be sized in accordance with:

- **705.28 Circuit Sizing and Current** (see Chapter 12 Wire Sizing) This is practically the same wire sizing techniques for all conductors carrying continuous current in the NEC. Nothing really new here except organization.
- Supply-side shall be at least **6AWG copper or 4AWG aluminum (new in 2020 NEC).**
- Supply-side shall be installed in accordance with either **230.30 Installation [of underground service conductors] or 230.43 Wiring Methods [service-entrance conductors.]**

**230.30 Installation** (Under heading 230 **Part III Underground Service Conductors**):

**230.30(A) Insulation** (underground supply-side):

Says conductors shall be insulated for proper voltage unless bare (exception).

(1) Bare Copper in Raceway
(2) Bare Copper Direct Burial for Approved Soil Conditions

(3) Bare Copper if Part of Approved Underground Cable Assembly
(4) Aluminum or Copper-Clad Aluminum where Part of Underground Cable Assembly

**230.30(B) Wiring Methods** (underground supply-side)

Must be one of the following wiring methods:

(1) RMC (Rigid Metal Conduit) Article 344
(2) IMC (Intermediate Metal Conduit) Article 342
(3) NUCC (Non-Metallic Underground Conduit with Conductors) Article 354
(4) HDPE (High Density Polyethylene Conduit) Article 353
(5) PVC (Rigid Polyvinyl Chloride) Conduit Article 352
(6) RTRC (Reinforced Thermosetting Resin Conduit (RTRC) Article 355
(7) IGS (Integrated Gas Spacer) Cable Article 326
(8) USE (Underground Service Entrance) Article 338
(9) MV or MC Identified for Direct Burial Article 328 and 330
(10) MI cable protected from damage and corrosion Article 332

**230.43** Wiring Methods for 1000 Volts, Nominal, or Less. (Under heading 230 **Part IV Service-Entrance Conductors**):

Says service-entrance conductors shall be installed by one of the following methods:

(1) Open Wiring on Insulators Article 398
(2) IGS (Integrated Gas Spacer) Cable Article 326
(3) RMC (Rigid Metal Conduit) Article 344
(4) IMC (Intermediate Metal Conduit) Article 342
(5) EMT(Electrical Metallic Tubing) 358
(6) Electrical Non-metallic Tubing (ENT) Article 362
(7) SE and USE (Service-Entrance) Cables Article 338
(8) Wireways Metal Article 376, Non-Metallic Article 378
(9) Busways Article 368
(10) Auxiliary Gutters Article 366
(11) PVC (Rigid Polyvinyl Chloride) Conduit Article 352
(12) Cablebus Article 370
(13) Metal-Clad (MC) Cable 330
(14) Mineral Insulated Metal Sheathed (MI) Cable Article 332
(15) Flexible Metal Conduit (FMC) (Not over 6 ft long) Article 348
(16) LFNC (Liquidtight Flexible Non-Metallic Conduit) Article 350
(17) HDPE (High Density Polyethylene Conduit) Article 353
(18) NUCC (Non-metallic Underground Conduit with Conductors) Article 354

(19) RTRC (Reinforced Thermosetting Resin Conduit (RTRC) Article 355
(20) Type TC-ER Cable Article 336

### *705.11(C) Overcurrent Protection (Supply-Side)*

The power source output (inverter output) circuit conductors shall be protected from overcurrents in accordance with **705.30 Overcurrent Protection**. 705.30 is covered later in this chapter on page 179. There is nothing big or new in 705.30, just reorganization and electron common sense. They probably do it this way on different planets, since it is based on physics.

If fuses are not inside the disconnecting means, then the disconnecting means shall be on the service side of the fuses (this way we can replace fuses without getting killed).

Installers often use fuses for a supply-side connection, but you can also use properly rated circuit breaker(s). Fuses are cheaper and tend to interrupt high utility currents very well.

If: The supply-side connection is made outside of the building:

Then: Overcurrent device shall be in readily accessible location either:

- Outside the building
- First readily accessible location inside building

If: Supply-side connection made inside building:

Then: Either 705.11(C)(1) or 705.11(C)(2) below

(1) OCPD located within point of connection:
  - 3m (10ft) of conductor length in dwelling
  - 5m (16.5ft) in non-dwelling

(2) Other non-dwelling (longer distances)
  - 20m (71ft) from connection point IF cable limiters are located within 5m (16.5ft) of connection point

Simplifying **OCPD Locations** for Supply-Side Connections
With metric/imperial banter

For dwellings:
**If connection is outsid**e, then readily accessible location outside building or first readable location inside entering building.
**If connection is inside**, then within 3m from connection point.

For non-dwellings:
**If connection is outside**, then readily accessible location outside building or first readable location inside entering building (same as for dwellings).

**If connection is inside**, then 5m from connection point.
**OR**
**If connection is inside**, then cable limiters 5m from connection point AND OCPD within 20m.
Discussion: As we can see here at this moment in time, the metric system has won out and we are advising everyone to go out and buy a metric tape measure. The units here are difficult to memorize in feet and easy in meters. According to 705.11(C) 3m = 10ft, so 3.33 feet per meter. But then 5m = 16.5ft, so 3.3 feet per meter and then we have 20m = 71ft, so 3.55 feet per meter. The internet says there are 3.28 feet per meter. It apparently depends on whose feet you are using. At 3.28 feet per meter, 20 meters is 65.6 feet, so there are benefits to having each type of tape measure handy.

### *705.11(E) Connections (Supply-Side)*

The connections shall be made using listed conductors as described in **110.14 Electrical Connections**. 110.14 pretty much says that we need to torque and install the listed conductors according to instructions, which was how they were tested during the listing process, with also paying attention to **110.14(C) Temperature Limitations**, which we will take into account in our wire-sizing chapter beginning on page 223 of this book.

## 705.12 Load-Side Connections

Most solar installers and electricians prefer a load side connection, since it is easy to turn off the main and safely pop in a solar breaker, just like they pop in a load breaker.

We are **permitted to connect** solar on the load side of ***any*** **distribution equipment on the premises**.

Examples of distribution equipment eligible for a load-side connection include:

- Panelboards

Article 100 Definition:

> A single panel or group of panel units designed for assembly in the form of a single panel, including busses and automatic overcurrent devices, and equipped with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall, partition, or other support; and accessible only from the front.

A main service panel and a subpanel are common examples of panelboards.

- Switchgear

Article 100 Definition:

> An assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) and containing primary power circuit switching, interrupting devices, or both, with busses and connections. The assembly may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors, removable covers or both.

- Switchboards

Article 110 Definition:

> A large single panel, frame, or assembly of panels on which are mounted on the face, back, or both, switches, overcurrent and other protective devices, buses, and usually instruments. These assemblies are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets.

Much of the load-side connection material in the 2020 NEC was rearranged, but it is mostly the same in practice and theory as it was in the 2017 NEC.

The exception of change is we can allow for a **705.13 Power Control System (PCS)** to control the direction and amplitude of the currents, which can prevent overcurrents on a conductor.

### *705.12(A) Dedicated Overcurrent and Disconnect*

Each source interconnection of one or more power sources in a system shall be made at a dedicated circuit breaker or fusible disconnecting means.

Discussion: In the past, some have interpreted the NEC to say that each inverter needed a dedicated overcurrent protection device, which was especially inconvenient for microinverter enthusiasts. Multiple inverters can have a single overcurrent device as long as those inverters have been listed and tested to work safely with a single overcurrent device. This would be reflected in the installation instructions.

We cannot, however, have a combination of a load and an interactive inverter on a branch circuit circuit breaker. This means that you cannot have a PV system that you plug into an outlet. There have been some good ideas that have been taken off the books because of this rule. This is also for good reason. If a homeowner started plugging in a new PV system to a power strip every week, before they reached a MW, something would catch fire.

### *705.12(B)(2) Bus or Conductor Ampere Rating*

We are about to explain how to do some math regarding how much current we can backfeed on a load-side connection. In the 2011 and earlier versions of the NEC, we were taught to use the inverter backfeed breaker size for our calculations. After the 2014 NEC we switched over to use 125% of the inverter current in most of our calculations. In most cases there will be no difference, but here are a few examples of how 125% of inverter current being used in the calculation can be beneficial:

- Rounding up to the next common breaker size.
  - Example: If we have a 3kW/240V inverter operating at 12.5A, we then multiply 12.5A × 1.25 = 15.6A. Since there are no 15.6A breakers, we then round up to a 20A breaker. If we use the 125% of inverter current in our calculation rather than the breaker size, we then get an extra 20A – 15.6A = 4.4A to play with.
- Using a 30A breaker, since a 25A breaker is uncommon.
  - Example: If we are using a 4kW inverter at 240V then our inverter current is 4kW/240V = 16.67A and 16.67A × 1.25 = 20.8A and in this case we can round up to a 25A breaker, however, electricians may find it difficult to locate a 25A breaker and often use a 30A breaker. It is acceptable to use a 30A breaker in this case as long as the conductor is large enough to be protected by a 30A breaker and as long as the inverter manufacturer allows a 30A breaker to protect the inverter. In this example 125% of inverter current is 20.8A and the breaker is 30A, so we have 30A–20.8A = 9.2A more of an allowance by using the 125% of inverter current rather than the breaker size method.

- Having a few microinverters on a circuit.

  Often times with microinverters we do not have the maximum number of inverters on a circuit. At times when the microinverter circuit has a long way to go to reach the interconnection, the designer will place less microinverters on a circuit to address voltage drop considerations. Other times, we see a few microinverters on a circuit, just because it is what fits on the roof.

  - Example: If we have three 250W microinverters on a 20A breaker at a house, then inverter current would be calculated 250W/240V = 1.04A and 125% of the current for each inverter would be 1.04A × 1.25 = 1.3A and for three inverters 125% of current is 1.3A × 3 = 3.9A. In this case the benefit of using 125% of inverter current rather than the breaker size is 20A – 3.9A = 16.1A benefit, so in this case it can make a big difference.

125% of inverter current is more difficult to explain, but is worth it, since it allows for more PV to be installed than in previous code cycles.

### *705.12(B)(1) Feeders*

An example of a feeder is a conductor that is going from a main service panel to a subpanel.

If we are going to connect to the middle of a feeder, we need to make sure that the conductor is properly protected on the load side of the feeder connection. The reason **we are concerned about the load side of the connection to the feeder rather than the supply side**, is because by adding more supply current with our interactive inverter to the feeder, we are no longer protected by the feeder supply breaker. Before the interactive inverter was added, the feeder supply breaker was the protection for the feeder. However, by adding another current source, we can have the potential for overcurrents if we do not comply with 705.12(B)(1)(a) [Ampacity of feeder] or 705.12(B)(1)(b) [Adding an OCPD] which follow.

***705.12(B)(1)(a) feeder ampacity protection.*** We add the feeder supply breaker plus 125% of the inverter current for this calculation. If the ampacity of the feeder on the load side of the inverter connection can handle the sum of these currents, then the feeder will be safe. If the existing feeder is not large enough, then we can replace that load-side portion of the feeder with a larger feeder. This would rarely ever happen in the field, but the option exists for those that want to use it.

***705.12(B)(1)(b) feeder overcurrent device.*** Another option rather than 705.12(B)(1)(a) is to place an overcurrent protection device on

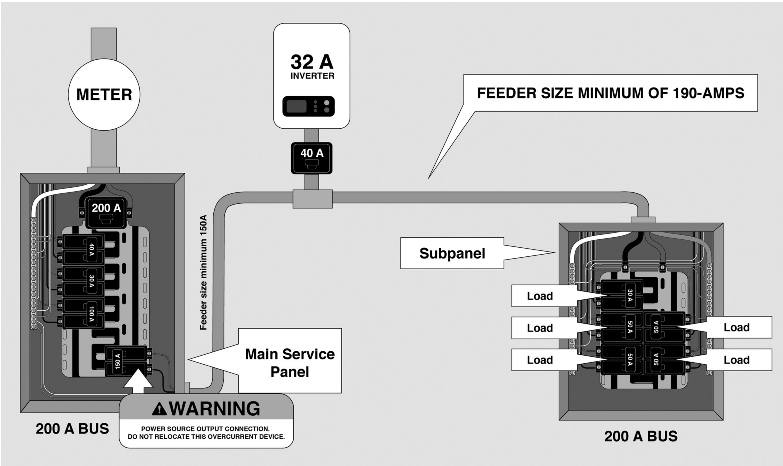


*Figure 9.1* 705.12(B)(1)(a) sufficient feeder ampacity
*Source:* courtesy Kylie Kwiatkowski

the load side of the connection of the interactive inverter to the feeder that is not greater than the ampacity of the feeder.

If we had a 100A feeder, a 100A feeder breaker and a 30A inverter, we could place a 100A breaker on the load side of the connection between the interactive inverter connection to the feeder and the loads.

There have been different interpretations on where this breaker can be placed. The safest place to put the breaker is adjacent to the connection of the inverter circuit to the feeder. This was the intent when this provision was drafted by Bill. Others have the opinion that a "main" breaker in the subpanel will provide this protection. The main reason for putting the breaker adjacent to the PV connection is that no one can argue that taps could be installed between the PV connection and the subpanel that could overcurrent the feeder conductor downstream of the PV connection.

We can best describe how far we can put the ***705.12(B)(1)(b) feeder overcurrent device*** from the connection point to the feeder by using the tap rules we will study in more depth next in **705.12(B)(2) Taps** on page 160. In most cases, we would use the 25-foot tap rule and we could place the ***705.12(B)(1)(b) feeder OCPD*** in the subpanel if it was within 25 feet of the connection point to the feeder. We could also place that ***705.12(B)(1)(b) feeder OCPD*** on that conductor anywhere within 25 feed of the connection point (it does not have to be at the subpanel). This special case of putting the OCPD in the subpanel,

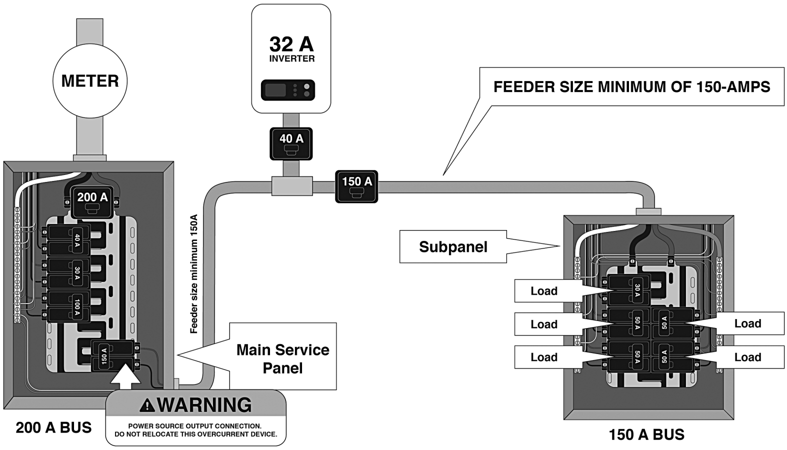


*Figure 9.2* 705.12(B)(1)(b) overcurrent device protecting feeder. Note: If **25-foot tap rule** is applied here, then the OCPD can be located up to 25 ft from inverter–feeder connection point

*Source:* courtesy Kylie Kwiatkowski

rather than directly on the load side of the PV connection assumes the tap rules in 240.21(B) are followed which requires that the tap is in a raceway. Few houses have conduit on any conductors other than their service conductors. There are some who think that they can place the ***705.12(B)(1)(b) feeder OCPD*** as far as they want from the connection point and it is up to the AHJ to decide.

### *705.12(B)(2) Taps*

When we are connecting an inverter to a feeder, we also need to make sure that the conductor going to the feeder from the inverter, and the conductor going from the connection point of the inverter to the feeder (to the subpanel or other electrical equipment) is large enough to have a chance to open up the feeder supply breaker in case of a fault (not overcurrent protection, but fault current protection).

**Solar Tap Rules, merging 705.12(B)(2) and 240.21(B)**

This is complicated, so pay careful attention and read this a few times. Speed reading not allowed here.

We are connecting an extra current source to a feeder, so we need to make sure if we go a long distance that all conductors involved can handle a short circuit and in turn open up that feeder protecting circuit OCPD. We are not just looking at the inverter output circuit, we are also looking at the load side of the point of connection to any overcurrent protection device.

If we have an inverter connected to a feeder, there are two things we should check.

One being the inverter output circuit. If we were applying the 25-foot Tap Rule for instance, we would need to make sure that there is an OCPD within 25 feet of where the inverter is connected to the feeder.

Two being, and applying the 25-foot Tap Rule again, we would need to make sure that any other circuit coming off of that feeder, including the portion of the feed after the connection point has to have OCPD within 25 feet of that connection point.

We should check the Tap Rules in addition to the 705.12(B)(1) Feeder Rules.

For the most part though, it will become obvious to a seasoned PV designer if and when these rules are being followed.

Electricians are familiar with the **tap rules in 240.21(B)** and solar installers are often confused about what a "tap" is since as solar installers we are often and, for the most part, incorrectly calling a supply-side connection a "line-side tap."

In order to apply the **tap rules in 240.21(B)**, we need an overcurrent protection device protecting the feeder that we are tapping into. A **705.11 supply-side connection** does not have any overcurrent protection on the supply side of the connection, thus **cannot follow the tap rules**.

The **705.12(B)(2) tap rules will add the feeder supply breaker to 125% of the inverter current** for this calculation.

There are a number of tap rules, and we will cover the **10-foot tap rule** and the **25-foot tap rule** for this discussion. Other tap rules will be found in 240.21(B).

*10-foot tap rule for solar*:

If the conductor from the connection point to the OCPD is **less than 10 feet**, then the ampacity of that conductor between the connection point and the OCPD can be no less than 10% of (the feeder supply breaker plus 125% of the inverter current).

10-foot Tap Rule Formula:

$$\text{Conductor to OCPD} \geq 0.1 \times [(\text{inverter current} \times 1.25) + \text{feeder supply breaker}]$$

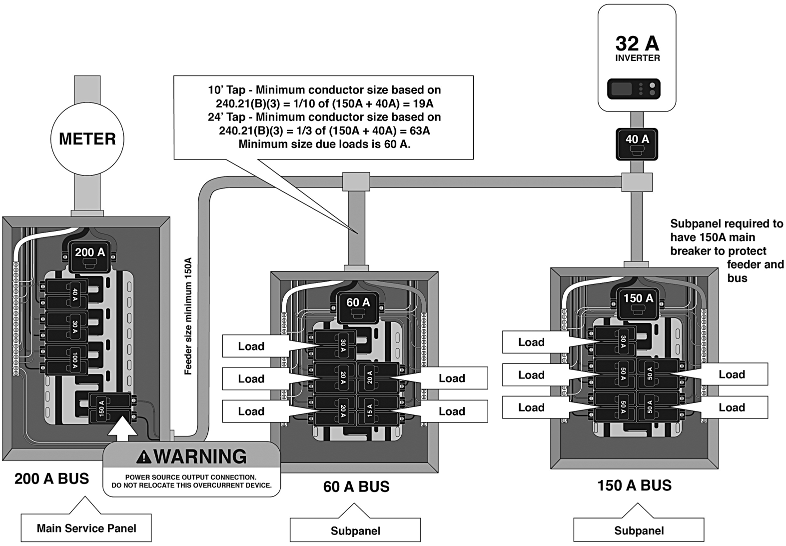


*Figure 9.3* Solar tap rules

*Source:* courtesy Kylie Kwiatkowski

*25-foot tap rule for solar*:

If the conductor from the connection point to the OCPD is **less than 25 feet,** then the ampacity of that conductor between the connection point and the OCPD can be no less than 1/3 of (the feeder supply breaker plus 125% of the inverter current).

$$\text{Conductor to OCPD} \geq 0.33 \times [(\text{inverter current} \times 1.25) + \text{feeder supply breaker}]$$

The reason that the conductor needs to be bigger if the distance is farther is because a long wire has more resistance and is less likely to open up the feeder supply breaker in case of a fault.

Recall that we are sizing the conductor going from the point of connection to the OCPD here. We still would need to apply 705.12(B)(1) to make sure that the feeder itself is protected on the load side of the connection point.

The examples for the tap rules are related to PV connections in this section. However, the very same rules are used for existing or new load taps and the required size of conductors for those taps.

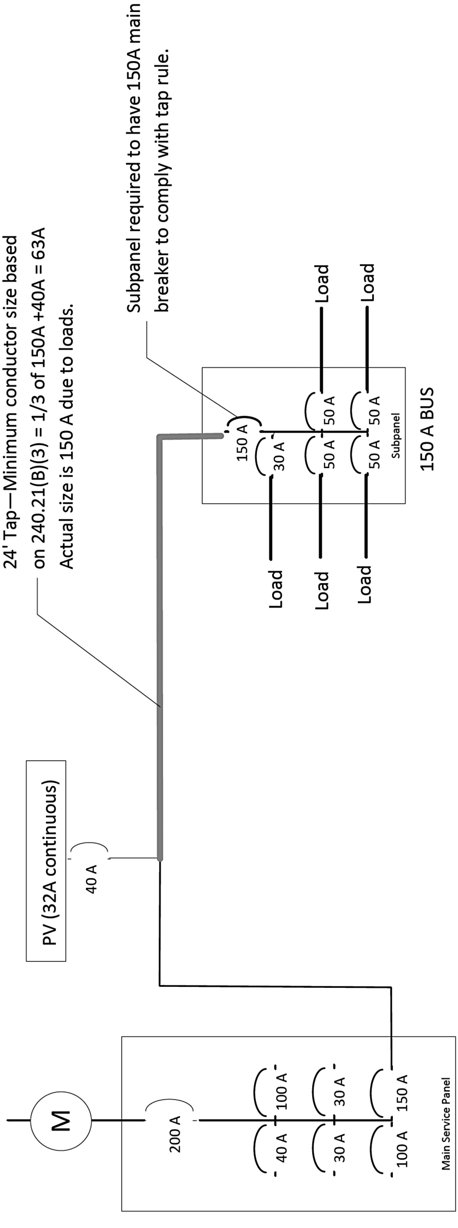


*Figure 9.4* 25-foot tap rule
*Source:* Bill Brooks

## *705.12(B)(3) Busbars*

Every solar installer's favorite way to install solar is on a busbar, since popping in a breaker on a busbar is often the safest and easiest way of installing solar.

Since we have currents coming from different sources on the busbar, we can be creative where we place the solar breakers and often get more out of the busbar than we would think at first glance.

### *705.12(B)(3)(1) 100% OPTION*

As long as 125% of the inverter current plus the main breaker does not exceed the rating of the busbar, we can place the inverter breaker anywhere on the busbar (it does not have to be on the opposite end from the main supply breaker).

For example, if we have a 225A busbar with a 200A main breaker, we can place a 20A solar breaker anywhere we want on the busbar. We can place up to 25A / 1.25 = 20A inverter anywhere we want on the busbar. We can also do the inverse math 25A x 0.8 = 20A. 0.8 is the inverse of 1.25.

Some installers think that the inverter breaker always has to go on the opposite side of the busbar from the main breaker. This is not true as long as 125% of the inverter current plus the main breaker does not exceed the rating of the busbar.

### 705.12(B)(3)(2) 120% OPTION (FORMERLY KNOWN AS 120% RULE)

NOTE: **We are changing the term from 120% "Rule" to 120% "Option" in this version of the book.** That is because so many installers

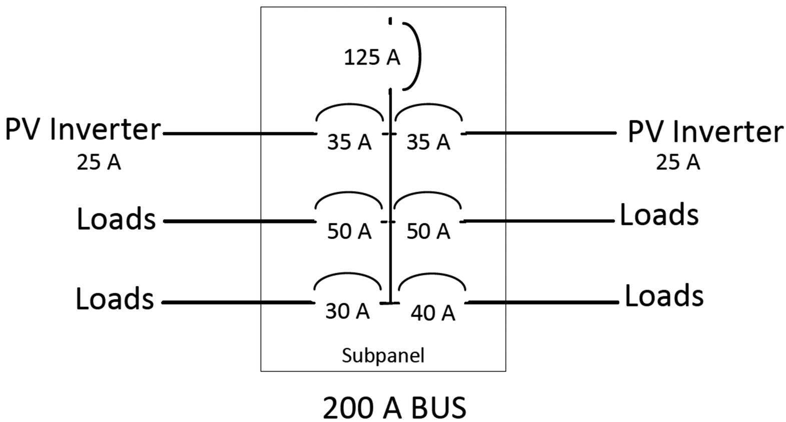


*Figure 9.5* **100% option**
*Source:* Bill Brooks

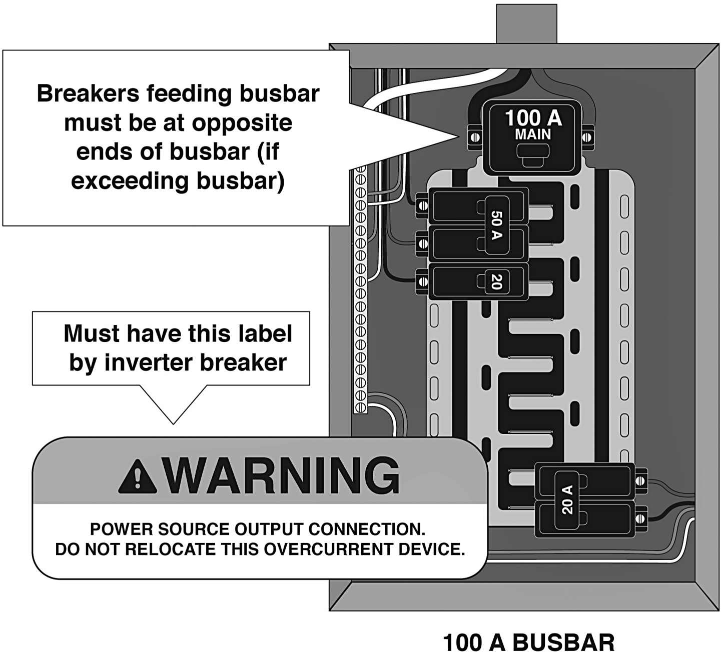


*Figure 9.6* 705.12(B)(3)(2) **120% option**
*Source:* courtesy Kylie Kwiatkowski

are fixated on the 120% restrictions, that it prevents them from using some of the better options that have been available since the 2014 NEC.

$$\text{Busbar} \times 1.2 \geq \text{Main Breaker} + (1.25 \times \text{inverter current})$$

We can exceed the rating of the busbar by up to 20% after adding the main supply breaker plus 125% of the inverter current as long as the supply breaker and the solar breaker are on opposite ends of the busbar. This opposite end clause was once interpreted in such a way that denied center-fed panelboards from being able to apply the **120% option**, but as we will soon see in 705.12(B)(3)(4), this is no longer the case.

Here is the **120% option math** from a few different angles:

$$\text{Main} + (1.25 \times \text{Inv current}) \leq \text{busbar} \times 1.2$$

$$1.25 \times \text{Inv current} \leq (\text{busbar} \times 1.2) - \text{main}$$

$$\text{Inv current} \leq \left(\left(\text{busbar} \times 1.2\right) - \text{main}\right)/1.25 \text{ or}$$

$$\text{Inv current} \leq \left(\left(\text{busbar} \times 1.2\right) - \text{main}\right) \times 0.8 \text{ note:} \left(0.8 = 1/1.25\right)$$

Maximum inverter power formula using **120% option:**

$$\text{grid voltage} \times \left(\left(\left(1.2 \times \text{busbar}\right) - \text{main}\right) \times 0.8\right) = \text{max inverter power}$$

Recall that backfed breakers will have to be located on the **opposite side of the busbar** from the main breaker and that there shall be a label saying the following words **or equivalent**:

Warning:
Power Source Output Connection—
Do Not Relocate This Overcurrent Device.

The reason that we can exceed the busbar rating is because we have currents feeding the busbar coming from different directions, which actually makes it easier on the busbar and prevents busbar "hot-spots" as could happen if the backfeed breaker were put next to the main breaker.

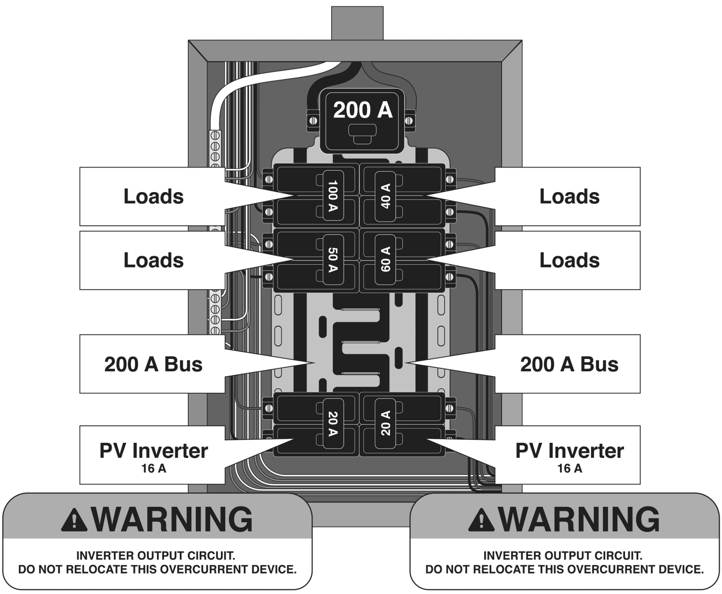


*Figure 9.7* 120% option with multiple solar breakers acceptable
*Source:* courtesy Kylie Kwiatkowski

The **120% option** will take some heat off of the main breaker when power is fed from a spot on the busbar distant from the main breaker.

705.12(B)(3)(3) SUM OF THE BRANCH BREAKERS OPTION

This option was primarily created so that subpanels could be logically used for **ac combiner** panels **without the restrictions of the 120% option**. This is a very simple option that uses the sum of the branch circuit breakers in a panel to protect the busbar of the panel. These branch circuit breakers can be any combination of generation and load breakers. Take note here that this is the only load-side connection that uses the ratings of the circuit breakers and not 125% of inverter current in the calculations.

The easiest way to understand how this rule works is by reading the label required to be installed on the distribution equipment which reads:

WARNING:
THIS EQUIPMENT FED BY MULTIPLE SOURCES.
TOTAL RATING OF ALL OVERCURRENT DEVICES
EXCLUDING MAIN SUPPLY OVERCURRENT DEVICE
SHALL NOT EXCEED AMPACITY OF THE BUSBAR.

In effect, what the "**Sum Option**" is doing is protecting the busbar in reverse, by making sure that the **sum** of all of the breakers on the load side of the busbar protect the busbar.

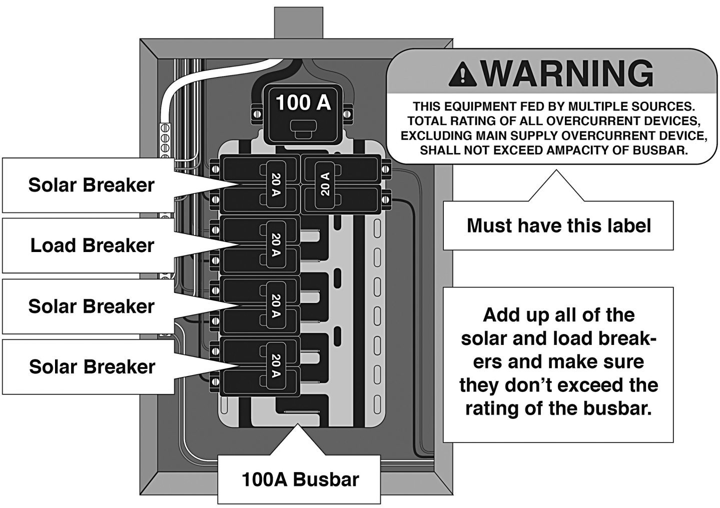


*Figure 9.8* 705.12(B)(3)(3) **Sum Option**

*Source:* courtesy Kylie Kwiatkowski

If you looked in the main service panel in your house, you would likely find that the sum of the branch circuit breakers is much more than the main breaker of busbar is rated for. We just do not turn on everything at once, so the main breaker does not trip.

With the "Sum Rule" we are protecting the busbar by making sure that we do not have too much current going from the inverter breakers toward the busbar. This rule is conservative if we have loads on the busbar.

One application for someone trying to avoid a supply-side connection is to put loads from a main service panel onto a subpanel until you have enough space on your main service panel to apply the "Sum Option" and add more solar. In Hawaii they are famous for getting creative with the Sum Option and they call it the **Hawaiian Tie-In!** Imagine taking a few subpanels and connecting them to an all-in-one meter main and applying the Sum Rule this way.

### Hawaiian Tie-In

There have been some creative and much needed installations done connecting to a feeder or using the Sum Option and we would like to hand it to the islanders for coming up with these. The problem is that it is difficult to make a supply-side

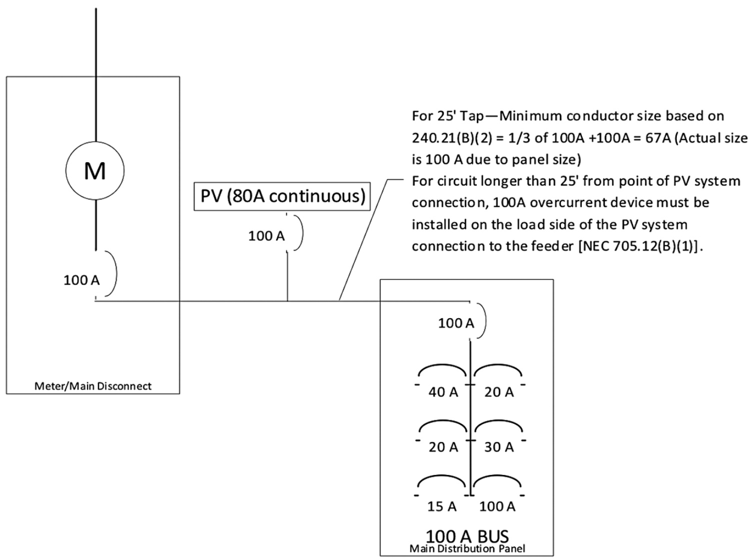


*Figure 9.9* Hawaiian Tie-In option using Sum Option

*Source:* courtesy Bill Brooks

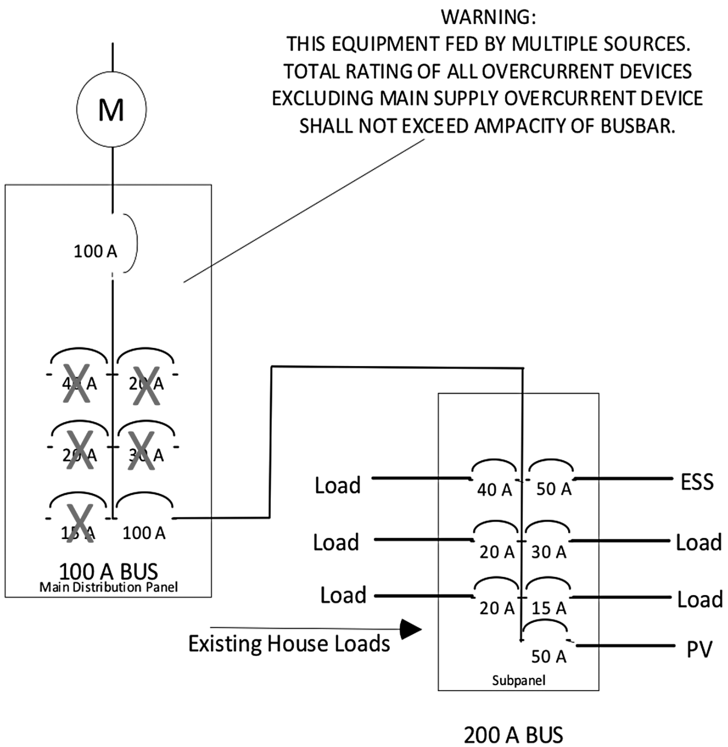


*Figure 9.10* Hawaiian Tie-In Mai Tai option using Sum Option
*Source:* courtesy Bill Brooks

connection with a meter-main combo or an all-in-one meter main panelboard, so instead we can do what you see here in Figures 9.9 and 9.10.

Another good aspect of using this method, is as we add batteries, it can be more advantageous to do a load-side connection. Supply-side batteries can make backup more difficult.

705.12(B)(3)(4) CENTER-FED 120% OPTION FOR DWELLINGS

*705.12(B)(3)(4) center-fed 120% rule* Center-fed panelboards are main service panels or subpanels that are fed *not* from one end, but will have loads connected on both sides of the main breaker.

Millions of dollars were spent on upgrading main service panels, before 2016 when we could not apply the 120% rule to center-fed

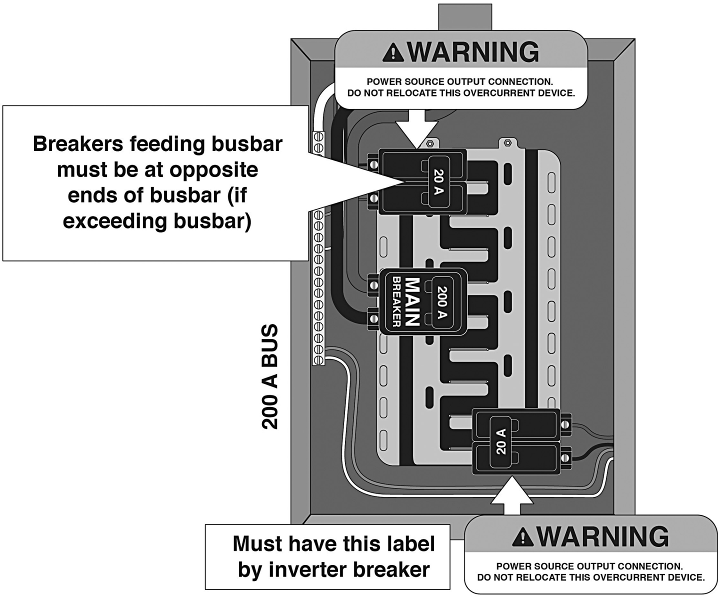


*Figure 9.11* 705.12(B)(3)(4) center-fed 120% option for dwellings
*Source:* courtesy Kylie Kwiatkowski

panelboards until there was a TIA (tentative interim amendment) in the summer of 2016 modifying the 2014 NEC to allow applying the 120% rule to center-fed panelboards.

This TIA means that if you are in some weird place that is still using the 2014 NEC, you can now apply the 120% option to center-fed panelboards on dwellings!

Before the 2020 NEC, the proper way to apply the **120% rule to center-fed** panelboards is to **only connect solar PV to one side of the busbar and not both**. In the 2020 NEC, we now allow it to be on both ends! Total from both ends can still only be 120%—nice try, if you wanted to put a 40-amp PV breaker at both ends of a 200-amp panel—that is not allowed. Stay tuned for 705.13—you will love it.

### 705.12(B)(3)(5) SWITCHGEAR, SWITCHBOARDS AND PANELBOARDS UNDER ENGINEERING SUPERVISION

According to the NEC, there are many things that we can do under **engineering supervision** and connecting to switchgear, switchboards and panelboards is one thing that we can accomplish.

In order to make these connections, which would typically be on commercial buildings, we have to have an **engineer supervise a study of available fault currents and busbar load calculations**.

705.12(B)(3)(6) FEED-THROUGH CONDUCTORS/LUGS

Some panelboards have lugs at the bottom of the busbars. If we are feeding these feed-through lugs we shall treat the feed-through conductors coming off the feed-through lugs as if they were feeders according to **705.12(B)(1) Feeders**. In this case, when applying 705.12(B)(1), we will want to protect the **feed-through conductors/feeders** as feeders with extra currents that come from 125% of inverter current plus the feeder supply breaker. In this case, the feeder supply breaker could be considered the main breaker from the panelboard containing the feed-through lugs and this could end up causing the **feed-though conductors/feeders** to be sized rather large. In this case, we can look at the feed-through conductors to be an extension of the busbar.

Another option is putting overcurrent protection at the supply end of the feed-through conductors/feeders and using the **busbar methods in 705.12(B)(3)**(1) through 705.12(B)(3)(3).

Recall:

705.12(B)(3)(1) is the 100% Option
705.12(B)(3)(2) is the 120% Option
705.12(B)(3)(3) is the Sum Option

Once we have overcurrent protection by the feed-through lugs, then we have a "main breaker" to work from and applying these rules shall be simple. Perhaps with applying the **705.12(B)(3)(3) Sum Option**, we could have a main supply breaker of any size, since we ignore the main supply overcurrent device in our calculations. This is because the **705.12(B)(3)(3) Sum Option protects from overcurrents in reverse** by adding up all of the branch circuit overcurrent protection devices.

### *705.12(C) Marking*

Marking Shall Indicate Presence of Multiple Sources

**Equipment containing a busbar or conductor** that is supplied from multiple sources that contains overcurrent devices shall be marked to indicate that it is being supplied by multiple sources. This is one

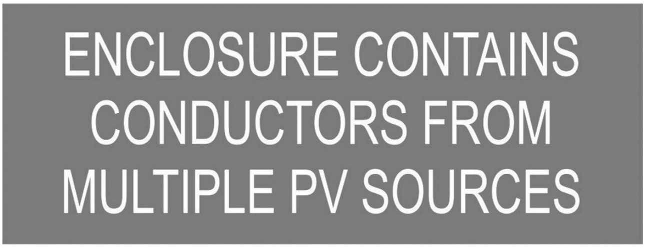


*Figure 9.12* 705.12(C) marking label indicating multiple sources

*Source:* courtesy [www.samedaysolarsigns.com/solarsigns/enclosure-contains-conductors-from-multiple-pv-sources]

instance where the NEC tells us to mark something but does not suggest wording. It is up to you! What do you think the AHJ will say about a clever label?

### *705.12(D) Suitable for Backfeed*

Fused disconnects unless otherwise marked are suitable for backfeed.

Circuit breakers not marked "line" and "load" are suitable for backfeed.

**Circuit breakers that are marked "line" and "load" can be suitable for backfeed if "specifically rated."**

Discussion: Circuit breakers are usually thermally activated, so they cannot tell the difference which way the currents are coming from. In fact, with alternating current, we have currents going both directions at about the speed of light, so we could say that everything is backfed in a way for some fraction of a fraction of a second. Did you know that, in about 1/60th of a second, electricity and light can cross the USA?

Some GFCI breakers are not suitable for backfeed.

### *705.12(E) Fastening*

**Interactive inverter circuit** snap-in circuit breaker connections are **not required to use an additional fastener** to hold them to the busbar.

Discussion: An interactive inverter circuit will immediately stop producing voltage after it is no longer connected to a primary power source (utility). Since we have this anti-islanding capability, we are not in danger of having an energized breaker popping loose and dangling around with voltage with an interactive inverter, as you would with a stand-alone inverter output circuit.

If an inspector requires you to fasten a breaker for an interactive inverter circuit, politely introduce them to 705.12(E).

## 705.13 Power Control Systems (PCS)

This is a **big new deal** in the 2020 NEC!

PCS needs to be listed and evaluated to control the output of power production sources, energy storage systems and other equipment. The PCS will limit currents on busbars and conductors supplied by the PCS.

This means that we can use electronics (think of that trendy acronym AI) to control the currents flowing around the circuits and busbars. Now you can theoretically connect PV, an energy storage system (ESS), a bidirectional electric vehicle and control loads so that you can get 400A while having a 100A service! Perhaps you need a fast charge on your new EV, so you take 200A from your ESS, 50A from your PV, 50A from your utility and another 100A from your old EV to get 400A while only drawing 50A from the utility.

The PCS shall control the currents to within 705.13(A) through (E).

### *705.13(A) Monitoring (PCS)*

PCS will monitor currents within PCS and busbars and conductors.

On the load side of the service disconnecting means **any currents not monitored** by the PCS shall comply with **705.12 Load-Side Source Connections**.

If PCS is connected on the supply side of the service disconnecting means as with **705.11 Supply-Side Source Connections**, then PCS will monitor currents on service conductors to prevent overload of service conductors.

### *705.13(B) Settings (PCS)*

The sum of all PCS-controlled currents plus all monitored currents from other sources of supply shall not exceed the ampacity of any conductor or busbar supplied by power production sources.

This is a basic rule that ensures that the settings of the PCS are capable of monitoring and controlling the power sources to a subpanel or conductor within the current ratings or ampacity of the equipment.

Where a PCS does not have control of all the sources feeding a subpanel (e.g., the utility feed), then the settings on the PCS must prevent more than the rated current to be fed to the subpanel. Therefore, if a 100-amp panel is being fed by PV and ESS through a PCS and the current begins to exceed the ratings of the 100-amp panel, then the PCS would have to reduce power which would cause the 100-amp feeder breaker from the utility to trip. This scenario would only happen in an overloaded panel.

### *705.13(C) Overcurrent Protection (PCS)*

The PCS shall function as an OCPD or work with other OCPDs.

> 705.13(C) Informational Note: A PCS can be listed to provide overcurrent protection. You can think of a PCS as a high tech, futuristic OCPD. Just do not call it an OCPD yet.

### *705.13(D) Single Power Source Rating (PCS)*

The rating of an OCPD for a device for a single power source controlled by a PCS shall not exceed the rating of the busbar or conductor.

This means that, although a PCS may be controlling the current, we can never feed more power to a busbar than its current rating. Also, we still need OCPD backup to make sure that the busbar or conductor is protected if the PCS were to somehow malfunction and try to supply more power.

### *705.13(E) Access to Settings (PCS)*

Access only to **qualified personnel** and in accordance with:

**240.6(C) Restricted Access Adjustable-Trip Circuit Breakers.**

Restricted access settings mean that you can have an ampere rating that is equal to the adjusted current setting (long-time pickup setting).

The long-time setting is used for continuous currents and the higher shorter setting are for high current short circuits.

**240.6(C)** says that **restricted access** must be **accomplished by one of the 4 following** methods:

240.6(C)(1) Located behind removable and **sealable covers** over adjusting means


*Figure 9.13* Adjustable-trip circuit breaker

*Source:* courtesy Eaton

240.6(C)(2) Located behind **bolted** equipment enclosure doors
240.6(C)(3) Located behind **locked doors** accessible only to qualified personnel
240.6(C)(4) **Password protected** accessible only to qualified personnel

In other words, when we are using a PCS to prevent overcurrents, we need to make sure that some burger flipper does not start messing with the settings to get the deep fryer working after it keeps tripping the breaker. An analogy would be how people in the 1970s used to put a penny under the fuse since the fuse kept blowing. It could get hot—and we are not talking global warming here, we are talking about flaming 911 hot!

## Diagrams Using 705.13 Power Control Systems

Here are a few ways to take advantage of our new PCS piece of Code.

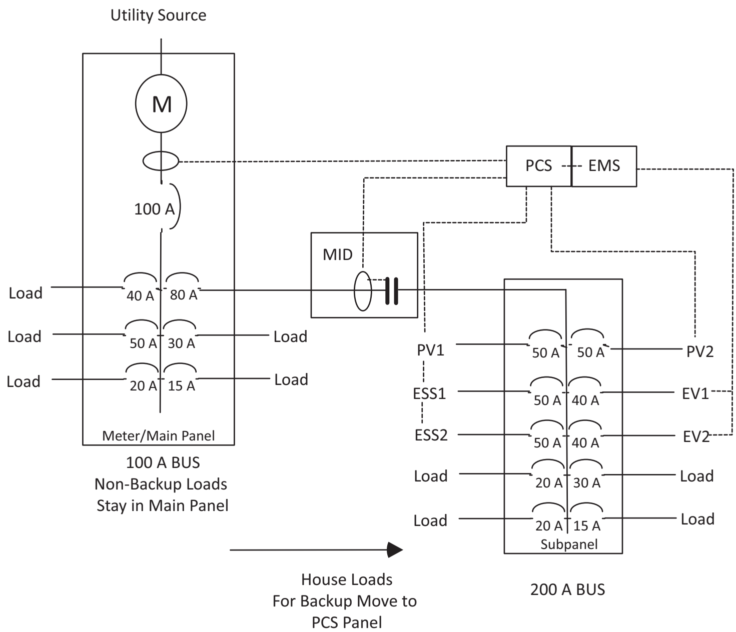


*Figure 9.14* Backup Power using Microgrid Interconnect Device (MID) Downstream of Main

*Source:* courtesy Bill Brooks

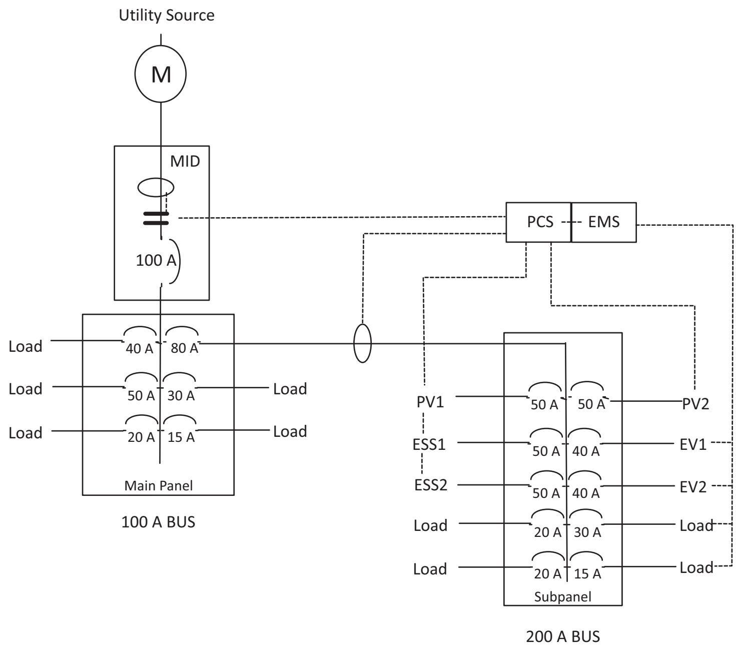


*Figure 9.15* Backup Power using Microgrid Interconnect Device (MID) at the Service Disconnect

*Source:* courtesy Bill Brooks

## 705.14 Output Characteristics

The output of a power production source shall be compatible with the voltage, wave shape and frequency with which it is connected.

Discussion: Interactive inverters installed in the US must be listed to UL 1741 and will satisfy 705.14 every time.

There is an informational note here that says **being compatible with the wave shape does not mean matching the wave shape.** Sometimes we will want to modify the wave shape in order to condition the power and make it better. For instance, many utility scale inverters are required to make reactive power, which means making a wave shape different than what is on the grid. Many smaller scale PV systems, such as the one on your house will make perfect power factor to a grid that has an imperfect wave form.

**Wave Shaping for a Better Grid with Inverters That Work at Night**

There are some inverters that are being modified to condition the power quality on the grid even at night when there is no solar energy available. Since we are putting the solar inverters on the grid, it does not take a lot to modify the inverters to condition the grid. All we need is the policy in place to make it feasible and in the UK an organization called Lightsource BP, is doing this. Get ready for more in the future, especially when there is energy storage involved.

Reference: www.greentechmedia.com/articles/read/lightsource-bp-makes-solar-pay-at-night

## 705.16 Interrupting and Short-Circuit Rating

With a PV interactive inverter, the danger of short circuits comes from the utility, rather than the inverter. There are other types of equipment feeding the grid such as generators with rotating machinery that can cause higher fault currents than inverters do.

***Authors' note:***

> Much of the information in Article 705 following 705.16 is also covered more specifically for PV systems in Article 690. For instance, 690.31 covers disconnecting means in more detail than Article 705. Since this book is geared toward solar PV systems, we will decrease the confusion by leaving out redundancies.
>
> Since we will be using UL 1741-listed inverters there are also parts of Article 705 which are satisfied by using listed inverters.
>
> We will leave out portions or go into less detail of Article 705 that are not covered in detail in Article 690.

## 705.20 Disconnecting Means, Source

Ungrounded conductors from power production sources must have a means for disconnecting. This applies to most anything in the NEC and was already covered in Article 690.

## 705.25 Wiring Methods

The wiring methods here are duplicative of what we see in 690.31 Wiring Methods and have already covered beginning on page 90 of this book.

## 705.28 Circuit Sizing and Current

Circuit sizing and current for PV systems is covered in **690.8 Circuit Sizing and Current** and covered beginning on page 33 of this book. Circuit sizing and current for PV systems and other loads or power sources throughout the Code follows the same rules and theory for the most part.

## 705.30 Overcurrent Protection

This lines up very closely with **690.9 Overcurrent Protection** on page 48 of this book and **Article 240 Overcurrent Protection**. You can also refer to Chapter 12 Wire Sizing in this book to see how to select overcurrent protection devices. 705.30 reminds us that **240.4(B) Overcurrent Devices Rated 800A or Less** allows us (with exceptions) to round up the OCPD to next higher ampacity above the conductor's ampacity if the resulting OCPD is below 800A. This is the step in wire sizing that is not completely logical at face value and we have an example in Chapter 12 where the ampacity of the OCPD is greater than the ampacity of the conductor that it is protecting on page 228.

**240.4(C) Overcurrent Devices Rated over 800A** tells us the opposite of 240.4(B), that we cannot have an overcurrent device that is greater than the conductor ampacity it is protecting.

## 705.32 Ground-Fault Protection

Interactive systems shall be installed on the **supply side of ground-fault protection equipment**.

## 705.32 Exception (connecting to the load side of ground-fault protection)

If there is ground-fault protection from all ground-fault current sources, then it is acceptable to connect to the load side of ground-fault protection equipment.

Discussion: It is difficult to protect against ground-faults if there are current sources on each side of ground-fault protection. Many solar professionals do not bother trying to connect on the load side of ground-fault protection. All new services of 1000A and larger, built after 2002, are required to include ground-fault protection. Most manufacturers of these systems are accustomed to providing documentation that their detection circuits can handle backfed power from a generator (like a PV inverter) on the load side of the ground-fault protector.

## 705.40 Loss of Primary Power Source

We are not allowed to feed the grid, when the grid (primary power source) is down!

Discussion: UL 1741 Inverters are safe with regards to not feeding the grid when the grid is down, AKA, anti-islanding.

Since Article 705 includes other sources of power being connected to the grid, including big diesel generators, there is a provision in 705 to require conductors to be disconnected automatically from the primary power source.

Interactive inverters, however, will stay connected and monitor the grid-connection and export power five minutes after a good clean grid power source is indicated. Interactive inverters cannot feed the grid when the grid is down. No exceptions. It cannot happen and it is certified to prevent such an occurrence.

Multimodal inverters can power loads when the grid is down and this is done with a separate output circuit coming out of the inverter that is not connected to the utility grid. Multimodal inverters have multiple (usually two) outputs that operate in different modes, such as an interactive mode output and a stand-alone (island) mode output. Some multimode inverters now have a single output and perform anti-islanding with a separate microgrid interconnect device (MID). See Island Mode Definition on page 206 in Chapter 11, or in Article 100 Definitions, which is new in 2020 NEC.

Chuck Norris Exception: When Chuck Norris's PV system disconnects from the grid, the grid goes into island mode. Source: www.chucknorrisfacts.net

### *Discussion*

According to UL 1741, listed interactive inverters will stop exporting power when one phase is down.

Other than interactive inverters must disconnect all phases when a phase is down.

It is not mentioned here in 705.40, but it is acceptable to have single-phase inverters connected to a 3-phase service and if a phase is down that is not connected to a single-phase inverter, then the single-phase inverter is allowed to export power on the good phases.

Often single-phase microinverters are connected to 3-phase services via a cable that rotates the phases by connecting different inverters to different phases.

## 705.45 Unbalanced Interconnections

- 705.45(A) Single Phase

  Single-phase inverters (and ac modules) shall be connected to 3-phase systems in order to limit unbalanced voltages to not more than 3%.

  Discussion: Just as loads can be strategically placed to limit unbalances on 3-phase busbars, so can single-phase inverters, but with reverse logic as with loads. If a building is out of balance and **inverters are placed on the phases with lower voltage,** which are the most heavily loaded phases, the inverters will reduce the utility load on those phases and help raise the voltage by sending power in a reverse direction. The result is that the imbalance of the service is reduced and the neutral current also goes down. Inverters cause voltage rise on a backfed busbar.
- 705.45(B) Three Phase

  Three-phase inverters (and ac modules) shall have all phases de-energize upon unbalanced voltage in a single phase unless the inverter is designed so that significant unbalances will not result.

  Discussion: UL 1741-listed inverters will automatically disconnect with large imbalances. There are new inverter standards, which have been adopted in California at the time of the writing of this book, such as UL 1741 SA, which will change the way inverters help support the utility grid and other standards that may have been released while you were reading this book. These new developing standards address a new level of saturation of distributed generation on the grid and can differ based upon where you live. Exciting times!

It is conceivable that someone could invent an inverter that could balance the voltages of different phases by injecting power where there is a phase with less voltage. This could even happen at night.

## Part II Microgrid Systems (formerly 705 Part IV in the 2017 NEC)

**Article 705, Interconnected Power Production Sources is by nature dealing with alternating current**, since our electric distribution systems are based on alternating current. The microgrid systems covered here in Article 705 are **ac microgrids**. These microgrids covered in Article 705 have the ability to disconnect from the utility and operate in stand-alone (island) mode. **Many solar professionals call smaller ac microgrids ac coupled systems.**

**Dc microgrids are covered in Article 712.** We discuss 712 on Page 199 in more depth.

### 705.50 System Operation (Microgrid Systems)

Microgrid systems are permitted to disconnect from the primary power source (grid) and operate separately from the grid (island mode).

### 705.60 Primary Power Source Connection (Microgrid Systems)

Connections to primary power sources (grid) shall comply with:

- **705.11 Supply-Side Source Connections (page 151)**
- **705.12 Load-Side Source Connections (page 155)**
- **705.13 Power Control Systems (page 173)**

### 705.65 Reconnection to Primary Power Source (Microgrid Systems)

Reconnection shall be provided with necessary equipment to establish a synchronous connection. Interactive and multimode inverters all provide this service.

### 705.70 Microgrid Interconnection Devices (MID) (Microgrid Systems)

See **705.2 Definitions** in NEC or on page 149 of this book for the definition of MID.

UL 1741-listed interactive and multimode inverters provide this service. This is about the ability of a microgrid to automatically anti-island and disconnect from the grid whenever the grid goes down or is not up to the specifications of voltage, current and waveform.

End of chapter thoughts:

At this point, we have covered the meat and bones* of PV and the NEC with Articles 690 and 705. Rather than going **meat-and-bones level** and creating a book that would be too heavy to carry and cover many things that are not specific to PV systems, we will go **broth level** on the rest of the Code.

*Solar planet-loving vegetarians: have no worries, the meat and bones used to make this book are actually soy-based, simulated meat products. Yum!

# 10 Storage Articles

As PV systems grow at an exponential pace and head toward the goal of someday saturating the grid, energy storage systems are a natural fit for bottling sunlight for nighttime photon usage (aka midnight solar).

This chapter will cover:

Article 480 Storage Batteries
Article 706 Energy Storage Systems
Article 710 Stand-Alone Systems
Article 712 Direct-Current Microgrids

With energy storage being in vogue at all of the solar conferences this decade (or millennia), we will take a ride on the **Article 480 Storage Batteries** train and see where that track crosses paths with the relatively new **Article 706 Energy Storage Systems** express at an intersection with **Article 710 Stand-Alone Systems** (formerly Section 690.10). An honorable mention will go to another article, Article **712 Direct-Current Microgrids**.

## Batteries and Energy Storage

In the 2014 NEC and earlier, **Article 480 Storage Batteries** was used along with **Section 690.10 Stand-Alone Systems** and **690 Part VIII Storage Batteries** for designing and installing energy storage for stand-alone PV systems. Much of that order was changed in the 2017 NEC and stays that way in the 2020 NEC. As usual, much of the changes are with the organization of the NEC, rather than changing the installation drastically.

When work started on Article 706, the intention was to take the information from Articles 480 and 690 and get rid of those sections. Somewhere along the way, the lead-acid folks decided they still needed Article 480 even though it is in the wrong chapter of the NEC and is no longer needed. The focus for field installations should be on Article 706 since storage batteries are never used by themselves—they are always part of an energy storage system.

Scopes of Article 480 Storage Batteries and Article 706 Energy Storage Systems:

- Article 480 scope applies to all stationary installations of storage batteries
- Article 706 scope applies to all permanently installed energy storage systems above 1kWh

As we can imagine, the scopes cross paths and both articles will need to be considered in battery systems with stored energy above 1kWh.

Article 480 Storage Batteries has been in the NEC longer than we have been alive (Thomas Edison was in his prime) and Article 706 Energy Storage Systems is a Code-cycle old. As you read Article 480, you will realize that much of the material is related to good old time-tested and reliable (and sweet-tasting) lead-acid battery technologies.

As we can see by reading Article 706, it focuses more on new modern technologies including, but not limited to, chemical batteries. Article 706 will cover the higher voltage lithium-derivative battery modules that are being sold, flywheel storage, capacitor energy storage and compressed air storage. Perhaps someday Article 480 will go away as it was originally planned.

Article 706 covers the energy storage "**system**," while Article 480 covers the batteries (really only lead-acid and nickel-cadmium batteries). In general, it is best to simply ignore Article 480 and focus on Article 706.

When designing an energy storage system with storage batteries, we should pay close attention to Article 706. We will notice that there are many reoccurring themes in this article and within the material in Articles 690 and 705 with regards to having separate energy sources with the ability to operate in parallel and the requirements of disconnecting systems from each other.

An outline of noteworthy NEC **energy storage articles, parts and sections follows**. *Italics are author comments*.

## Article 480 Storage Batteries

### *480.1 Scope*

Applies to all stationary applications of storage batteries.

*This means that Article 706 does not overrule 480 (another possibility for contradictions in the NEC).*

**480.2 Definitions:**

**Nominal Voltage (Battery or Cell)**
Value assigned for convenient designation (nominal is in name only).
Informational Note:
Nominal voltages for different chemistries are listed as:

| | |
|---|---|
| Lead-acid | 2V/cell |
| Alkali | 1.2V/cell |
| Lithium | 3.6 to 3.8V/cell |

*It is a race between lead-acid and lithium that lead-acid has been winning since as early as 250 BC according to some sources. It looks as if that is changing with lithium battery technology going down in price and up in quality. As you can see, there is a range for the lithium battery nominal voltage. Some say that this is because the battery manufacturers have an incentive to increase the nominal voltage, so that when they multiply it by the Ah, they get more power on paper. Additionally, there are many different lithium technologies that do have different characteristics.*

**Storage Battery (Battery)**
A single or group of rechargeable cells connected together electrically in series, in parallel, or in a combination of both, and composed of lead-acid, nickel cadmium or other electrochemical types.

***480.3 Equipment***

Storage batteries and equipment shall be listed, with the exception of lead-acid batteries.

*Interesting how we do not have to list lead-acid batteries.*

*480.7(A) Disconnecting Means (in 480.7 Disconnect Methods)*

Disconnecting means required for stationary battery system ungrounded conductors with voltage over 60V.

*Apparently, battery systems below 60V are not required to have disconnects. This was a last-minute change to the 2017 NEC and should not be followed as it creates very real safety hazards. This is another reason to disregard Article 480 in general at this point. Energy storage systems however are required to have disconnecting means according to* ***706.15(A) ESS Disconnecting Means****, so it would be a good idea to have a disconnecting means.*

*480.7(B) Emergency Disconnect*

One- and two-family dwellings with a stationary battery system shall have a disconnect or remote-controlled disconnect outside of the building at a readily accessible location that is labeled "EMERGENCY DISCONNECT."

Perhaps this new in the 2020 NEC requirement for an emergency disconnect is the rapid shutdown version of the battery system. When batteries/energy storage were taken out of 690 in the 2017 NEC, rapid shutdown was taken out of the requirements as related to energy storage systems/batteries. Now we have some way so that the firefighters can know there are no live conductors going through the building that are energized from batteries (except, of course, the wires that had to come out to this disconnect—unintended hazard).

*480.7(F) Notification*

Marking shall include:

(1) Nominal battery voltage
(2) Available fault current (available from manufacturer)
(3) Arc-flash label
(4) Date short-circuit current calculation performed

Points (2), (3) and (4) are not required on one and two-family dwellings. Only nominal battery voltage is required on one- and two-family dwellings

### *480.10 Battery Locations*

480.10(A) Ventilation

VENTILATION APPROPRIATE TO BATTERY TECHNOLOGY

Lead-acid and nickel-cadmium batteries can create explosive hydrogen gasses.

*Lithium batteries do not require ventilation as some inspectors once required and since 480 used to call for it. Lithium batteries do not release hydrogen when overcharged, like lead-acid batteries do. Electrolysis is a way of making hydrogen with electricity. Water molecules are split into hydrogen and oxygen.* ***If you stick a positive and a negative electrode into water, hydrogen will come off of the negative and oxygen will come off of the positive.***

*480.10(B) Live Parts*

Live parts shall be guarded in accordance with **Section 110.27 Guarding of Live Parts**.

*480.10(C) Spaces About Battery Systems*

Spaces around batteries shall comply with **Section 110.26 Spaces about Electrical Equipment** and **110.34 Work Space and Guarding**.

For battery racks, there shall be a 1-inch space between a cell container and any wall or structure on a side not requiring access for maintenance.

*This was on a national certification exam, so it must be important.*

### *480.13 Ground-Fault Detection*

Battery circuits over 100V between conductors or to ground shall be permitted to work with ungrounded conductors, if there is ground fault detection and interruption.

*This means that we are not required to have a grounded conductor.*

## Article 706 Energy Storage Systems

### *706.1 Scope*

Article 706 applies to permanently installed energy storage systems over 1kWh.

*In the 2017 NEC, the scope of Article 706 was systems that were over 50Vac or 60Vdc. Now in the 2020 NEC we have switched from voltage to energy for the scope. It is also interesting for the scope they also use the units of 3.6MJ, which equals 1kWh. A joule is a watt second, so, since there are 3,600 seconds in an hour, 3.6 million joules = 1 kWh. You do not see as many people using joules in this industry as you do in physics classes. People with megajoules are rich and flashy dressers.*

### *706.2 Definitions*

Diversion Charge Controller definition:

> Equipment that will divert power away from an ESS to loads or the utility.
>
> *Typically, when ESSs are charged, rather than wasting potential PV power, we can send it somewhere else. This can also happen*

*during an absorption charge where some of the power goes to the battery, but the rest goes to the diversion load or utility. When we charge batteries, a bulk charge is the fast charge where we typically give it all we have and then we slow down the charge to the absorption charge to let the battery slowly take in the last bit of energy. When people are fast-charging their cars on a long trip, they will typically only charge 80% or so with the bulk charge, rather than waiting around for a longer time to get that last 20%. When you charge the batteries on your building, you will also have a bulk charge and an absorption charge. A float charge is like a trickle charge just to keep the batteries topped off. When you are driving your car, you are usually just giving the starter battery a float charge, since the battery is usually fully charged.*

Energy Storage System (ESS) definition:

> "One or more components assembled together capable of storing energy and providing electrical energy into the premises wiring system or an electric power production and distribution network."
>
> *ESS(s) can include, but are not limited to,* ***batteries, capacitors and kinetic energy devices*** *(e.g.,* ***flywheels and compressed air****). These systems* ***can include inverters and converters*** *to change stored energy into electrical energy.*

Flow battery definition:

> "An energy storage component **similar to a fuel** cell that stores its active materials in the form of **two electrolytes external to the reactor interface**. When in use, the electrolytes are transferred between reactor and storage tanks."

*Two popular types of flow batteries are zinc bromine and vanadium redox. Sometimes they are referred to as pumped electrolyte energy storage systems.*

### *706.4 System Requirements (marking and labeling)*

ESS shall be provided with a nameplate that is plainly visible and includes the following:

(1) ESS Manufacturer's name or identifying information
(2) Frequency
(3) Number of phases (ac only of course)

(4) Rating in kW or kVA
(5) Available fault current at ESS output terminals
(6) Max output and input current at terminals
(7) Max output and input voltage at terminals
(8) Utility interactive capability

*As we can see here, all of the markings are not always required, since it is possible to have a dc energy storage system which would have no frequency or number of phases. It is also interesting to note that the power characteristics are required, but there are no energy characteristics required. It is also nice to see that we do not have to calculate Ah! Now, when someone talks about Ah, you know they are trying to say that they have been around for a while.*

### *706.5 Listing*

ESS have to be listed!

### *706.6 Multiple Systems*

Multiple ESS can be on a single building or structure.

### *706.7 Maintenance*

ESS need to be maintained according to manufacturer's requirements and industry standards with written records kept.

### *706.8 Storage Batteries*

Storage batteries not associated with an ESS shall comply with Article 480.

*We may be able to infer here that if the storage batteries are associated with the ESS, then then 480 cannot be used. The poor telecom folks that thought they were getting away with not having to comply with 706 are going to have a rude awakening. You can't have storage batteries without it being an energy storage system unless you use the storage batteries as sculptures rather than energy storage devices.*

### *706.9 Maximum Voltage*

The maximum voltage is the rated input and output voltages on the nameplate or listing of the ESS.

### *706.15 Disconnecting Means*

Disconnecting means required for all ungrounded conductors and may be within the ESS.

*706.15(A) ESS Disconnecting Means*

(1) Readily accessible
(2) In sight of ESS
   - If not practical to be within sight, then as close as possible and marked
(3) Shall be lockable in the open position *(think lockout-tagout)*

In one- and two-family dwellings, the disconnecting means or a remote-disconnecting means shall be in a readily accessible location outside the building. *This is good for firefighters*!

*706.15(C) Notification and Marking*

ESS disconnecting means shall indicate whether on or off and be marked “ENERGY STORAGE SYSTEM DISCONNECT.”

Disconnecting means shall also be marked to indicate:

(1) Nominal ESS voltage
(2) Available fault current
(3) Arc-flash label
(4) Date calculation performed

One- and two-family dwellings can omit points (2) through (4), *so they only need nominal voltage*.

- Battery equipment suppliers can provide fault current information
- NFPA 70E Standards for Electrical Safety in the Workplace has requirements for arc-flash labels
  - *Unlike PV, which is current-limited, ESSs can have excessive short-circuit currents which can be more dangerous with regards to arc-flashes*

If the line and load terminals of the disconnect may be energized in the open position, then we need this familiar label:

WARNING
ELECTRIC SHOCK HAZARD
TERMINALS ON THE LINE AND LOAD
SIDES MAY BE ENERGIZED IN THE OPEN POSITION

*706.15(D) Partitions Between Components*

Where circuits from the terminals of an ESS go through a wall, floor or ceiling, then a readily accessible disconnect shall be provided within sight of the ESS.

***706.16 Connection to Energy Sources***

706.16 says to comply with all of 706.16(A) through (F) below

(A) **Source Disconnect—**If a disconnect has multiple sources, then it shall shut off all sources when in the off position.
(B) **Identified Interactive Equipment—**If we operate in parallel to ac sources, then equipment shall be listed and identified as interactive.
(C) **Loss of Interactive System Power—**If loss of primary power source, then interactive inverter circuit shall anti-island as described in 705.40 Loss of Primary Power Source (page 180).
(D) **Unbalanced Interconnections—**If unbalanced interconnection, then shall comply with **705.45 Unbalanced Interconnections** (page 181).
(E) **Other Energy Sources—**If connected to other energy sources, then shall be in accordance with:
- 705.12 Interconnected Power Production Sources
- 712 Part III Disconnecting Means (712 is Dc Microgrids)
- 712 Part VI Protection

(F) **Stand-Alone Operation—**If the ESS can operate as stand-alone, then we follow **710.15 General (710 is Stand-Alone Systems)**

***706.20 General (of ESS)***

We will summarize these requirements in 706.20 below.

*706.20(A) Ventilation*

Ventilation shall be appropriate for battery technology (this repeats Article 480). Ventilation can be done according to manufacturer's instructions.

*706.20(B) Dwelling Units*

An ESS shall not exceed 100V between conductors or to ground, unless **during routine maintenance live parts are not accessible and then 600Vdc shall be acceptable.**

*Many packaged ESS have voltages over 100V and have live parts that are not accessible during routine maintenance, which are hidden in the ESS. Lithium-ion batteries cannot be maintained so there is no reason to open a lithium ESS—unless you watched a YouTube video that taught you how to make your own Tesla Powerwall.*

*706.20(C) Spaces about ESS*

706.20(C)(1) GENERAL

Repeats Article 480.10(C) in saying **Section 110.26 Spaces about Electrical Equipment** and **110.34 Work Space and Guarding.**

706.20(C)(2) SPACE BETWEEN COMPONENTS

Spacing is done in accordance with manufacturer's instructions. *After all it was tested and listed that way.*

### *706.21 Directory (Identification of Power Sources)*

706.21(A) Facilities with Utility Services and ESS

Plaques in accordance with **705.10 Identification of Power Sources** (Interconnected Power Production Sources page 147) and **712.10 Directory** (Dc Microgrid page 199).

*706.21(B) Facilities with Stand-Alone Systems*

Plaques in accordance with **710.10 Identification of Power Sources** (Stand-Alone Systems page 195).

## 706 Part V Circuit Requirements

The circuit requirements are very much the same throughout the NEC, especially when calculating a wire size for a renewable energy system.

Here are a few things to take note of regarding current and an ESS.

- **706.30(A)(1) Nameplate-Rated Circuit Current**—Oftentimes an ESS will charge and discharge through the same conductors. If the charge and discharge rated currents are different, the greater current shall be used in wire sizing—makes sense.
- **706.30(A)(3) Inverter Input Circuit Current**—If the input of an inverter is connected to a battery, then the battery voltage will go up and down depending on the state of charge of the battery and the load put on the battery. As it used to say in Article 690, we still consider the **lowest voltage to be the highest current**. We will discuss this further when we see it again soon on page 195 as we cover **Article 710 Stand-Alone Systems**.
- **706.33(B)(1) Sole Means of Regulating Charge**—We cannot rely solely upon a diversion charge controller to control a charge. If that diversion load would break, then we would have nothing to prevent a perhaps dangerous overcharging of the battery.
- **706.33(B)(2) Circuits with Diversion Charge Controller and Diversion Load** we need to have:
    - Current of diversion load ≤ current rating of diversion load charge controller
    - Voltage rating of the diversion load > maximum ESS voltage
    - Power of diversion load must be ≥ 150% power of charging source
    - Ampacity diversion load circuit ≥ 150% max current diversion charge controller
    - OCPD diversion load circuit ≥ 150% max current diversion charge controller

If the diversion load is the utility, then we do not need to follow 706.33(B)(2) according to **706.33(B)(3) ESS Using Interactive Inverters** (too bad, I was hoping to use this to control the big bad utility company).

## 706 Part V Flow Batteries of Energy Storage Systems

- Flow batteries use pumps to move electrolyte
- 706.40 General (***Flow Batteries***)
- *Unless otherwise directed by Article 706*, **flow batteries shall comply with the provisions of Article 692 Fuel Cell Systems**. *A flow battery is like a fuel cell in many ways.*

## 706 Part VI Other Energy Storage Technologies

Part VI says to follow the Code!

## Article 710 Stand-Alone Systems

In the 2014 NEC, this material was covered in 690.10. Since then, the NEC has separated energy storage systems from PV systems.

### *710.1 Scope*

This article covers electric power production sources operating in island mode and not connected to the grid. These systems can be an isolated microgrid or interactive with other sources.

**Stand-alone mode** has been officially changed to **island mode** in the 2020 NEC at the insistence of the islanders in Hawaii. They deserve it, given how often the power goes out there.

Multimode inverters can operate in island mode or interactive mode, but if a multimode is never connected to the grid, then it would only operate in island mode.

### *710.10 Identification of Power Sources*

A plaque or directory will be at a service equipment location or an approved visible location and shall show each power source's disconnecting means. A common theme throughout the Code, if there are multiple source locations, then each location must indicate where the other locations are and the plaque or directory is going to have the wording: "CAUTION: MULTIPLE SOURCES OF POWER."

### *710.12 Stand-Alone Inverter Input Circuit Current*

We mentioned (not too many pages ago) when we were discussing **706.30(A)(3) Inverter Input Circuit Current** that we would go into more detail here.

Maximum current shall be the continuous inverter input current when inverter is **producing rated power at lowest input voltage**.

Discussion: A stand-alone inverter takes power from a battery and the **battery will go through a range of voltages**, depending on whether the battery is **fully charged**, **charging** fast or slow, if the **load is surging** and the **minimum allowable voltage**, before the inverter will no longer take power from the battery in order to protect the battery from too deep of a discharge.

Since power = voltage × current, for consistent power, **as the battery voltage becomes lower, then the current will have to be higher in order to have consistent rated output power**.

For example, with a 1000W inverter, if the voltage is 14V as the battery is charging and we ignore inverter losses, then the required current would be calculated as:

1000W/14V = 71A

As the battery voltage goes down to 11.5A, then the calculation would be:

1000W/11.5V = 87A

If we had a 90% efficient inverter (hope it is better than 90%), then we could also calculate for the extra input current required to compensate for inverter losses to be a factor of 0.9.

87A/0.9 = 97A

Stand-alone inverters **require more input current at lower voltages to make the same amount of power**.

In the inverter installation manual, it may say that at a lower battery voltage, power (and thus current) will be reduced, so be sure to read the instructions. NEC 110.3(B) says we have to follow instructions, since that is how the equipment was tested and listed. Instructions, however, do not supersede the NEC; we have to follow both.

**Stand-alone inverters** often have values for continuous current, which match the power rating of the inverter, but also have **current values for surges of current that are greater than the continuous current rating of the inverter**. For instance, it is not unusual for a 2kW stand-alone inverter to be able to handle a surge of 4kW for several seconds. This is because loads often require surge currents to get started. We size the wires based on the continuous currents and the stand-alone inverter output circuit maximum current, the wires and equipment of which are sized by the continuous current, which is less than the surge currents. **We do *not* size the wires based on the stand-alone inverter's greater surge currents**.

| Models: | Sealed<br>FXR2012A |
|---|---|
| **Instantaneous Power** (100ms) | 4800VA |
| **Surge Power** (5 sec) | 4500VA |
| **Peak Power** (30 min) | 2500VA |
| **Continuous Power Rating** (@ 25°C) | 2000VA |
| **Nominal DC Input Voltage** | 12VDC |
| **AC Output Voltage** (selectable) | 120VAC (100-130VAC) |
| **AC Output Frequency** (selectable) | 60Hz (50Hz) |
| **Continuous AC Output Current** (@ 25°C) | 16.7AAC |
| **Idle Power** | Full: ~34W Search: ~9W |
| **Typical Efficiency** | 90% |

*Figure 10.1* Partial datasheet from outback stand-alone inverter
*Source:* courtesy Outback Power

Note that, in Figure 10.1, there are power ratings that require much more current for time frames that are less than three hours (continuous). Wire sizes are based on currents that are continuous. 16.7A is based on 2000W at 120V. For short periods of time, there will be surges of double the current. Since the time is short, the wire will not have time to heat up and cause a problem.

Since we are on the subject, an inverter operating at full power will essentially have **no** surge capability, because even short surges will typically trip the inverter. To get the full surge capability, it is best to operate at half power. Using our example of a 2000W inverter, if we run it at 1000 watts, it will be ready to give us 4000 watts for short periods of time whenever we need it.

### *710.15(A) Supply Output*

Power supply can have less capacity than the calculated load.

Power supply shall be at least as much as the largest load. This is a bit of a *duh* statement, but it needs to be stated. Don't connect a 10kW load to a 5kW inverter. It will not work out for you. It's not unsafe unless you consider stupidity a hazard. Never forget that everyone is entitled to one fatal mistake.

Power supply can include multiple power supplies, such as solar, generator and energy storage.

*Oftentimes off-grid system owners will turn on a generator when using high power loads.*

### *710.15(C) Single 120V Supply*

Often a 120V inverter is used in stand-alone systems, and 120/240V designed service equipment **may be used** (bonding L1 to L2).

- The neutral bus must be rated greater than the sum of the loads
- No multi-wire branch circuits since neutral currents will not cancel each other out and a sign must read:

WARNING:
SINGLE 120-VOLT SUPPLY. DO NOT CONNECT MULTI-WIRE BRANCH CIRCUITS!

### *710.15(D) Energy Storage or Backup Power Requirements*

"Energy storage or backup power supplies **not required**"

*Direct PV systems are stand-alone systems, which only work when the sun is shining.*

### *710.15(E) Back-Fed Circuit Breakers*

Back-fed plug-in type circuit breakers for stand-alone supply circuits must be secured so that pulling on breaker will not remove breaker.

*We do not want an energized breaker loose and dangling around if it accidentally pops off.*

*Interactive circuits are not required to be secured because they anti-island.*

## Article 712 Direct-Current Microgrids

### *712.2 Definitions*

Many of these definitions clarify other areas of the Code, such as with types of system grounding.

***Direct-Current Microgrid (Dc Microgrid)***

A direct-current microgrid is a power distribution system consisting of more than one interconnected dc power source, supplying dc-to-dc converter(s), dc load(s), and/or ac load(s) powered by dc–ac inverter(s). A dc microgrid is typically not directly connected to an ac primary source of electricity, but some dc microgrids interconnect via one or more dc–ac bidirectional converters or dc–ac inverters.

A dc coupled PV system that is grid-interactive and provides power to dc loads fits the definition of a dc microgrid.

*Grounded, Functionally*

A system that has a ground reference that is not solidly grounded.

*Nice simple definition that really explains what functionally grounded is.*

***Grounded 2-Wire Dc System***

A system that has a solid connection or reference-ground between one of the current-carrying conductors and the equipment-grounding system.

Reference-grounded dc microgrids are similar to functionally grounded PV systems.

Definition could be solidly or not solidly grounded.

*A Three-Wire Dc System on the other hand would be bipolar.*

***Nominal Voltage***

A value assigned to a circuit or system for the purpose of conveniently designating its dc voltage class.

- An example is that a 12V lead-acid system will charge at over 14V and sit fully charged at 12.6V
- Nominal is often defined as "in name only"

For more explanations see 480.2 Definition on page 186.

***Reference-Grounded System***

A system that is not solidly grounded but has a **low-resistance electrical reference to ground** that maintains voltage to ground in normal operation.

A fuse-grounded system is an example of a reference-grounded system, which is not solidly grounded and should **not** have a white-colored grounded conductor if installed after the advent of the 2017 NEC.

*712.10 Directory*

Directory will indicate dc sources. Permanent plaque or directory outside building with location of each power source disconnecting means.

***712.30 System Voltage***

System voltage will be determined by either of (1) through (3) below.

(1) Solidly grounded systems—nominal voltage to ground
(2) Reference-grounded systems—nominal voltage to ground
(3) Ungrounded and resistively grounded systems—highest nominal voltage between conductors

Note: What was known as an ungrounded system in the 2014 NEC and earlier, such as the previously known as "ungrounded" inverter, is not really ungrounded and would be considered a reference-grounded system.

*712.35 Disconnection of Ungrounded Conductors (disconnecting means)*

Ungrounded, reference-grounded and resistive-grounded systems shall open all "non-solidly grounded" current-carrying conductors.

*Only solidly grounded conductors are* **not** *opened.*

*712.37 Directional Current Devices (disconnecting means)*

If the device is for single current direction, it must be listed and marked for single current direction.

Examples of single current direction devices are **magnetically quenched contactors** and **semiconductor switches**.

*712.52(B) Over 300V (Wiring methods/system grounding)*

Dc microgrids over 300V shall be **reference grounded** or **functionally grounded**.

Solidly grounded or ungrounded dc microgrid systems over 300V are not allowed. Once again, ungrounded here does not mean the old "ungrounded" inverter definition. In actuality, an ungrounded inverter would be like a fuse-grounded inverter operating without a fuse and the voltage would be floating.

**Article 625 Electric Vehicle Power Transfer System** contains section **625.48 Interactive Systems**, which will direct **electric vehicles that have the ability to backfeed the grid** to Article 705. Section 625.48 also indicates that these **bidirectional batteries on wheels** need to be listed for exporting power.

When you are connecting your electric vehicle to your house as an optional standby system, you are encouraged to follow the Code and use **Article 702 Optional Standby Systems**. Article 702 is most often used when backing up a house with a generator. There are some YouTube videos that show people how to connect electric cars to their houses in order to operate in stand-by mode in a non-Code compliant way. Be careful! Do not have too much fun! Article 702 is about connecting a backup power source through a transfer switch. Most PV systems used for backup power connect to a multimode inverter or work with a microgrid interconnect device (MID) so we do **not** use Article 702. The requirements of automatic transfer switches in 702.4(B)(2) are to be avoided as they can prevent us from doing most backup system projects.

As you and your customers contemplate implementing energy storage into a grid-connected PV project, be sure to understand the regulations and incentives for connecting energy storage to the grid. Policies are evolving, and the Public Utilities Commissions are working hard to determine how energy storage will be brought into the grid. A good source for finding out about incentives for all things renewable is the Database of State Incentives for Renewables and Efficiency at www.dsireusa.org, which is from North Carolina, just like Bill. In fact, he helped start the organization that developed and maintains this database.

# 11 Chapters 1–4, Chapter 9 Tables and Informative Annex C

So far, we have covered the NEC articles that are used often in the solar industry, including 690, 705, 480, 706, 710 and 712. These articles often refer to other articles in the NEC and this chapter will go over the different articles of the NEC from a PV perspective.

First, we will cover Chapters 1–4 of the NEC, which apply generally to all electrical installations. We will then mention the relevance of, and when to use, the articles in Chapters 5–7. Finally, we will cover Chapter 9 and look at the informative annexes that we can use when designing PV systems.

Chapters 1–4 have been referenced throughout this book, especially with respect to Article 690 and 705.

Here are some of the top articles to be familiar with in Chapters 1–4:

- Article 100 Definitions
- Article 240 Overcurrent Protection
- Article 250 Grounding and Bonding
- Article 310 Conductors for General Wiring [especially the 310 tables!]
- Article 358 Electrical Metallic Tubing: Type EMT

## Chapters 1–4 of the NEC

The NEC is divided into chapters, and the number of the chapter precedes the three-digit number of the article. For instance, Chapter 6 Special Occupancies includes Article 690 Solar PV Photovoltaic Systems and Chapter 1 General begins with Article 100 Definitions. Chapters 1–4 apply to all electrical installations, including PV systems.

An outline of **often used for PV articles, parts and sections** in Chapters 1–4 of the NEC follows. *Italics are author comments*.

Recall the hierarchy of NEC organization: Chapters/Articles/Parts/Sections

## Chapter 1 General

### *Article 100 Definitions*

This is a great resource for defining terms throughout the NEC, including "**PV.**"

*First off, in article 100 definitions, we see **three types of accessible,** one being **applied to equipment,** the other **applied to wiring methods** and the third is the well-used term **readily accessible.** Let's start off out definitions with the three accessibles.*

### *Accessible (as applied to equipment)*

"Capable of being reached for operation, renewal or inspection."

*Remember that accessible equipment can be reached.*

### *Accessible (as applied to wiring methods)*

"Capable of being removed or exposed without damaging the building structure or finish or not permanently closed in by the structure or finish of the building."

*Remember that if it is a wiring method and you have to dismantle something, then it is not an accessible wiring method.*

### *Accessible, Readily*

"Capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to take action such as to use tools (other than keys), to climb over or under, to remove obstacles, or to resort to portable ladders, and so forth."

*Remember that **readily accessible** means you can get at something with a key or less and do not need tools or a ladder to get at something.*

### *Dc-to-dc Converter*

Discussion: The dc-to-dc converter (**"optimizer is a SolarEdge term"**) definition was put into the Code in 2014 and first put into a diagram in the 2017 NEC and kept in the 2020 NEC. The definition is left rather wide open, so that new equipment not yet in use or invented can be put into use and save lives. For instance, Figure 1.2 on Page 8 (also known as the first image in Article 690) shows dc-to-dc converters connected to PV source circuits and then the dc-to-dc converters are connected to each other in parallel to make a dc-to-dc converter output circuit. This is not unheard of, but uncommon. The way we usually see it in practice, at the publication of this book, is with the dc-to-dc converters connected to one PV module per optimizer, and then the optimizers are connected together in series and then connected to the inverter. There are some optimizers that work almost the same, but with two modules in series and others that have two modules connected per optimizer, so that we can shut down the PV modules individually to comply with module level rapid shutdown. These optimizers with two modules in series probably do not comply with module level shutdown requirements (80V cold temperature corrected) in **690.12 Rapid Shutdown**. This definition was moved from 690.2 Definitions to Article 100 definitions in the 2020 NEC.

### Power optimizers

Dc-to-dc converters are commonly referred to in the industry as "power optimizers," which is really a marketing term from SolarEdge. If a dc-to-dc converter did not work as well as advertised or was clipping power (reducing power on purpose), perhaps we would call it a "power-pessimizer."

We could also have dc-to-dc converters that are not associated with PV and were part of an energy storage system. In a way a maximum power point tracking (MPPT) charge controller is a dc-to-dc converter taking one voltage in and another voltage out. Also, within our string inverters electronically, there is usually one or more dc-to-dc converters and we could call each separate MPPT in the inverter a dc-to-dc converter. A transformer converts ac voltage and current to a different level like a dc-to-dc converter converts dc voltage and current to a different level. Perhaps in the future we can call a transformer an ac-to-ac converter.

There is a way to comply with 690.12 Rapid Shutdown without having module level shutdown, which was put into the NEC because of the building-integrated PV (**BIPV**) lobby but could be used for other PV systems besides BIPV. This method is **690.12(B)(2)(3)** and requires that the "PV arrays shall have no **exposed wiring methods** or conductive parts and be installed more than 8ft from exposed grounded conductive parts." We will now look at the definitions of exposed.

### *Exposed (as applied to live parts)*

"Capable of being inadvertently touched nearer than a safe distance by a person."

*As far as rapid shutdown is concerned, since the PV is usually on a roof that requires a ladder, we can say that we do not have exposed live parts on a roof.*

### *Exposed (as applied to wiring methods)*

"On or attached to the surface or behind panels designed to allow access."

*At first someone might think that panels means solar panels here, but solar panels are no longer in the NEC, so especially in the 2020 NEC, this is not what panels means. These panels are access panels that cover equipment but allow fairly easy access. Yet another good reason we got rid of the term solar panel from the NEC in 2020!*

### *Generating Capacity, Inverter*

This is the output of the inverter. This is measured in kW or W and at 40°C. We often call this our ac system size. **690.7 maximum voltage** and **690.8 circuit sizing and current** have some special exceptions for systems with a generating capacity over 100kW and **Article 691 large-scale photovoltaic (PV) electric supply stations** has exceptions that apply to systems with a generating capacity of 5000kW (5MW) or greater, among other criteria. Moved from 690.2 Definitions to Article 100 Definitions in 2020 NEC.

### *Interactive System*

Discussion: On the street, they call this a grid-tied system.

Perhaps because of the fact that an ac coupled PV system can use interactive inverters, we have to use this fancy term to describe a grid-tied inverter without a grid. In a way, an ac coupled system battery inverter will trick an interactive inverter into thinking there is a grid to turn on the interactive inverter. That is a tricky battery inverter that is not interactive, yet interacting with an interactive inverter to turn it on.

We might call this true sine wave inverter coupling love! Moved from 690 to 100 in the 2020 NEC. **Interactive inverters** operate in what can be called **current-control** mode. A **stand-alone inverter** operates in **voltage-control** mode.

### *Inverter, Multimode*

Discussion: A multimode inverter can work in **interactive** mode (**current-control** mode) or it can work in island (**stand-alone**) mode (**voltage-control** mode). A multimode inverter will typically have **different outputs for the interactive and stand-alone circuits**. A multimode inverter has also been called a bimodal inverter in some books since there are normally two primary modes (current mode and voltage mode). Very often multimode inverters are **incorrectly (to the NEC) called hybrid inverters**. Inverters may not be hybrid. A NEC defined hybrid PV system will have another source of power **besides PV or batteries**, such as a generator.

### *Inverter input circuit*

Conductors connected to the dc input of an inverter.

### *Inverter output circuit*

Conductors connected to the ac output of an inverter.

### *Island Mode (New in 2020 NEC)*

**Stand-alone mode**. Not working in parallel with the grid (electric power production and distribution network). Can be a multimodal inverter or microgrid that is disconnected from the grid.

### *Photovoltaic (PV) System*

"The total components, circuits, and equipment up to and including the PV system disconnecting means that, in combination, convert solar energy into electric energy."

*The PV system used to include the energy storage system and even some loads in the 2014 NEC and earlier. Since renewable energy is taking over, we get to have more specialized code and separate articles for these different systems. We can often say that this disconnecting means is the disconnecting means closest to the point of interconnection for* *an interactive system. For a dc coupled stand-alone system, this disconnect would be the dc disconnect going to the energy storage system.*

***Power Production Equipment** (New In 2020 NEC)*

Electrical generating equipment supplied by any source other than utility service, up to the source disconnecting means.

***Service***

2020 NEC definition: The conductors and equipment **connecting the** serving utility to the wiring system of the premises served.

2017 NEC definition: The conductors and equipment **for delivering electric energy from the** serving utility to the wiring system of the premises served.

*2020 NEC service definition can go both ways (bidirectional).*

***Service Conductors***

"The conductors from the service point to the service disconnecting means."

*On your house this would be between the meter (service point) and the main breaker. We typically make the supply side connection on the service conductors.*

***Service Equipment***

Main disconnect and associated equipment.

***Service Drop and Service Lateral***

"The conductors between the utility supply system and the service point."

*A service drop is overhead and a service lateral is underground. Often coming from a transformer to your meter.*

***Stand-Alone system***

Synonym: Off-grid or possibly optional standby system (Article 702).

NEC wording: "A system that is capable of supplying power independent of an electric power production and distribution network."

Note: Article 710 is Stand-Alone Systems.

### *Article 110 Requirements for General Installations*

Article 110 is mostly used for electrical connection rules, working spaces around equipment and enclosure types.

**110.14(C)(1) covers the terminal temperature ratings** as they relate to equipment ratings and conductor ratings. It tells us that we can only operate a conductor up to its current ampacity (at 30°C) for the temperature of the terminal to which it is connected. Therefore, a 10 AWG THWN-2 conductor can be operated at no greater than 35A if the wire is connected to a 75°C terminal on a circuit breaker. (stay tuned for wire sizing examples in next chapter).

### *110.21(B) Field-Applied Hazard Markings*

Often referred to in 690 and 705. Labels meeting these requirements shall

(1) Warn of hazard using effective words, colors, symbols
(2) Permanently attached and not handwritten unless handwritten information is subject to change
(3) Durable for environment

There are ANSI (American National Standards Institute) standards **recommended in informational notes** that go into colors, font sizes, wording, design and durability.

### *110.26 Spaces About Electrical Equipment*

**This is often 3 feet back and 30 inches wide or the width of the equipment for wider equipment. Also 6.5 feet high or height of equipment, whichever is greater.** Table 110.26(A) has different spaces for higher voltage equipment and if there are exposed live parts, the distances can be greater. Recall that exposed live parts means: "Capable of being inadvertently touched nearer than a safe distance by a person."

### *Table 110.28 Enclosure Types*

This includes NEMA enclosure types for wet areas, wind, dust, etc. Remember that any NEMA with a 3 in it is most commonly used outdoors, along with other NEMA ratings.

## Chapter 2 Wiring and Protection

### *Article 200 Use and Identification of Grounded Conductors*

### 200.6 Means of Identifying Grounded Conductors

Applying 200.6 is less common for 2020 NEC designed PV systems than for 2014 NEC designed PV systems since the new functionally grounded inverter definition requires no dc grounded conductor marking. See page 87. We still do have white colored grounded conductors on the ac side of most inverters, just not on the dc side.

### *Article 230 Services*

Supply-Side Connections need to be properly bonded using best practices similar to service equipment since they are exposed to utility currents. In the 2020 NEC, these provisions are found (hidden) in **250.25 Grounding Systems Permitted to Be Connected on the Supply Side of the Disconnect.** We have referred and explained some of the information in Article 230 when covering 705.11. Services typically have no OCPD coming from the utility and have enough short circuit current to vaporize metal in some cases. Vaporizing metal is not recommended.

### *Article 240 Overcurrent Protection*

### 240.4 Protection of Conductors

#### *240.4(B) Overcurrent Devices Rated 800 Amperes or Less*

**You can round up over the ampacity of the conductor to the next higher overcurrent device size.** This is the part of the following chapter that does not make sense and can allow a conductor to have an ampacity less than the OCPD that is protecting it. 240.4(C) tells us that once your OCPD is 800A or more that the ampacity of the conductor has to be greater than the OCPD.

#### *240.4(D) Small Conductors*

"*Small conductor rule*"

- 14 AWG copper wire needs at least 15A overcurrent protection
- 12 AWG copper wire needs at least 20A overcurrent protection
- 10 AWG copper wire needs at least 30A overcurrent protection

*There is more information in 240.4(D) about small aluminum conductors in the NEC.*

### *240.6 Standard Ampere Ratings*

- Special fuses
    - 1A, 3A, 6A and 601A (not used for us much)
- Fuses and breakers standard sizes
    - 5A increments 15 to 50A
    - 10A increments 50 to 110A
    - 25A increments 125 to 250A
    - 50A increments 250 to 500A

We are allowed to use a larger OCPD than calculated if the installation instructions of the equipment, such as the inverter say that we can (if it was tested that way). For instance, since 25A breakers are difficult to find, we can often use a 30A breaker as long as the wire sizing checks work as we will see in the next chapter.

240.6(C) Restricted Access Adjustable-Trip Circuit Breakers

Covered on page 174.

### *240.21(B) Feeder Taps*

We covered this when we covered 705.12(B)(2) page 160.

- 240.21(B)(1) 10-foot tap rule
- 240.21(B)(2) 25-foot tap rule
- 240.21(B)(5) Outside taps of unlimited length

### *Article 250 Grounding and Bonding*

**690 Part V** is also Grounding and Bonding; see page 109.

**690 Part V** often refers to 250.

### *Part III Grounding Electrode System and Grounding Electrode Conductor*

This is where experts differ and there is confusion. You could say that with different conditions, such as lightning and the resistance of earth, there is no perfect solution to grounding, which is why there may be so many different opinions. **Lightning protection is not covered in the NEC** and is covered in **NFPA 780: Standard for the Installation of Lightning Protection Systems**.

### *250.52(A) Grounding Electrodes Permitted*

1 Metal Underground Water Pipe (*common*)
2 Metal In-ground Support Structure
3 Concrete-Encased Electrode (*common*)
4 Ground Ring
5 Rod and Pipe Electrodes (*common*)
6 Other Listed Electrodes
7 Plate Electrodes (*common in Canada*)
8 Other Local Metal Underground Systems (underground metal well casing, tanks, piping systems, etc.)

### *250.53 Grounding Electrode System Installation*

Learn how to install electrodes here and memorize where to go.

### *Table 250.66 Size of ac Grounding Electrode Conductors*

The size of the ac grounding electrode conductor (GEC) is based on the size of the largest ungrounded service entrance conductor.

Usually, when dealing with PV on an existing service, you already have an existing ac grounding electrode conductor and do not need to go to **Table 250.66**.

### *Part VI Equipment Grounding and Equipment Grounding Conductors*

#### **250.122 Size of Equipment Grounding Conductors** (EGC)

EGC sizes are based on the size of the overcurrent protection device. See page 124. This table address of 250.122 may be worth memorizing, since it is commonly used for ac and dc.

### *250.166 Size of The Direct-Current Grounding Electrode Conductor*

For most PV systems, including functional grounded systems, there are no dc grounding electrode conductor requirements. In these systems, the **ac equipment grounding conductor and ac grounding electrode conductor provide reference and a pathway to ground.**

690.47(A)(1) "**For PV systems that are not solidly grounded, the equipment grounding conductor for the output of the PV system, where connected to associated distribution equipment connected to a**

**grounding electrode system, shall be permitted to be the only connection to ground for the system.**"

In past Code cycles, it was common for an AHJ to require a separate dc electrode or dc grounding electrode conductor for most PV systems. It is now silicon crystal clear that this is no longer the case.

An example of a PV system that requires a dc grounding electrode conductor is a dc direct PV water pumping system.

## Chapter 3 Wiring Methods and Materials

### *Article 300 General Requirements for Wiring Methods and Materials*

300.7 Raceways Exposed to Different Temperatures

#### *300.7(A) Sealing*

If a raceway is going to areas of different **temperature changes**, seal the raceway at the junction of the temperature change to **prevent condensation** where warm air would otherwise meet cold pipe. *New in 2020 NEC it was added that the sealant shall be identified for use with cable insulation, conductor insulation, a bare conductor or other components. Some molecules do not play well with others. Duct seal is often used.*

#### *300.7(B) Expansion*

If a raceway is long enough and exposed to enough changes in temperature, calculations similar to voltage temperature calculations can be made to determine the need for expansion joints or flexible conduit. These calculations also apply to the expansion of solar rails.

We can take the difference between the low and high temperature and then multiply the difference in temperature by a coefficient to get the expansion.

*A PV fire was once blamed by some on expansion joints scraping the insulation off of a wire on a PV output circuit. Some electricians will use some flexible conduit between stretches of rigid conduit to allow for expansion, rather than expansion joints.*

### *Article 310 Conductors for General Wiring*

#### *310.14(A)(2) Selection of Ampacity*

If different sections of a circuit have different ampacities, then the lowest ampacity shall apply unless the shorter section is **less than or equal to 10 feet or 10% of the circuit length, whichever is less.**

### *310.15 Ampacity Tables (Includes Tables 310.16 and 310.17)*

### *310 Tables [Most Often used in the pages in the NEC!]*

For examples see Chapter 12 "Wire Sizing" of this book.

310.15(B)(1) Ambient Temperature Correction Factors Based on 30°C (Formerly Table 310.15(B)(2)(a)) is used to derate conductor ampacity in hot places, such as outside in the summer.

Recommended by authors to use ASHRAE 2% average high temperature data found at www.solarabcs.org/permitting.

Table 690.31(A)(a) page 93 is like an extension of 310.15(B)(1) and shall be used for solar PV system wires rated for 105°C and 125°C.

**Table 310.15(C)(1) adjustment factors for more than three current-carrying conductors** [Formerly Table 310.15(B)(3)(a)] Four or more conductors in conduit or cable will have trouble dissipating heat and shall be derated.

**Not to be applied if distance is less than 24 inches.**

Not to be applied to neutrals carrying only unbalanced currents.

**Removed Table 310.15(B)(3)(c) Ambient Temperature Adjustment for Raceways or Cables in Sunlight on a Roof** (last seen in the 2014 NEC and has been *removed*).

**310.15(B)(2) Rooftop** (not a table) is in the 2020 NEC and says that if our raceways or cables are **7/8 inch or less above rooftop**, we shall add a 33°C adder.

It is recommended to be at least 1 inch above rooftop to avoid the adder and to keep debris from building up on the rooftop.

**310.16 Allowable Ampacities of Insulated Conductors not in Free Air [formerly 310.15(B)(16)]** is for conductors, such as in raceway, cable or buried.

This is the most used page in the NEC. It gives the ampacities of conductors in cables, raceways, direct buried and everything else that is not in free air.

**Table 310.17 Allowable Ampacities of Insulated Conductors [formerly Table 310.15(B)(17)] for conductors in free air,** like the PV wire under an array.

You will get to see us using all of these tables in the next chapter on wire sizing. Tables 310.16 and 310.17 have columns that have temperature ratings of conductors on them. Some of the commonly used conductor insulation types are listed, such as THWN-2 and USE-2, which are commonly used wires for PV systems and 90°C rated. This means that they can have the amount of current going through them in the column for the specific wire size without having a chance of going over the temperature rating. We are not allowed to go over the temperature rating of the insulation of the conductor. Once again, it is best to see our examples in the next chapter, Chapter 12 Wire Sizing, and then follow them to size your own wires and OCPDs using the same pattern, hopefully all in the same sitting, until you get the hang of it. Repetition helps here, especially when coupled with common sense.

In Table 310.16, look at a 10AWG THWN-2 and you will see in the 90°C insulation column that conductor would have an ampacity of 40A when at 30°C (the entire table is for 30°C). If it is hotter than 30°C or if there are greater than 3 current-carrying conductors in a raceway, then we would have to correct the 30°C value to the lower value and have a lower conductor ampacity.

Articles 320–362 various cables and conduits

From EMT to NMC (Romex), you will find it here

### *Article 330 Metal-Clad Cable: Type MC*

MC Cable is a cable assembly sold with conductors inside of an armor of interlocking metal tape. MC Cable can be installed in a wet location if the conductors under the metallic covering are listed for wet.

MC Cable or raceway is cited in **Article 690.31(A) Wiring Systems** for an option for a wiring method for PV source and output circuits in readily accessible locations. Also see page 93.

MC Cable or metal raceway is a wiring method for PV dc circuits inside of buildings that is cited in **690.31(D) Direct-Current Circuits on or in Buildings**. Also see page 102.

*MC Cable is in no way related to MC connectors. MC connectors are made by the company Multi-Contact, a Swiss company that has not quite a monopoly on the PV connector industry.*

### *Article 334 Non-metallic-Sheathed Cable: Types NM and NMC*

Also commonly known as **Romex**, which is a brand name of wiring commonly seen in residential buildings. You can have your ac inverter circuits in Romex where NM and NMC can be used.

This is a factory assembled cable with insulated conductors within a non-metallic jacket. You will see a lot of this going in and out between the studs of a house being built. It is usually yellow or white.

Romex cannot be installed in storage battery rooms.

### *Article 336: Power and Control Tray Cable: Type TC*

Factory assembled of two or more insulated conductors under a nonmetallic jacket.

### *Article 338 Service-Entrance Cable: Types SE and USE*

This is where we learn about the USE-2 that we use in our dc circuits under the array which also has to be listed as RHW-2 at the same time, which is normal for most USE-2 wire. We can see more about USE-2 uses in PV systems in **690.31(C)(1) Single-Conductor Cable**.

Article 338 says that USE cable cannot be used for interior wiring, however when it is dual listed as RHW-2, then it can be used indoors, so it really can be used indoors, since it is almost always dual listed as RHW-2. The requirement for USE-2 to be dual listed as RHW-2 is new in the 2020 NEC.

### *Article 342 Intermediate Metal Conduit: Type IMC*

IMC is a steel threadable raceway which is good at providing physical protection and for the most part can be used interchangeably with RMC (next).

*In some AHJs, such as many in the Chicago area EMT is not allowed for solar circuits and everyone is using more heavy-duty IMC. An AHJ can make up their own rules.*

### *Article 344 Rigid Metal Conduit: Type RMC*

RMC can be used in the same manner as IMC (above). IMC is easier to bend and work with and RMC is thicker.

### *Article 350 Liquidtight Flexible Metal Conduit: Type LFMC*

Liquidtight Flexible Metal Conduit is a metallic raceway, which can be used for dc PV circuits inside and outside of buildings. Some solar installers will use the more expensive LFMC rather than EMT. Note that most LFMC is rated 60°C when wet.

### *Article 352 Rigid Polyvinyl Chloride Conduit: Type PVC*

PVC is most often used in Hawaii outside of buildings due to high corrosion rates. PVC cannot be used inside of buildings for dc PV circuits, since it is not metal. Easily broken in cold weather.

### *Article 356 Liquidtight Flexible Non-metallic Conduit: Type LFNC*

Liquidtight Flexible Non-metallic Conduit looks a lot like Liquidtight Flexible Metallic Conduit from the outside, since the metal version, which we just covered in Article 350 has the metal inside of plastic.

Many times, you will see solar installers connecting inverters to junction boxes, disconnects, monitoring and other equipment using LFNC on the outside of a building. You see electricians in the field refer to this wiring method as just **liquidtight**.

### *Article 358 Electrical Metallic Tubing: Type EMT*

EMT conduit is the most often used wiring method among solar installers on the **mainland United States**. EMT takes some practice to be good at bending. Journeymen electricians have EMT bending competitions and champions. You can get 10-foot sticks of ¾ EMT for just a few bucks.

EMT is typically a thin-walled steel raceway that we will fill with conductors, such as THWN-2.

EMT can be inside or outside and where exposed to physical damage.

EMT is not threaded and we will use watertight connectors when outside (wet location).

Although we may be using EMT that is in a wet location with watertight connectors, we still need to have a conductor inside the EMT that is listed for wet locations. When conduit will go outside the conductors inside it will have a good chance of getting wet be it from rain or condensation.

### *358.30(A) Securely Fastened*

The EMT is to be secured every 10 feet (3 feet from junction boxes and equipment).

### *Article 392 Cable Trays*

Cable trays are often used around arrays to manage wires. PV wire is allowed in cable trays as we can see **690.31(C)(2) Cable Tray** on page 99.

## Chapter 4 Equipment for General Use

### *Article 400 Flexible Chords and Cables*

Referenced earlier in this book on pages 100 and 101, these cables are often used for solar trackers, which follow the sun and storage batteries. See **690.31(C)(4) Flexible Chords and Cables Connected to Tracking PV Arrays** on page 100. Additionally, see Table **690.31(C)(4) Minimum PV Wire Strands** and **690.31(C)(5) Flexible, Fine-Stranded Cables**.

### *Article 480 storage batteries*

See Chapter 10 storage with Article 480 Storage Batteries starting on page 185.

### *Article 490 equipment over 1000V, nominal*

490.2 High voltage is defined as 1000V for this article.

For PV systems 1500V and less we do not need to apply Parts II and III of Article 490 as we can see in 690.7 Maximum Voltage.

## Chapter 5 Special Occupancies

If you are installing a PV system in a barn, on a gas station, an aircraft hangar or other special occupancy, you will need to comply with the special requirements in Chapter 5 Special Occupancies.

Some examples of special occupancies where you may be installing PV are:

- Hazardous locations
- Commercial garages
- Aircraft hangars
- Gas stations (boom!)
- Bulk storage plants
- Facilities using flammable liquids
- Health care facilities
- Assembly occupancies (for over 100 people)
- Theaters
- Amusement parks
- Carnivals (fun!)

- Motion picture studios
- Motion picture projection rooms
- Manufactured buildings
- Agricultural buildings (what the hay?)
- Mobile homes (classy!)
- Recreational vehicles
- Floating buildings
- Marinas (wet!)

Just remember, if you are installing PV in a special place, such as one of the locations listed above, you should take Chapter 5 into consideration.

## Chapter 6 Special Equipment

Article 690 which is what most of this book covers is the most important article in Chapter 6 **Special Equipment**, and there are more articles that may relate to PV installations that we shall mention, such as:

Article 625 Electric Vehicle Charging System
Article 645 Information Technology Equipment
Article 646 Modular Data Centers
Article 647 Sensitive Electronic Equipment
Article 670 Industrial Machinery
Article 680 Swimming Pools, Fountains and Similar Installations
Article 682 Natural and Artificially Made Bodies of Water
Article 692 Fuel Cell Systems
Article 694 Wind Electric Systems

If your PV system incorporates wind, fuel cells or electric car charging or is a floating PV system (floatovoltaics), you should look to other articles in Chapter 6 **Special Equipment**.

## Chapter 7 Special Conditions

There are many other special conditions besides the interconnection to the grid, which we already covered in Chapter 9 of this book, where we covered Article 705. We also already covered other special conditions in this book in Chapter 10 where we covered energy storage related articles, such as Article 706 Energy Storage Systems, Article 710 Stand-Alone Systems and Article 712 Direct-Current Microgrids.

Other articles in Chapter 7 Special Conditions that we may have to reference one day include:

Article 701 Legally Required Standby Systems
Article 702 Optional Standby Systems
Article 720 Circuits and Equipment Operating at Less Than 50V
Article 750 Energy Management Systems

## Chapter 8 Communication Systems

Chapter 8 Communication Systems is not subject to the requirements of Chapters 1–7 of the NEC except where referenced in Chapter 8. These systems are separate from PV systems, although they may be powered by solar energy. As solar and energy storage incorporate more with the internet and there is talk of using blockchain technology, AI and IT for energy and power transactions, we may have to increase the length of this chapter in the future by a few kilobytes.

## Chapter 9 Tables

Chapter 9 tables are referenced throughout the NEC. We will take a look at a few tables that relate to PV system design that will let us know about voltage drop and how many conductors we can physically fit in conduit.

**Chapter 9 Table 1 Percent of Cross Section of Conduit and Tubing for Conductors and Cables** is used to determine how much of the cross-sectional area of a conduit can be used for wire and how much extra space needs to be left over for air, cooling and pulling wires. This table is really about geometry and how many circles can fit in a circle. There are three categories in this table. One conductor in a conduit, which is unusual, can take up 53% of the space inside of the conduit. Two conductors in a conduit, which is also not common can only take up 31% of the cross-sectional area in the conduit. When we have three or more conductors in conduit, which is usually the case, we can take up 40% of the cross-sectional area of the conduit.

**Chapter 9 Table 4 Dimensions and Percent Area of Conduit and Tubing** is used to determine the interior cross-sectional area of conduit and can be used with Chapter 9 Table 1. This table covers many types of conduit and is many pages long. Additionally, this table gives us the data for the percentages of cross-sectional area that are required by

Chapter 9 Table 1, so we do not need to even look at Chapter 9 Table 1 when we are using Chapter 9 Table 4.

For example, the common conduit used for residential PV projects is 3/4-inch EMT and we can use Chapter 9 Table 4 to see that 40% of the interior cross-sectional area of **3/4-inch EMT is 0.213 square inches**. This is how much space we can use without wires and we will see how much space the wires take up next.

**Chapter 9 Table 5 Dimensions of Insulated Conductors and Fixture Wires** can be used to determine the cross-sectional area dimensions of wires. Like Chapter 9 Table 4, this table is many pages long. This table is also used with Chapter 9 Table 4.

An example of the dimensions of a commonly used wire in the PV industry would be using this table to determine the cross-sectional dimensions of 10 AWG THWN-2. We go down the left column until we see THHN, THWN, THWN-2, which all have the same dimensions and we can see that **10 AWG THWN-2 has a cross-sectional area of 0.0211 square inches**.

If we use our examples from Chapter 9 Tables 4 and 5, we can divide the cross-sectional area of 3/4-inch EMT, which is 0.213 square inches by the cross-sectional area of 10 AWG THWN-2, which is 0.0211 square inches and we get:

$$0.0213/0.0211 = 10.1\,\text{conductors}$$

We have to round down to 10 conductors in this example to fit in this conduit. We will see a little later in this chapter that we can use Informative Annex C to cut down on math.

### *Rounding up for number of conductors in conduit*

**Chapter 9 Note 7** [aka 9.0(7)] tells us that we can **round up if we are 0.8 over a whole number** when calculating the number of conductors that will physically fit inside a conduit.

People in the field do not like using the maximum number of conductors that can fit in a conduit, because a tight fit can be very difficult to work with. It is recommended to have extra space. This is where there is often a disconnect between the engineers designing the PV system and the swearing installers in the field trying to cram conductors in conduit.

**Chapter 9 Table 8 Conductor Properties** is used often to calculate voltage drop, but there are also other convenient properties of this table. In our discussion of wire sizing in Chapter 12 of this book, we will use Chapter 9 Table 8 for calculating voltage drop, using the resistance values in ohm per kilofoot (kFT) in order to determine the resistance of a wire.

For instance, we can see that an uncoated copper stranded 10 AWG wire has a resistance of 1.24 ohms per kFT. This means that 1000 feet of 10 AWG wire has a resistance of 1.24 ohms, so 500 feet would have half of that. One thing in this table that often confuses people is the uncoated vs. coated column in this table. The **coated wire is usually a copper wire that was dipped and has a tin-plating on it to help with corrosion**. We most often do not use coated wire and this **coating has nothing to do with the wire having insulation**, as is often confused.

Chapter 9 Table 8 also has the metric cross-sectional area of the wire. **In most of the world, square mm cross-sectional area is used to designate a wire's dimensions** rather than the AWG system. Here we can use this table to convert.

We can also see wire dimensions in circular mils. **A circular mil is the cross-sectional area of a circle with a diameter of 1/1000 of an inch** (very small). Often times **larger wires are measured in thousands of circular mils (kcmil).**

**Chapter 9 Table 9 Alternating-Current Resistance and Reactance for 600-Volt Cables, 3-Phase, 60Hz, 75°C—Three Single Conductors in Conduit** is used to calculate voltage drop for ac voltage drop for larger conductors. With larger conductors, there is a greater difference between ac and dc with regards to voltage drop.

Skin effect is when the alternating current has a tendency to ride on the outer "skin" of the wire with larger wires, thus making ac less efficient than dc with larger wires. This is one reason that larger wires are run in parallel, such as when you see multiples of three wires running along huge utility power poles. This is also why there are also high voltage dc (HVDC) transmission lines popping up around the world, with some over 1MV!

There are also more variables with these calculations, such as the type of conduit, the power factor and copper vs. aluminum wire.

**With wires smaller than 250 kcmil, the difference between using Chapter 9 Table 8 and Chapter 9 Table 9 is usually less than 5% more voltage drop.**

Table 10 deals with the number of strands in typical cables. The most common conductors use Class B stranding. Standard terminals are designed for Class B stranded conductors. For higher strand counts, as is required for tracking systems in **690.31(C)(4) Flexible Chords and Cables Connected to Tracking PV Arrays** page 100 and **Table 690.31(C)(4) Minimum Wire Strands**, special connectors are required to properly terminate the conductors (see 690.31(C)(5) page 101. Most PV modules have Class C or similar stranded PV wire for the module leads.

## Informative Annexes

Further in the back of the NEC are Informative Annexes and Informative **Annex C Conduit and Tubing Fill Tables for Conductors and Fixture Wires of the Same Size** (long name) is especially useful for determining how many conductors fit in a conduit, in many cases avoiding the math involved with using the tables in Chapter 9.

If we wanted to arrive at fitting 10 10 AWG THWN-2 conductors in a 3/4-inch EMT conduit, we can look for THWN-2 in the left column of Informative Annex C and, a few pages in, we see THWN-2, we match 10 AWG with 3/4-inch EMT and can see that 10 conductors fit. Informative annex C does not work for conductors of different sizes within the same conduit.

Informative Annexes are not part of the requirements of the Code, but contain helpful shortcuts.

## Index

Last but not least in the NEC is the Index, which contains everything from ac to zones. Become familiar with the index and use it often, especially if you are planning on taking an open book NEC exam, or need to fall asleep fast without damaging your liver. The smartest people know how to use the index.

Since we are talking about the index here, "index" shall be in the index of this book.

We have now covered PV and the NEC. The next and final chapter will use the NEC by working out wire sizing examples.

# 12 PV Wire Sizing Examples

Wire sizing has been so complicated that many experts disagree on how to correctly size a wire and many books have conflicting methods for how to do it properly. This is also why there are no wire sizing programs on the internet that work for anything besides voltage drop. If someone was good enough at coding to make a good wire sizing program, they would be too busy at Google making $300k per year instead of making NEC wire sizing programs.

In sizing a wire there are many different checks that should be done. Some of the checks seem so obvious that they are usually skipped, while others are sometimes just given a brief statement such as "then check that the overcurrent device satisfies Article 240 Overcurrent Protection."

We will give a few examples of wire sizing and then let you practice on your own. Practice makes perfect. Someone who sizes PV wires every day will often skip most checks, since they know from experience which check will determine the wire size in their particular situation.

It is recommended that you sit down with your NEC and use the following tables to practice these wire sizing exercises. You can also photocopy or screenshot the following tables and rules for your wire sizing kit:

310.16 Ampacities of Conductors NOT in Free Air Based on 30°C
310.17 Ampacities of Conductors in Free Air Based on 30°C
310.15(B)(1) Ambient Temperature Correction Factors Based on 30°C
310.15(C)(1) Adjustment Factors for More Than Three Current Carrying Conductors
240.4(D) Small Conductor Rule
240.6(A) Standard OCPD Sizes

Become an expert yourself or hire Bill and Sean to do your wire sizing at attorney-like prices. The difference with Sean and Bill vs. attorneys is that Sean and Bill have souls.

Legend:

COU = Conditions of Use (adjustment and correction factors)
Ampacity = Conductor's ability to carry current
Imax = Maximum Circuit Current 690.8(A)
Icont = required ampacity for continuous current = Imax × 1.25
OCPD = Overcurrent protection device

## Wire Sizing Example 1

### *Inverter Output Circuit Wire Sizing*

Given the following information:

- Inverter continuous rated output current = **10A**
  - If it were on a house, then 240V × 10A = 2.4kW inverter
- Number of current-carrying conductors in conduit **2**
  - Do not include ground or balanced neutral
- ASHRAE 2% high temperature from www.solarabcs.org = **40°C**
- Distance above roof conduit in sunlight = 1 inch (irrelevant info using 2020 NEC)
- Terminal temperature limits = **75°C**
  - Terminals are what we attach ends of wires to.
- Wire type to be used = THWN–2
  - **90°C** rated wire
  - We can see this in Table 310.15(B)(16)
  - –2 or at end of wire designation means 90°C rated

### *Discussion*

Defining current for this exercise:

690.8(A)(3)

Maximum circuit current = continuous rated output current = 10A = Imax

690.8(B)(1)

Required ampacity for continuous current = Imax × 1.25 = 12.5A = Icont

This example and these steps use a 90°C rated wire and a 75°C rated terminals.

We are going to break this down into 10 steps (at least it's not 12 steps—although you might need to recover with a 12-step program after we are done). Some of the steps will seem useless in most cases, but it is possible to have a 75°C rated wire with 90°C rated terminals, although we have never seen it happen. We could make fewer steps and then find an unusual exception where the four-step process does not work.

10 steps (almost as effective as a 12-step program—this is Ampacity Anonymous)

Step 1 is really without wires (we are powerless, and our electrical systems are unmanageable).

1 Round up Icont to fuse size
2 Pick conductor size [perhaps from intuition, Tables 310.16, 310.17 or 240.4(D).]
3 75°C ampacity
4 75°C ampacity ≥ Icont good!
5 75°C ampacity ≥ OCPD good!
6 90°C ampacity
7 90°C ampacity ≥ OCPD good!
8 90°C ampacity × COU deratings = COU derated wire
9 COU derated wire ≥ Imax good!
10 COU derated wire round up to OCPD ≥ OCPD from step 1 good!

Working the 10 steps with our example 1

1 Round up Icont to fuse size
   - 12.5A rounds up to 15A
   - 240.6
2 Pick conductor size
   - Educated guess or from 240.4(D)
   - 14 AWG copper is smallest wire from 240.4(D)
3 75°C ampacity (75°C terminals)
   - 14 AWG = 20A
   - Table **310.15(B)(16) conduit** or (B)(17) if free air
4 75°C Ampacity ≥ Icont good!
   - 20A ≥ 12.5A good!
   - If not good, increase the conductor size here

5 75°C Ampacity ≥ OCPD good!
- 20A ≥ 15A good!
- If not good, increase the conductor size

6 90°C ampacity (90°C rated wire)
- 14 AWG = 25A
- **Table 310.15(B)(16)** conduit or (B)(17) if free air

7 90°C ampacity ≥ OCPD good!
- 25A ≥ 15A good
- If not good, increase the conductor size here

8 90°C ampacity × COU deratings = COU derated wire
- COU = Conditions of Use
- COU deratings from 310.15(B)(1) and 310.15(C)(1)
- 310.15(B)(1) 40°C for 90°C rated wire = 0.91 derating
- 310.15(C)(1) no derating for two current-carrying conductors
  - Do not count balanced neutral and ground
- 25A wire × 0.91 = 23A **rounded to nearest whole number**

9 COU derated wire ≥ Imax good!
- 23A ≥ 10A

10 COU derated wire round up to OCPD ≥ OCPD from step 1 good!
- 23A wire rounds up to 25A
- 25A ≥ 15A

Conclusion: 14 AWG wire satisfies the requirements of the code. In this case, however, most people would use a larger wire due to voltage drop. Ten years ago, everyone used a 10 AWG wire, and today many people still use a 10 AWG wire, but the less expensive PV 12 AWG wire is becoming more common, and the 14 AWG wire does not violate the NEC.

**Step 10, Rounding up wire to common overcurrent device**

One of the most difficult concepts for people to get is that, in step 10, we can take the ampacity of the wire and round up to the next common overcurrent protection device size. This is not an actual overcurrent protection device; this is just saying that a wire derated to 23A can actually handle 25A because there is extra ampacity built into 310.16 and a 23A wire in reality can handle 25A. This rounding up comes from 240.4(B) Overcurrent Devices Rated 800A or less (also seen on page 209). For overcurrent devices over

> 800A, you do not get to round up the ampacity of the conductor over the overcurrent device size, which makes more sense.

Wire sizing for voltage drop is a good idea, but it is never a Code issue with the NEC. We will do voltage drop calculations later in this chapter, after we focus on Code compliant wire sizing.

***Example 2***

PV Source Circuit Wire Sizing

Sizing a PV source circuit given the following information:

- Isc = 8A
- Number of PV source circuits in a conduit = 20
- ASHRAE 2% high temperature from www.solarabcs.org = 40°C
- Distance above roof conduit in sunlight = 1 inch
- Terminal temperature limits = 75°C
- Wire type to be used = THWN-2

## Discussion

Defining current:

690.8(A)(1)
Maximum circuit current = Isc × 1.25 = 8A × 1.25 = 10A = Imax (Imax is different from, and not to be confused with, Imp) Required ampacity for continuous current = Imax × 1.25 = 12.5A = Icont
(Icont = Isc × 1.25 × 1.25 = Isc × 1.56)
THWN-2 = 90°C rated wire and we are using 75°C terminals as mentioned.
20 PV source circuits = 40 current-carrying conductors

**Working the 10 steps with our example 2**

1 Round up Icont to fuse size
   - Icont = 12.5A rounds up to 15A fuse as per 240.6
2 Pick conductor size
   - 15A fuse requires at least 14 AWG copper as per 240.4(D)
3 75°C ampacity (75°C terminals)
   - 75°C 14 AWG = 20A as per Table 310.16

4. 75°C Ampacity ≥ Icont good!
   - 20A ≥ 12.5A good!
5. 75°C Ampacity ≥ OCPD good!
   - 20A ≥ 15A good!
6. 90°C ampacity (90°C rated wire)
   - 14 AWG = 25A per Table 310.16
7. 90°C ampacity ≥ OCPD good!
   - 25A ≥ 15A good
8. 90°C ampacity × COU deratings = COU derated wire
   - 310.15(B)(1) 40°C for 90°C rated wire = 0.91 derating
   - 310.15(C)(1) for 40 conductors in conduit = 40% = 0.4
   - 25A wire × 0.91 × 0.4 = 9A rounded to nearest whole number
9. COU derated wire ≥ Imax good!
   - 9A is *not* ≥ 10A, so go back to use next larger wire 12 AWG
   - **12 AWG = 30A** per Table 310.16
   - **30A** × 0.91 × 0.4 = 11A rounded to nearest whole number
   - **11A ≥ 10A** (notice we are not using Icont here)
10. COU derated wire round up to OCPD ≥ OCPD from step 1 good!
   - **11A wire rounds up to 15A** as per 240.6
   - 15A ≥ 15A

Conclusion: **12 AWG satisfies the requirements of the Code here.** It is interesting to note that the condition of use rated wire is 11A and we can round that up to 15A and have an **11A wire protected by a 15A overcurrent protection device!** If you go to Europe, you will see that their wires can carry more current for the same size wire than AWG wires can. We have a buffer of protection built into our wires that will let us deny common sense and round up a wire's ability to carry current.

Would we use a 12 AWG wire here in reality? I think I would use a 10 AWG wire, just to be safe and simple. We do not want to push our luck here with what we have learned in Chapter 12.

## Voltage Drop

When it comes down to voltage drop, what we really want to know is how much money our wire will save for us if we invest more money in the wire. There may be complex calculations, which would have to include tilt, azimuth, copper prices, PV prices, soiling, PV to inverter ratio and weather. In order to perform those calculations, it is recommended to use complex software and perhaps to hire a team of engineers, (or do what everyone else does and use a 10AWG wire).

For the purposes of this book, we will use the maximum output current of the inverter, which is being very conservative, since most if not all of the energy generated from a PV system is going to be less than the maximum output current. For PV source and PV output circuits, we will use the current at maximum power (Imp), which is considerably less than the currents we used to calculate Code compliant wire sizes and is more than we will often see on a PV source circuit.

Some designers will use 80% of these numbers as a rule of thumb, since most of our energy is made when it is not a cold, windy, bright summer noon (optimal PV conditions). We will use Imp and inverter maximum output current for this book, which is conservative and leads to less energy loss over the year than voltage drop percentage in the calculation.

If you are performing voltage drop calculations for a job that you have won a bid on or are bidding on, you should carefully read the requirements of the request for proposal.

We will use a simple calculation to arrive at an AWG wire size given the following information:

Voltage = 240V
Current = 16A
Voltage Drop Percentage = 2%
Distance from inverter to interconnection = 200 feet

Here is the formula that can be used with Chapter 9 Table 8 of the NEC

$$\textbf{Ohms/kFT} = \left(\mathbf{5 \times \% \times V}\right) / \left(\mathbf{I \times L}\right)$$

Ohms/kFT will give us an AWG wire size in Chapter 9 Table 8
5 is a constant derived from (1000FT/kFt)/100%/2 wires in a circuit)
% is the percentage, so we use 2 (not 0.02) for 2%
V is the operating voltage, which is 240V at your house
I is the current of the inverter in this case, which is 16A for a 3.8kW inverter
L is the 1-way distance in feet which is 200 FT

We will plug it in to the equation:

$$\text{Ohms/kFT} = (5 \times \% \times \text{V}) / (\text{I} \times \text{L})$$

$$\text{Ohms/kFT} = (5 \times 2\% \times 240\text{V}) / (16\text{A} \times 200\text{FT})$$
$$= 2400/3200 = 0.75\,\text{ohms/kFT}$$

If we **look up 0.75 ohms/kFT in Chapter 9 Table 8** we see that an uncoated 6 AWG copper wire will have a resistance of 0.491 ohms/kFT and a smaller 8 AWG stranded copper wire will have a resistance of 0.778 ohms/kFT.

Since voltage drop is not a Code issue here, you can choose to round up or down from a 6 AWG or an 8 AWG wire.

This calculation will work for ac and dc wires because the values in Table 9 are essentially the same for ac circuit running at unity power factor. If you are using a large wire for ac and running the circuits at a power factor of 0.85 (may be required occasionally by utilities for grid support), then the values in Table 9 differ from those in Table 8. It's best to get an engineer involved for larger systems as these calculations can get complicated.

In order to use these calculations for 3-phase power, just remember that there is a benefit to using 3-phase that is proportional to the square root of 3 (about 1.73). If we divide the square root of 3 by 2 we get 0.886, so we will have 88.6% of the resistance with 3-phase wires or we can multiply our ohms/kFT answer by 0.866. In the example we used, instead of 0.778 ohms/kFT, we could use a wire that is 0.778 × 0.866 = 0.67 ohms per kFT for 240V 3-phase.

The reason we divide the square root of 3 by 2 is because, with 3-phase, our currents are not directly opposing each other (square root of 3) and we are converting from a calculation that is from single phase power where we have to double the one-way distance of our wire to calculate the resistance of a circuit.

A circuit is a circle and if you are going to have your inverter 200 feet from the interconnection, you need to run electrons through 400 feet of wire and will have 400 feet = 0.4 kFT of resistance. With 3-phase, you will need to have current on three wires, but it will be less current, since the currents are 120 degrees out of phase with each other.

Some people say that understanding 3-phase power takes more than a lifetime to truly understand, but if Tesla (a crazy genius) could figure out how 3-phase power worked all on his own, you can too!

Thank you for reading this book! Sean and Bill.

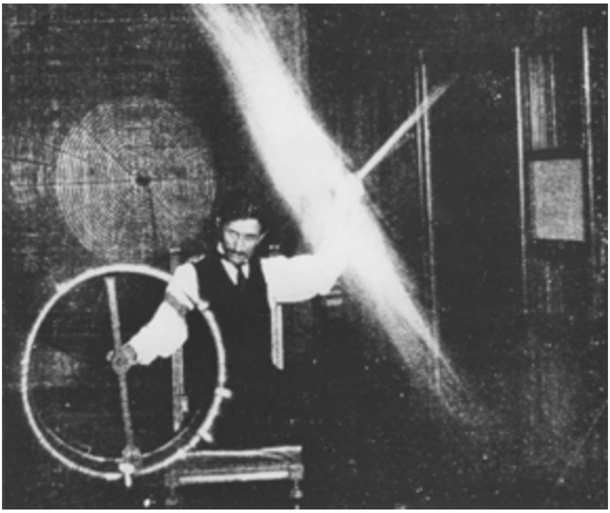

*Figure 12.1* Nicola Tesla demonstrates how to truly understand 3-phase in 1899

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