*A SunCam Online Continuing Education Course*

# National Electrical Code
# (NEC®)

## Solar Power

NEC History / Solar Theory / NEC Solar Photovoltaic Requirements

**Future Courses**

***Special Conditions [Standby Power]***

by

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**Nomenclature**[1]

| | |
|---|---|
| AGND | Analog Ground |
| AWG | American Wire Gauge |
| BOL | Beginning of Life |
| BMS | Battery Management System |
| C | charge/discharge rate of battery in rated A-h |
| CAD | Computer Aided Design |
| DC | Direct Current |
| DGND | Digital Ground |
| DoD | Depth of Discharge |
| EoCV | End of Charge Voltage |
| EoDV | End of Discharge Voltage |
| EOL | End of Life |
| EMC | Electromagnetic Compatibility |
| EMI | Electromagnetic Interference |
| EPS | Electric Power System |
| LIB | Lithium-Ion Battery |
| PMAD | Power Management and Distribution |
| PSIA | Pounds per Square Inch Absolute |
| p-s | parallel-series |
| s | complex "signal" frequency |
| s-p | series-parallel |
| SOC | State of Charge |
| UL | Underwriters Laboratories |
| WCA | Worst Case Analysis |

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[1] Not all the nomenclature, symbols, or subscripts are used in this course—but they are related, and may be found when reviewing the references listed for further information.

**Symbols**

| | |
|---|---|
| A | area |
| A-h | ampere-hours |
| AM | Air Mass |
| C | charge rate |
| I | current |
| L | length |
| N | number |
| P | power |
| R | resistance |
| s | complex frequency |
| t | time |
| T | temperature |
| V | voltage |
| W | watt |
| z | zenith |
| $\rho$ | resistivity |
| $\lambda$ | wavelength |
| $\nu$ | frequency |

**Subscripts**

| | |
|---|---|
| 0 | initial (zero value) |
| avg | average |
| BW | bundled wire |
| C | capacity |
| d | discharge |
| f | final / frequency |
| SW | single wire |

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## HISTORY and CODE OVERVIEW[2]

Edison invented the first practical incandescent light bulb in 1879. In the very same year, the National Association of Fire Engineers met for the purpose of establishing requirements for electrical installations. As with many standards, in a few years there were six different standards in place. Therefore, in 1896 the various concerned groups convened a national meeting and one year later the *National Electrical Code* (NEC) (hereafter referred to as the "Code") was born. [A][3]

The Code is official endorsed by ANSI (American National Standards Institute). The National Fire Protection Association (NFPA) committee responsible for the code is known as ANSI Standards Committee C1. The Code is utilized nationwide with local jurisdictions adoption en masse though with the occasional supplemental additions or deletions. The Code applies to electrical installations within or on public and private buildings up to and including connection to the providing power supply, see Fig. 1. Its overall purpose: prevent fires!

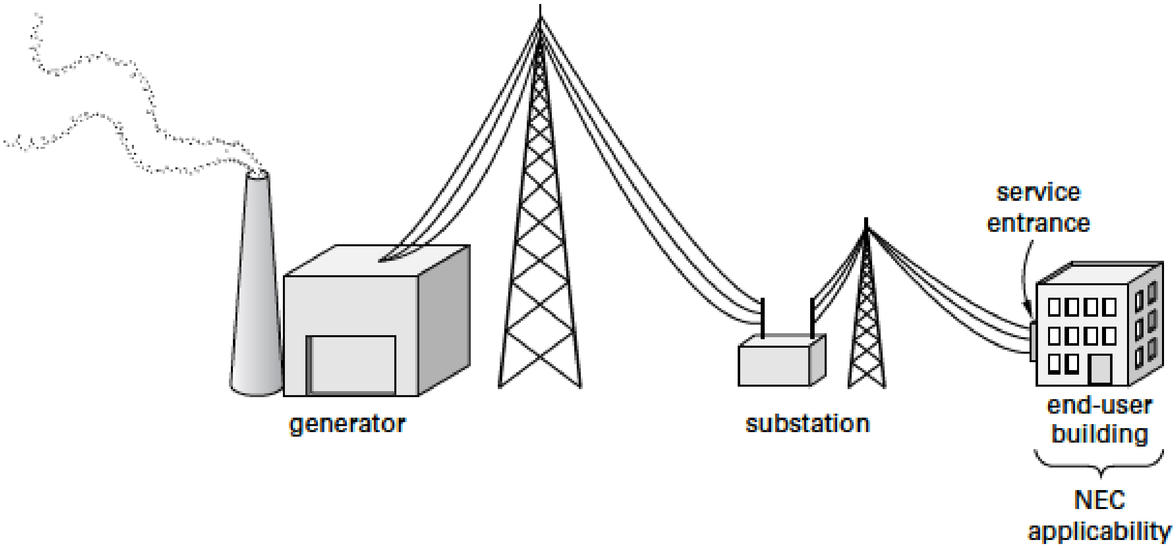

**Figure 1: NEC Coverage**
[Source: *Power Reference Manual for the PE Exam*]

The building code at the international level is International Electrotechnical Commission (IEC) Standard 60364-1, *Electrical Installations of Buildings*. The principles of protection and safety in the IEC code are addressed in the NEC, making it widely applicable.

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[2] Paraphrased from the author's book published by Professional Publications Incorporated of Belmont, CA—now a Kaplan Company: John Camara, *Power Reference Manual for the PE Exam*, 3rd ed., (2018), (Kaplan, Inc., 2018), Chap. 56. In the 4th ed., the NEC is in. Chap. 44.
[3] References will be shown in the "[*]" format.

This course will focus on requirements for such buildings (residential and commercial) and their internals for items with voltages less than 1000 V—including solar power applications.[4] Units will be both SI and USCS (United States Customary System)[5], reflecting their usage in the NEC. The code itself often displays both units with primary emphasis on SI units except where USCS units are still more often used. Conversion between the units in the Code are defined as either *soft* or *hard conversions.* Soft conversions are a change in the description of the measurement *without* changing the actual dimension—thus, the part will be interchangeable. Hard conversions change the dimensions making the part different than the original. As an example, a soft conversion of ½ is 12.7 mm, while a hard conversion is 13 mm.

The course will refer directly to Code Chapters (1-9), Parts (I, II…) Articles (###), Sections (A, A(1), B, B(1)…), and Informative Annexes (A–J).[6] While a copy of the code will be adequate for verification and usage, for those whose occupations require a deeper understanding of the Code and its three-year updates, I recommend the following.[7]

NFPA 70®
National Electrical Code®
HANDBOOK
by
Mark W. Earley, PE
Editor-in-Chief
[B]

This is an official publication of the NFPA with numerous advantages over a mere copy of the Code. For instance, the Handbook contains commentary text in blue, which is used to explain the reasons for the requirement or its application. Revised Code text is shaded gray for ease of noting

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[4] Indeed, this course focuses primarily on those items in the NEC most likely to be encountered during the design and installation of solar project, with emphasis on the specific Solar requirements in Chapter 6 presented in-depth.
[5] Informally referred to as the English Engineering System. Differences do exist but are unimportant for our purposes.
[6] Articles are single-subject entries and Sections and Sub-Sections contain the rules themselves. The word "Article" is often used for "Section" though technically the terminology "Section" should be used. Additionally, in this course, not all Parts are mentioned. They are mentioned when the topics are considered significant.
[7] The author is not associated with this text or the NFPA. I have simply found this handbook extremely useful throughout the years. Also, regardless of the NEC update year, the principles provided in this course will be useful guidance—some article locations may change with the occasional technical update or addition as well.

changes. A single circular bullet on an empty line space, such as that below, indicates deleted sections of the code.

•

The Greek delta symbol ("change"), Δ, when used by a section number indicates words were deleted; when used beside a table it signifies a revision of the data within. An italic *N* reveals a new article, section, table or figure. The Handbook also contains a "See also" marking bringing to the reader's attention other Code areas where additional information is found.[8] Finally, and arguably the most useful features, are the Exhibits containing figures or pictures that bring the words to visual life, Calculation Examples providing scenarios for application of the Code requirements, and a Summary of Technical Changes listed prior to the Code itself.

The Code consists of an introduction followed by nine chapters, which are further subdivided into articles, parts, and sections. It ends with "informative annexes" that provide useful information but no actual requirements.

Introduction

Chapter 1: General
Chapter 2: Wiring and Protection
Chapter 3: Wiring Methods and Materials
Chapter 4: Equipment for General Use

Chapter 5: Special Occupancies
Chapter 6: Special Equipment
Chapter 7: Special Conditions

Chapter 8: Communications Systems

Chapter 9: Tables

Annex A: Product Safety Standards
Annex B: Application Information for Ampacity Calculations
Annex C: Conduit, Tubing, and Cable Tray Fill Tables…
Annex D: Examples
Annex E: Types of Construction
Annex F: Critical Operations Power Systems…
Annex G: Supervisory Control and Data Acquisition (SCADA)

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[8] The "see also" feature is new and extremely helpful. This course will focus on the methodology of finding all the information required to ensure compliance. The Handbook's use of this feature is very much along these lines.

Annex H: Administration and Enforcement
Annex I: Recommended Torque Tables…
Annex J: ADA Standards for Accessible Design

The breaks shown in the bullet list are to resolve the NEC into relevant areas. The Introduction is just that. Chapters 1–4 generally applies to all electrical installations. Chapter 5–7 supplements or modifies the information in Chaps. 1–7. Chapter 8 stands alone unless it specifically references an earlier requirement. Chapter 9 contains major tables and are used when referenced as applicable in the Code. The annexes are for information only and are not mandatory for compliance with the Code.

**Article 90 Introduction**

The Introduction of the code explains its purpose as the "practical safeguarding of persons and property from hazards arising from the use of electricity." Such hazards may exist due to a lack of conformity to the code or not allowing for future expansion of electrical system loading.

The scope of the Code includes public and private building, parking lots, industrial substations, carnivals, installations that connect to the electricity supply, and those electric utility installations that are not an integral part of the power generation, among others. New to the 2020 Code is application of the Code to power to ships, marinas, and shipyards.[9] Also new is coverage of installations that allow power from vehicles to be exported into premises. Check Art. 90.2 for a complete list of items covered and exempted.

The Code is meant to be a legal document for interpretation and implementation by local governmental bodies. Most implement the Code en masse. However, some may adjust portions of the Code as required for local needs. Mandatory Rules are those where action is specifically required or prohibited. The words "*shall*" or "*shall not*" are indicative of such rules. Permissive Rules are those where action is allowed but not required. The words "*shall be permitted*" or "*shall not be required*" are indicative of such rules. Explanatory Materials is contained in Informational Notes. Such notes are just that, "*information*," and as such are not enforceable portions of the Code. Another unenforceable portion of the Code are the Informational Annexes, which provide guidance on Code use.

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[9] This is a timely addition given the increased prevalence of ESD—Electric Shock Drowning. Many "drownings" around boats are labeled as such when in fact they may be due to electric current flowing in the water due to a faulty wiring condition on a nearby boat.

## Chapter 1 General

### Article 100
*Definitions*

This article contains essential definitions; that is, those indispensable to the Code while exempting common technical terms found in other codes and standards.

*Accessible equipment* is capable of being reached for “operation, renewal, and inspection.” *Accessible wiring* is that capable of being “removed or exposed without damaging” a structure or finish. *Readily Accessible* indicates the ability to reach equipment or items without using tools (except for keys) or having to remove interfering equipment.

*Ampacity* is the maximum current a conductor can carry without exceeding its temperature rating. The *Authority having Jurisdiction* (AHJ) is the authority with responsibility for enforcing the Code or approving installations, equipment, et cetera.

*Bond* and *Bonding* is the connection or cable/wire, and process used to ensure electrical continuity and conductivity. Bonding is NOT grounding, do not confuse the two. A *Ground* is the earth with *Grounding* indicating the connection to the ground or the connective body that extends to the ground.

Consider a typical distribution system as shown in Fig. 2. The definitions for the individual portions, though somewhat self-explanatory, are also contained in Art. 100. A *branch circuit* are the conductors between the final overcurrent device and the outlet(s). A *continuous load* is one in which the maximum current is expected to last for 3 hours or more. *Continuous duty* is operation at a substantially constant load for an infinitely long time.

Electrical circuits are subject to overcurrent conditions and as such a system should be designed for *selective coordination*; that is, localization of an overcurrent condition to the circuit or equipment effected. Meaning, should a fault occur, it impacts the circuit or equipment with the fault and not the rest of the system. This is isolating closest to the fault and as far from the source as possible. Also, of note for those designing protective systems, overcurrent is a fault condition exceeding the range of the equipment, which could result in damage. *Overcurrent* (faults) can ripple through a poorly designed system and are defined as any current in excess of rated equipment current or ampacity of the conductor and may result from short circuit, ground fault, or overload. *Overload* is a condition where current is slightly above the maximum, which could result in overheating. Overloads generally impact one circuit or piece of equipment only. Per Fig. 2, a fault on the lower branch circuit should open the fixed overcurrent protective device in the panelboard and not any protection for the feeders in the power supply source.

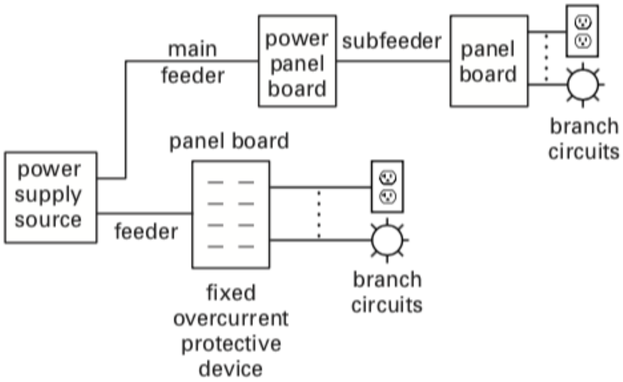

**Figure 2: Typical Distribution System**
[Source: *Power Reference Manual for the PE Exam*]

Figure 3 should be referred to for the bonding and grounding explanation that follows. The generic terms used by electricians and engineers for the grounding wiring doesn't match-up with the technical names provided by the NEC, so understanding the differences is very helpful in the field.

A *Bonding Conductor* or *Jumper* is a reliable conductor necessary to ensure electrical conductivity between metal parts. The Bonding Jumper is shown as yellow in the NEC figures. An *Equipment Bonding Jumper* provides connection between two or more portions of the *Equipment Grounding Conductor*, the latter of which is the green wiring. That is, when all the metal parts are not electrically connected, the bonding jumper provides the continuity to the grounding (green) system. Of note, the equipment grounding conductor (green) is NOT meant to carry current under normal conditions. It is there for safety in the event of a fault to prevent the metal parts from achieving a voltage above that of earth ground and thus presenting a hazard to people. The *grounding electrode* is a conducting object through which a direct connection to Earth. The *grounding electrode conductor* connects the system *grounded conductor* (intentional grounded conductor—white wire, the neutral) or the *equipment grounding conductor* (safety ground—green wire), or both, or to a point on the grounding electrode system.[10]

The *Main Bonding Jumper* is the connection between the *grounded circuit (service) conductor* (white—commonly called the "neutral") and the *equipment grounding conductor* (green—commonly called the "ground") or the *supply-side bonding jumper*, or both. All are shown in Fig.

---

[10] The "grounded conductor" is almost always the neutral conductor; that is, the white wire. One exception is a corner grounded delta, which does not have a neutral point but instead grounds one end of two different phases.

3. The terminology shown in quotations represents the name one might hear in the field, from electricians, or those familiar with wiring and its usage.

The numbering and connection scheme on the panelboard in Fig. 3 are standard. The black “hot” wire is connected to breaker slots #1 and #2. The red “hot” wire is connected to breaker slots #3 and #4. The potential between the red and black wires is 208 V for most households. The potential between the red and neutral, or black and neutral, is 120 V. Therefore, if a double breaker setup is used between slots #1 and #3, the voltage is 208 V. Now consider the single receptacle shown in the diagram. The red hot wire in slot #36 (not labeled in order to show the circuit breaker) connects to the hot side of the receptacle. The neutral white wire connects to the larger receptacle opening. The voltage on the receptacle and between slot #36 and neutral is 120 V. The equipment grounding conductor, the green wire, is connected to the grounding input on the receptacle—no current intentionally flows on this green wire, only during as fault does current use this path thus keeping the potential at Earth ground potential, 0 V, and protecting anyone touching the receptacle metal.

Breakers used in the household panel boards provide overcurrent, overload, arc fault circuit interruption (AFCI), and ground fault circuit interruption (GFCI), all of which will be covered in the appropriate articles.

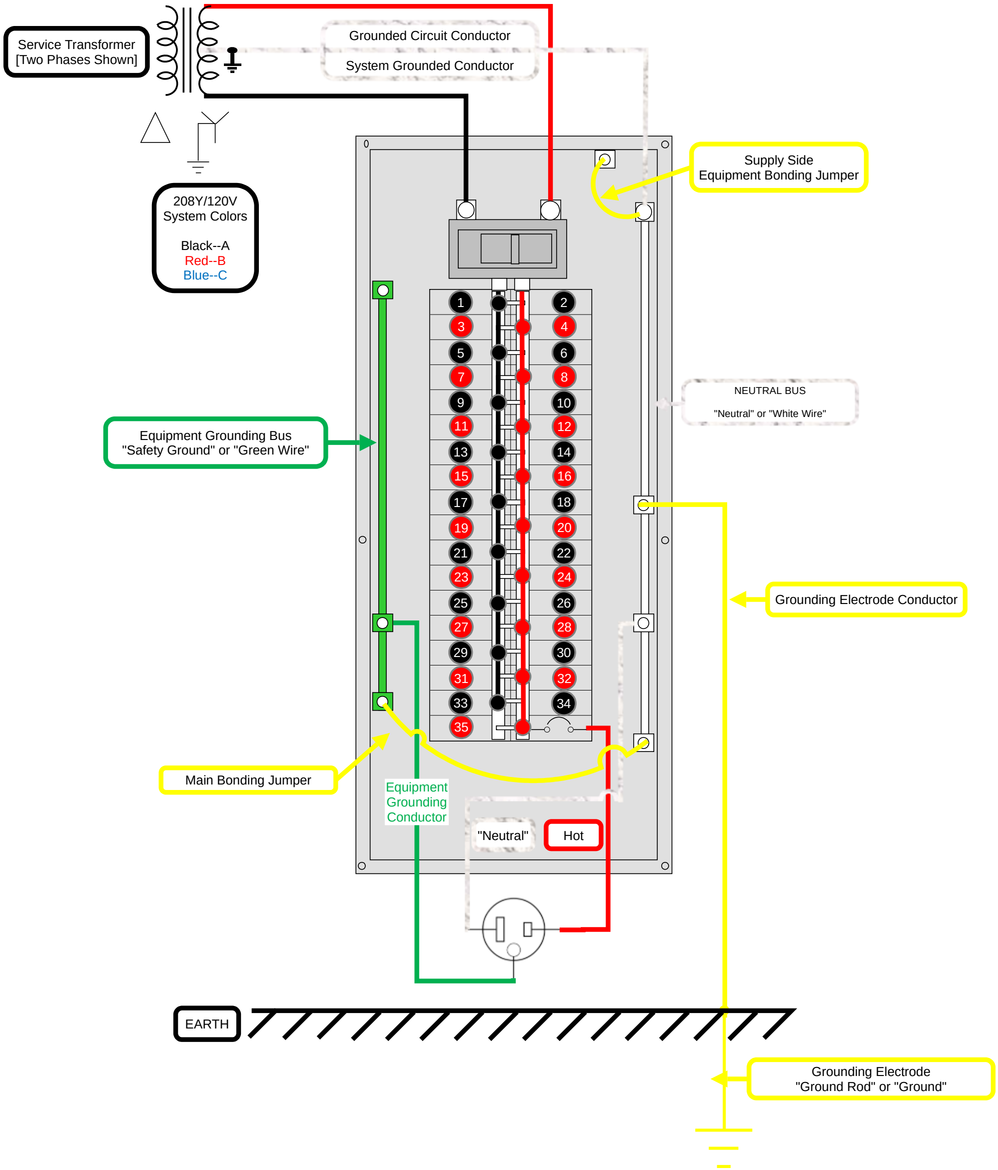

**Figure 3: Bonding and Grounding Terminology**

The *demand factor* is the ratio of the maximum demand of the system (or portion thereof) and the total connected load. This value is always less than one. This is not to be confused with the diversity factor, which is not found in the NEC—instead it is found in the IEC 61439 (Low Voltage Switchgear and Control Gear Assemblies), and is used in electrical switchgear designs outside the purview of the NEC. Think of this as the requirements for industrial low voltage assemblies.

The *diversity factor* is the ratio of the sum of the individual maximum demand of the systems to the total connected load. The diversity factor is greater than or equal to one. The distinction is a demand factor is time independent (and conservative), which results in the need for larger wires—and thus is the standard in the NEC. The diversity factor accounts for time, meaning, not all the maximum loads will occur at the same time. So, for example, an 80% diversity means a device or subsystem operates at its maximum 80% of the time it is turned on. Residential loads have the highest diversity factors while industrial systems generally have the lowest.

When performing feeder calculations with the NEC, the load is multiplied by the demand factor lowering the overall wiring size. When performing feeder calculations for feeders upstream of the service entrance panel to a residence or in and industrial facility for switchgear assemblies, the load is divided by the diversity factor to lower the overall wiring size.

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**Example 1**

Four feeders in a large hotel complex are utilized to provide power to lighting loads. The feeder power is as follows.

Feeder #1: 15 kVA
Feeder #2: 10 kVA
Feeder #3: 50 kVA
Feeder #4: 75 kVA

Demand Factor 1: 60% for first 20 kVA
Demand Factor 2: 50% for 20,001 VA to 100 kVA
Demand Factor 3: 35% for total loads > 100 kVA

What total power must the incoming transformer provide, and the incoming service feeder carry, using the demand factors shown?

**Solution**

The maximum total loading is as follows.

$$\begin{aligned} L_{Total} &= L_1 + L_2 + L_3 + L_4 \\ &= 15\text{ kVA}+10\text{ kVA}+50\text{ kVA}+75\text{ kVA} \\ &= 150\text{ kVA} \end{aligned}$$

Applying the demands factors gives the demand factor (DF) load, which the transformer must be designed for and the feeders must carry at the appropriate voltage, gives the following.

$$\begin{aligned} L_{DF} &= (20\ \text{kVA})(0.60) + (80\ \text{kVA})(0.50) + (50\ \text{kVA})(0.35) \\ &= 12\ \text{kVA} + 40\ \text{kVA} + 17.50\ \text{kVA} \\ &= 69.5\ \text{kVA} \end{aligned}$$

---

### Example 2

Loading studies for the hotel complex in Example #1 determine that the maximum system loading occurs in the evening and is expected to be 50 kVA. What is the diversity factor? What minimum size transformer must be used for such a diversity factor?

**Solution**

Recall the *diversity factor* is the ratio of the sum of the individual maximum demand of the systems to the total connected load.

$$\begin{aligned} DF &= \frac{L_1 + L_2 + L_3 + L_4}{L_{SystemMax}} \\ &= \frac{15\ \text{kVA} + 10\ \text{kVA} + 50\ \text{kVA} + 75\ \text{kVA}}{50\ \text{kVA}} \\ &= \frac{150\ \text{kVA}}{50\ \text{kVA}} \\ &= 3 \end{aligned}$$

The loading of the transformer and feeders using the diversity factor ($F_{df}$) is thus given by the following.

$$\begin{aligned} L_{df} &= \frac{L_{Total}}{F_{df}} \\ &= \frac{150\ \text{kVA}}{3} \\ &= 50\ \text{kVA} \end{aligned}$$

The demand factors come from the NEC Table 220.42. The diversity factor was fictional but would be based on studies or the data in IEC 61439. Clearly, the latter requires a smaller transformer and wiring. Which is used depends upon local rules from the *authority having jurisdiction* (AHJ).

Continuing with definitions from Art. 100, an *electrical datum plane* is a specified distance above a water level above which electrical equipment can be installed and electrical connections made. This includes rain and snowfall, the opening of dams and floodgates but NOT manmade or natural disasters. An *equipotential plane* are the accessible conductive parts bonded together to reduce voltage gradients.

*Available fault current* is the largest amount of current delivered to the fault point in a system during a short circuit. The current available can be limited by wiring resistance, overcurrent protective devices, and transformer capability (rating).[11]

When applied to a conductor, *free air* indicates an open *or ventilated* (italics are the author's) environment allowing for heat dissipation and air flow around said conductor.

*Island mode* is an operational mode of a stand-alone power production equipment or isolated microgrid. Such island mode setups are increasing common and involve the use of solar equipment as well as standard diesel generators. Isolated microgrids differ from interconnected microgrids whose latter requirements are in Art. 705.

Locations are classified as *damp*—subject to moisture, *wet*—underground or in direct contact with the earth, and *dry*—which is a location not normally subjected to dampness or wetness but could be temporarily exposed.

A *service* is the conductors and equipment connecting the serving utility to the wiring of the premises. A *separately derived system* is one other than a source. Examples include generators, transformers, or solar systems that have no direct connection (other than incidentally through grounding or metal enclosures) to another source.

The *voltage* of a circuit is the greatest root mean square (rms), also known as *effective*, difference in potential between any two conductors. For example, 208Y/120 V and 480Y/277 V. The first voltages listed are those between ungrounded (phase) conductors whereas the voltages listed second (i.e., 120 V and 277 V) are the voltages from a conductor (phase) to the grounded conductor (neutral). A *nominal voltage* is a value assigned for the purpose of conveniently designating a circuit's or system's voltage class. For example, 240/120 V, 480/277 V, and 600 V.

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[11] Once a transformer saturates, it can no longer deliver any additional energy to its secondary windings.

## Article 110

*Requirements for Electrical Installations*[12]

The scope of this article includes the general requirements for installation, use, access, and examination and approval of such electrical systems (Art. 110.1). Conductors and electrical equipment must be approved (Art. 110.2). This approval is often from the electrical inspection authority, or listing from laboratories (such as UL—Underwriters Laboratories), or testing from field-based third-party laboratories. The Occupational Safety and Health Administration (OSHA) provides recognition of qualified testing laboratories (Art. 110.3(C) Informational Note).

Conductors in the Code refer to copper, aluminum, or copper-clad aluminum only. If not specified, the conductor referred to is copper (Art. 110.5). Conductor sizes are specified as AWG (American Wire Gauge) or in circular mils (cmil or kcmil) (Art. 110.6). Wire sizes up to 4/0 (called “four aught" or exactly as 0000 AWG) are in AWG while those above (larger) are in circular mils. The wire sizes then are 4/0, 3/0, 2/0, 1/0, 1 AWG through 40 AWG, from largest to smallest. The unit circular mil represents an area equal to the area of a circle with a diameter of 0.001 inches. Various conversions to more standard areas are as follows.

$$A_{cmil} = \left( \frac{d_{inches}}{0.001} \right)^2$$

$$A_{\mathrm{in}^2} = 7.854 \times 10^{-7} \times A_{cmil}$$

$$A_{\mathrm{cm}^2} = 5.067 \times 10^{-6} \times A_{cmil}$$

Electrical equipment shall be installed in a “neat and workmanlike manner” per Art. 110.1. Many discrepancies occurring during inspections fail this category. While somewhat subjective, guidelines are in ANSI/NECA 1-2015, *Standard for Good Workmanship on Electrical Construction*.[13]

Exposed live parts, for systems 1000 V nominal or less, have height, depth, and width restrictions as laid out in Art. 110.26. The clearance depth depends how the live parts are exposed and are delineated in Table 110.26(A)(1). The minimum width is the width of the equipment or 30 inches, whichever is greater, and must allow for 90 degree opening of hinged panels per Art. 110.26(A)(2).

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[12] From this point onward, the “Chapter, and Part” designations generally will not be utilized. While helpful when directly viewing the table of contents, the individual article / section numbers will take one directly to the required information.

[13] NECA stands for National Electrical Contractors Association.

The clearance height shall be 2.0 m (6 ½ ft) or the height of the equipment, whichever is greater per Art. 110.26(A)(3).

## Chapter 2 Wiring & Protection

### Article 200 Use and Identification of Grounded Conductors

An insulated grounded conductor size AWG 6 or smaller shall be identified as follows (Art. 200.6(A)).

- Continuous white outer finish
- Continuous gray outer finish
- Three continuous white or grey stripes on other than green insulation
- Colored tracer threads in the braid identifying the source of manufacture[14]
- Mineral-insulated, metal-sheathed cable (Type MI) shall be identified by distinctive markings at its terminations
- Fixture wires shall be identified by one or more continuous stripes (Art. 402.8; See also 400.22(A)-(E))[15]
- Aerial cables may comply with thee above or by having a ridge on the exterior of the cable as the means of identification

An insulated grounded conductor size AWG 4 or larger shall be identified by the first three methods above or by white or gray markings on the terminations (Art. 200.6(B)).

Grounded conductors of different systems in the same raceway, cable, et cetera, are identified as above but differently from one another (Art. 200.6(D)). For example, the neutral in a 480Y/277 V system could be gray while the other neutral for the 208Y/120 V would then be white.

Receptacles, plugs, and connectors terminal connections for the grounded conductor (neutral) shall be white, marked “W” or “white” or be silver in color. The other terminal (hot) shall be different—often brass (Art. 200.10(B)).

## Chapter 3 Wiring Methods & Materials

## Chapter 4 Equipment for General Use

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[14] This allows an electrician to trace a neutral through a conduit or raceway containing multiple neutrals and know at the other end the correct one for the system being worked.

[15] A fixture is a piece of equipment in a fixed position, while cord- and plug-connected wiring may be easily moved.

## Article 480 Storage Batteries

The article itself covers stationary battery installations. It starts with a note listing many IEEE and UL standards that are applicable. These standards are in an "information note" and as such are not part of the requirements of the NEC, but by listing them they clearly should be read and understood. Figure 4 shows some battery terminology.[16]

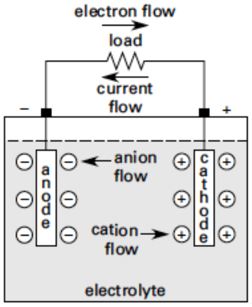

**Figure 4: Battery Standard Terminology**
[Source: *Power Reference Manual for the PE Exam*]

### *480.2 Definitions*

**Nominal Voltage (Battery or Cell)**: The value assigned to a cell or battery for the purpose of convenient designation. The operating voltage varies depending on a variety of factors.

*Informational Note*: Lead-Acid has a nominal cell voltage of 2 V/cell. Alkali systems have a nominal of 1.2 V/cell. Li-ion cells, now in widespread use to due high energy density, have a nominal voltage of 3.6 V/cell to 3.8 V/cell.

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[16] Anode is from a Greek word meaning ascent, sometimes translated as high water. When Ben Franklin performed his famous kite experiment, it appeared to him as if a cup was being filled to overflow. He named those charges as positive and from that we get anode since current (water) flows from high to low. Unfortunately, the sparks he observed were electrons, which were discovered later and given the negative charge. So now, as engineers we learn that "conventional current flows" from positive to negative (which it does inside the battery, hence the anode/cathode designations) and positive to negative when discharging outside the battery, hence the red cover on the cathode connection of the battery and the label +, and the black cable on the anode connection of the cable and the label –.

### Example 3

A standard car battery is lead-acid and operates at approximately 12 V. Approximately how many cells does the car battery contain?

**Solution**

Using 2 V/cell nominal gives the following number of cells.

$$\begin{aligned} N_{\text{cells}} &= \frac{V_{\text{operating}}}{V_{\text{per cell}}} \\ &= \frac{12\ \text{V}}{2\ \text{V/cell}} \\ &= 6\ \text{Cells} \end{aligned}$$

### *480.10 Battery Locations*

Battery spaces require ventilation to prevent an explosive mixture from forming. Mechanical ventilation may not be required. Hydrogen disperses easily though. It accumulates at the top of spaces and a means of removal must be installed. Certain batteries called "Valve-Regulated" are considered to be sealed but even during normal operation may emit some hydrogen.[17] During failure of such a battery large amounts of explosive gasses can be released. Only Li-Ion and Nickle Chloride do not require ventilation during normal and abnormal charging conditions.

## Chapter 5 Special Occupancies

## Chapter 6 Special Equipment

This will be covered in-depth with emphasis on solar power installations.

## Chapter 7 Special Conditions

This will be covered in-depth in a future course with emphasis on standby power, that is, *critical operations power systems* (COPS).

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[17] VRLA stands for Valve-Regulated Lead Acid.

## Chapter 8 Communication Systems

## Chapter 9 Tables

Chapter 9 is a mandatory part of the NEC. Since the metric system is worldwide with the exception of the US, the tables for conduit list a metric trade designator and trade size. These can be found in Table 300.1(C). For example, a ¾ inch conduit metric designator 21 and trade size ¾.

One of the more commonly used tables during construction or remodeling is ***Table 1 Percent of Cross Section of conduit and tubing for Conductors and Cables***. The remaining tables provide the allowable fill for the different types of conduit. Since most conduit carries two or more wires, the author recommends remembering one number from the table for immediate recall: 40%. That is, for two or more wires in the conduit the area filled cannot exceed 40%.

General guidance, not part of the NEC itself is something called the *jam ratio*. The jam ratio is defined as follows.

$$R_{\text{jam}} = \frac{ID_{\text{raceway/conduit}}}{OD_{\text{conductor}}}$$

To avoid jams in conduits or raceways, avoid values between 2.8 and 3.2.[18]

### NEC Annexes

Recall that all annexes are not part of the NEC per se, meaning they are not requirements.

### Annex A

Annex A contains an extensive list Product Safety Standard references with very specific applications.

### Annex B

Annex B provide guidance and examples for ampacity calculations.

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[18] Source NFPA 70 NEC Handbook guidance in Chapter 9.

**Annex C**

Annex C contains fill tables for various configurations

**Annex D**

*This annex just might be the most useful in that it contains example calculations directed related to dwelling requirements.*

**Annex E**

This annex contains construction guidance for buildings. For those requiring more information, see *NFPA 5000, Building Construction and Safety Code*.

**Annex F**

The title for this annex says it all, *Availability and Reliability for Critical Operations Power Systems; and Development and Implementation of Functional Performance Tests (FPTs) for Critical Operations Power Systems*.

For those responsible for standby power systems, this is the appropriate annex.

**Annex G**

This annex covers *Supervisory Control and Data Acquisition (SCADA)* systems. One important suggestion given is that the COPS loads be separate from the rest of the building.

**Annex H**

This annex is meant to be a template for local jurisdictions adopting the NEC. It should be noted that some jurisdictions will adopt the code and modify, delete, or add requirements. Those modifications, of whatever type must be understood when building in an area of a given AHJ (Authority Having Jurisdiction).

**Annex I**

This annex contains recommended tightening torque tables from UL Standard 468A-486B.

**Annex J**

This annex contains guidance to meet ADA standards in buildings.

## SOLAR THEORY

A solar cell, also called a photovoltaic cell, is a device that absorbs the energy of photons of light changing those photons into electricity. The conversion is both physical and chemical. The photovoltaic cell properties of voltage, current, and resistance vary with the application of light.[19] Of note, light is defined as the part of the electromagnetic spectrum visible to the human eye.

The photovoltaic cells form building block known as modules, called in the vernacular a "solar panel." A silicon cell produces 0.5 V to 0.6 V. Therefore, multiple modules must be connected in series to obtain the desired voltage. [C] The symbol for a solar cell is shown in Fig. 5.[20]

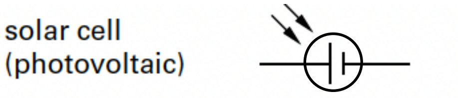

**Figure 5: Solar Cell Symbol**
[Source: *Power Reference Manual for the PE Exam*]

The cell functions because of an energy gap in materials, between a valence band and a conduction band. A generic overview is shown in Fig. 6 for conductive metals, for non-conductive insulators, and for semiconductors that form solar cells. A bit more explanatory view between a metal and silicon is shown in Fig. 7.

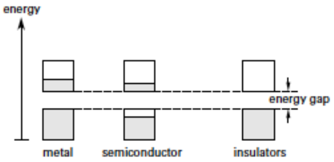

**Figure 6: Energy Band Diagrams**
[Source: *Power Reference Manual for the PE Exam*]

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[19] The variation occurs not so much with frequency given that light is restricted to 400 nm – 700 nm in wavelength or about $4 \times 10^{14}$ Hz – $7 \times 10^{14}$ Hz.

[20] The symbol is shown within a circle (that is, an enclosing envelop). This is only done if the device has an essential operating function, for example, it is a single cell. If part of a module or an entire panel, it is shown without the circle (or sometimes with the circle but with the + or – shown). See IEEE-STD-315 or ANSI Y.32.2 for information.

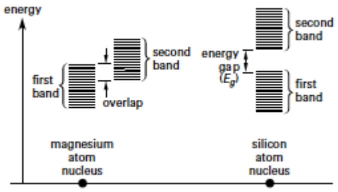


**Figure 7: Multiple Energy Bands**
[Source: *Power Reference Manual for the PE Exam*]

A detailed few displaying how the energy gap forms with atomic spacing is shown in Fig. 8.

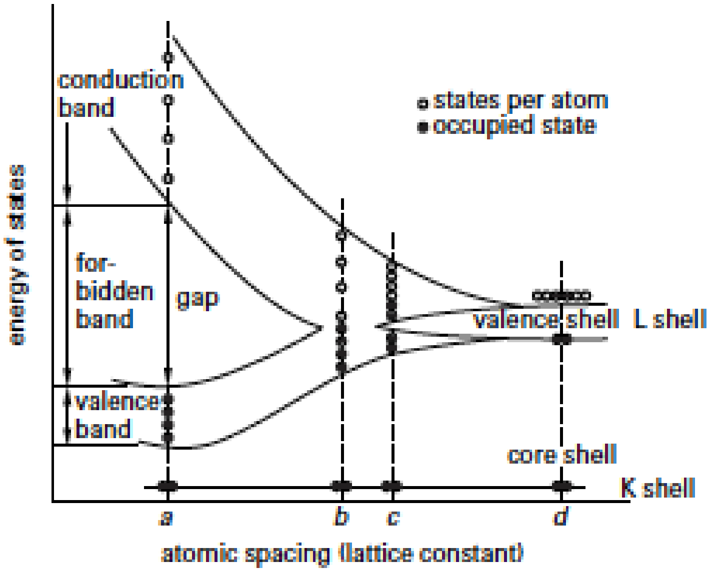


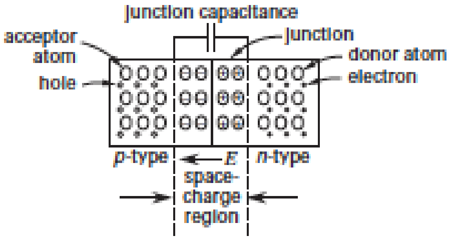
**Figure 8: Energy Bands of Carbon as a Function of Atomic Spacing**
[Source: *Power Reference Manual for the PE Exam*]

More information on the interaction of radiation (photons) with matter, the formation of energy gaps, and related topics should study the phenomena of quantum mechanics. A focus on quantum mechanics as it impacts electrical engineering can be found in [D]. One of the more important relationships impacting solar cells is the wavelength and frequency formula show in Eq. 1. Lambda is the wavelength in meters (m), c is the speed of light at approximately 3 x $10^8$ m/s, and nu is frequency in Hz.

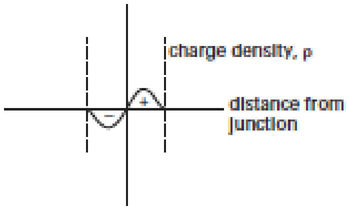
**Equation 1: Frequency and Wavelength**

$$l = \frac{c}{n}$$

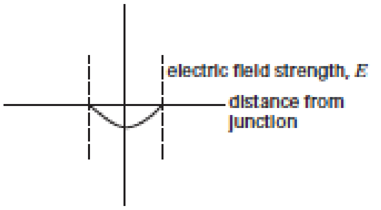
To utilize this energy gap in semiconductors, a *pn* junction is formed as shown in Fig. 9, which forms the basis of the solar cell.



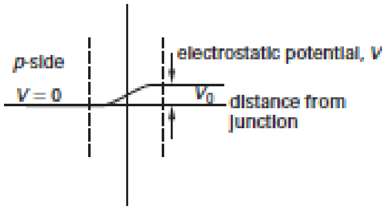
(a) *pn* junction



(b) charge density



(c) electric field intensity



(d) electrostatic potential

**Figure 9: Junction Characteristics of a pn Junction**
[Source: *Power Reference Manual for the PE Exam*]

The concentration gradient across the junction causes holes to diffuse to the right, and electrons to diffuse to the left. As a result, the concentration of holes on the p-side near the junction is depleted and a negative charge exists, Fig. 9(a). The concentration of electrons on the n-side near the junction is depleted as well, and a positive charge exists. The result of this diffusion is shown in Fig. 9(b), the shape of which is determined by the level of doping. The diffusion process continues until the electrostatic field set up by the charge separation is such that no further charge motion is possible. The net electric field intensity is shown in Fig. 9(c) with the potential shown in Fig. 9(d). The net result is a small region in which no mobile charge carriers exist. This region is called the space-charge region, depletion region, or transition region. Holes have a potential barrier they must overcome to move from left to right and similarly for electrons moving from right to left.

If a semiconductor junction is constructed so that it is exposed to light, the incoming photons generate electron-hole pairs. When these carriers are swept from the junction by the electric field, they constitute a photocurrent, which is seen as an increase in the reverse saturation current. The holes generated move to the p-type material and the electrons move to the n-type material in response to the electric field that is established whenever p- and n-type semiconductors are joined (see Fig. 9). Such devices are used as light sensors and are called photodiodes. When the device is designed without a biasing source, it becomes a solar cell.

A diode with a voltage source apply a forward bias will inject carriers across the junction that are above thermal equilibrium. When the carriers recombine, they emit photons from the *pn* junction area. The photon is caused by the recombination of electron-hole pairs. The wavelength depends on the energy band gap and thus on the material used. Gallium arsenide (GaAs) and other binary compounds are commonly used. When the photon is in the infrared region, the mechanism is called electroluminescence and the diodes are called electroluminescent diodes. If the photons are in the visible region, the devices are called light-emitting diodes (LEDs).

The major differences between an LED and a Solar Cell are shown in Table 1.

**Table 1: Properties of a Solar Cell vs LED**

| **Solar Cell** | **LED** |
|---|---|
| Converts Light Energy into Electric Energy | Converts Electrical Energy into Light Energy |
| Output: DC Electrical Current | Output: Light |
| Principle: Photovoltaic Effect | Principle: Electroluminescence |
| Large *pn* Junction Area | Small *pn* Junction Area |

Junction specifically designed as solar cells can be modeled as shown in Fig. 10.

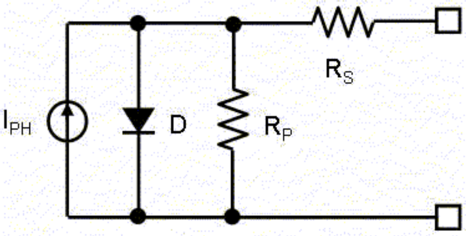


**Figure 10: Solar Cell Equivalent Circuit**

The term $I_{PH}$ is the photon generated current created by the cell. The term $R_p$ represents non-ideal properties of the cell resulting in a parallel current. The series term $R_s$ represents losses caused by connections to cell. The diode D provides overall control of the output voltage of the cell (panel). As the current rises with sunlight the voltage will build. The diode forward biases at some desired level (often 20% higher than the output circuit requires) clamping the output. The many equations used for actual design of terrestrial solar cell systems can be found in [E]. Effects of temperature, operating points, distance from the sun, battery charging considerations for space arrays can be found in [F].

Some generalities to keep in mind. The higher the temperature of the solar cell result in less efficient conversion. Solar cells are often made with silicon with efficiencies of 15%–20%. More efficient cells, which absorbed more of the wavelengths of light, are made with GaAs or InSe with efficiencies of some 30%.[21] Approximately 1380 W/m$^2$ of the Sun's energy exists at the top of Earth's atmosphere [G]. Only approximately 30% of that is available on the surface (depends greatly on the latitude), which averaged over a spherical Earth is 340 W/m$^2$. Thus, with solar cell efficiencies, at best some 30% of the 30% available will be converted to usable energy.

## NEC Photovoltaic Requirements

### Article 690 Solar Photovoltaic (PV) Systems

*Part I General*

*690.1 Scope*

The scope is given in 690.1 and is primarily focused on smaller solar photo voltaic (PV) systems, with large-scale PV systems covered in Art. 691. It covers PV systems that are stand-alone or interactive. The term "interactive" refers to the output of the system, which can be ac or dc, and which connects to *another power production and distribution network*, that is, the PV system is

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[21] Recently, 2022, a multi-junction cell absorbing multiple wavelengths was able to reach an efficiency of 39.5%, though with a significantly increased cost over commercial solar panels.

not the only source.[22] Figure 11 shows a standalone system. Note it does contain a battery backup (located before the system output) and the output goes to loads that have no other connection to a power *production* or distribution network; that is, no other power source. The battery is considered part of the PV system.

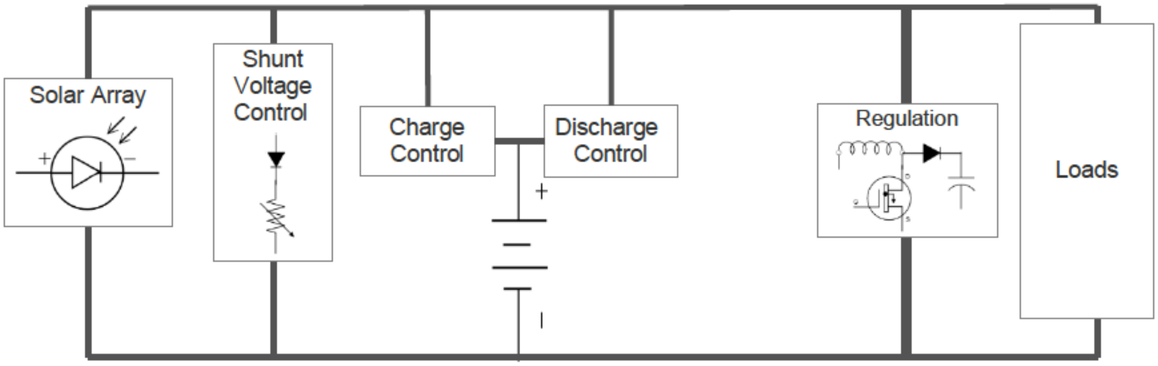

**Figure 11: Standalone PV System**

If there are multiple sources, connected through a multimode invertor (DC to AC), and some of the loads are on the DC side, the system is called a DC coupled multimode system. If the loads are located on the AC side only, the system is called an AC coupled multimode system. The symbol (one of many) is shown in Fig. 12. The solid line above the dashed line indicates DC changing to AC. The AC symbol indicates the AC output side of the inverter. The diagonal dashed line indicates power can flow both ways (DC to AC or AC to DC).

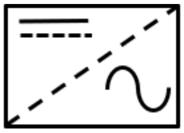

**Figure 12: Multimode Inverter**

### *690.4 General Requirements*

Photovoltaic (PV) systems are allowed to be used in combination with any other electrical supply system(s) [690.4(A)]. The requirements for such interconnected power production sources may be found in Art. 705. Components used in PV systems must be listed or evaluated for the given

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[22] If the PV system is connected by an "interactive inverter", the output is AC and its referred to as an interactive system. If the PV system is connected by a "multimode inverter", the AC and DC power can flow both ways, and its referred to as DC coupled (when loads are on the DC and/or AC side) and AC coupled (if loads are on the AC side only). See Figs. 15 and 16.

application and have field labels applied to so indicate [690.4(B)].[23] PV equipment or disconnects are not allowed to be installed in bathrooms [690.4(E)]. However, power converters may be installed on roofs or other inaccessible areas [690.4(F)] but their disconnecting means have to be installed per 690.15. The term "accessible" is in the Definitions Art. 100.[24]

### *Part II Circuit Requirements*

### *690.7 Maximum Voltage*

The maximum voltage of which the PV system is capable shall be used as the voltage for application of the Code. Additional restrictions are that PV system DC circuits shall not exceed 1000 V within or originating from arrays attached to buildings and circuits inside buildings. If in a one- and two-family dwellings, the restriction is 600 V. If such a system exceeds 1000 V, compliance with 690.31(G) is mandatory.

The maximum DC voltage is calculated using one of the following three methods depending upon type of cell or capacity of the system. One, use the sum of the PV module-rated open-circuit voltage of the series connected PV string corrected for the expected lowest temperature using temperature coefficients from the listing or labeling of the equipment [690.7(A)(1)]. Two, for silicon modules use the sum of the PV module-rated open-circuit voltage of the series connected PV string corrected for the expected lowest temperature using the factors in Table 690.7(A) [690.7(A)(2)]. (An excerpt of the table is given in Table 2.) Three, for an inverter with a generating capacity of 100 kW or greater, a documented and stamped PV system design voltage is required using an industry standard method calculated by a licensed professional electrical engineer.

**Table 2: Voltage Correction Factor for Crystalline and Multicrystalline Silicon Modules**

| **Correction Factors for Ambient <25ºC (77ºF)** | | |
|---|---|---|
| **Ambient Temperature (ºC)** | **Factor** | **Ambient Temperature (ºF)** |
| 24 – 20 | 1.02 | 76 – 68 |
| 4 – 0 | 1.10 | 40 – 32 |
| –16 to –20 | 1.18 | 4 to –4 |

From Table 2 one can note that decreasing temperature increases the open circuit voltage. Or, to invert the logic, as temperature increases the open circuit voltage decreases. This occurs because

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[23] Third party field evaluation bodies are covered in NFPA 790. Field evaluation of equipment is covered in NFPA 791.

[24] Definitions that were previously located in their associated articles were moved to Art. 100 in the 2023 Code.

increasing temperature results in a lower energy gap in the semiconductor affecting the semiconductor properties, importantly, the output voltage.

### Example 4

A silicon solar module designed for a 12 V system has an open circuit voltage of 21 V maximum. Ten of the modules are to be used in series. The system is to be utilized in a cold clime of Wisdom, Montana where the ambient temperature is expected to be 35ºF.

What is the maximum voltage value to be used for design purposes?

**Solution**

The nominal voltage of 12 V is NOT used. The maximum voltage of 21 V for the module is the voltage of interest. Since there are 10 modules ($N = 10$) in series, the maximum voltage is as follows.

$$\begin{aligned} V_{\text{max}} &= V_{\text{module max}} N_{\text{series modules}} T_{\text{factor}} \\ &= (21\text{ V})(10)(1.10) \\ &= 231\text{ V} \end{aligned}$$

### *690.8 Circuit Sizing and Current*

There are two methods for calculating the maximum current. In the first, the maximum short-circuit current is the sum of the current ratings of the modules in parallel multiplied by 125% [690.8(A)(1)(a)(1)].[25] Or, for systems with a capacity of 100 kW or greater, the current determined by an industry standard method calculated by a licensed professional engineer shall be documented and stamped on the system. It is a calculation of the highest 3-hour current based on local irradiance accounting also for the elevation and array orientation. This value cannot be less than 70% of the value calculated using the 125% method [690.8(A)(1)(a)(2)].

The second method involves a circuit connected to an electronic power converter. If this is the case, and when the circuit is protected by an overcurrent device that prevents current from

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[25] The 1.25 factor is because an array may provide more than rated currents during 3 hours near solar noon.

exceeding conductor ampacity, the maximum current is the rated input current of the electronic power converter.

Conductor ampacity is calculated based on the first method mentioned above multiplied again by 125% [690.8(B)(1)]. Or one can use the value of the current calculated from the first method and then apply conductor adjustment and correction factors [690.8(B)(2)].

Where multiple PV String Circuits are involved [690.8(D)] the *conductors* must be sized based on the sum of the rating of the overcurrent device and the sum of the currents as calculated in 690.8(A)(1)(a). However, guidance on the source circuit configurations and restrictions should be obtained from the manufacturer.

### *690.9 Overcurrent Protection*

Overcurrent protection is NOT required if *both* if the following conditions are met: a) the conductors have the capacity for the maximum circuit current and b) the current from all sources does not exceed the protective device rating for the PV module or electronic power converter [690.9(A)(1)].

The short-circuit current of a solar cell is normal listed in terms of current density to remove the dependence on panel size. Commercial silicon solar cells have current densities in the range of 3 mA/cm$^2$ to 28 mA/cm$^2$. For cells using the standard AM 1.5 spectrum, the maximum density is 46 m/cm$^2$. [H] The “AM” refers to the “Air Mass” coefficients used to characterize the performance of solar cells and refers standardized conditions found in ASTM G173-03.[26] [I]

The coefficient, $AM$, is related to the path length through the atmosphere, $L$, and the solar radiation incident angle $z$ relative to the normal to the Earth’s surface (zenith) where $L_0$ is pathway length to zenith. [I] The Air Mass coefficient can be calculated from the following. [J]

**Equation 2: Air Mass Coefficient from Light Pathway**

$$AM = \frac{L}{L_0}$$

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[26] AM 0 is used for space applications and is found in ASTM 490. The standard AM 1 and AM 1.5 are both found in ASTM G173-03, along with others. ASTM formerly known as American Society for Testing and Materials is now ASTM International.

A first-order approximation of the Air Mass coefficient can be calculated from the following.[27]

**Equation 3: Air Mass Coefficient from Angle to Zenith**

$$AM \text{ » } \frac{1}{\cos z}$$

Some if the terms are illustrated in Fig. 13.

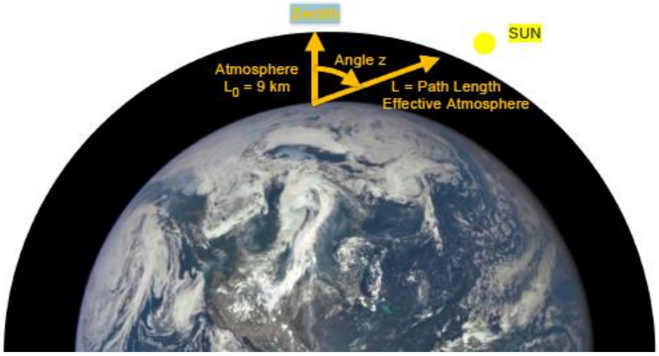

**Figure 13: Air Mass Equation Fundamentals**

Overcurrent protection is required if a conductor is rated properly but connected also to higher current sources, such as parallel-connected PV strings [690.9(A)(2)]. The overcurrent device must be connected to the higher current source end of the conductor.

Other circuits that don't comply with either 690.9(A)(1) or (A)(2) meet overcurrent requirements by a variety of methods depending upon length, protection on both ends, location or enclosures, and disconnecting means, all of which are very installation specific [690.9(A)(3)].

Overcurrent devices must be listed for use in PV systems.[28] They should be rated at maximum currents multiplied by 1.25, if calculated using 690.8(A) or if this device is part of assembly it may be used at its 100% rating.

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[27] This is good to about 75º. It reflects the tilt of the panels.

[28] This is because PV systems are subject to environmental stresses and this ensures devices are designed for such systems. Additionally, DC fault currents are more difficult to interrupt than AC fault currents because, for one, there is no natural zero current condition in DC systems. [K]

### *690.11 Arc-Fault Circuit Protection*

PV systems operating and 80 V DC or greater must be protected by arc fault circuit interrupters. An exception is made for metal clad-cables and those run in metal raceways or metal cable trays. However, the exception is applicable only if (1) they are NOT installed in or on buildings, or (2) they are in a separate structure whose sole purpose is to support or contain PV system equipment.

### *690.12 Rapid Shutdown of PV Systems on Buildings*

PV system circuits installed on or in buildings shall have a rapid shutdown function to reduce the shock hazard to firefighters. A couple of exceptions are made to align with fire codes that specify the types of structures firefighters typically perform rooftop installations.

For the purposes of this rapid shutdown, conductors are "controlled" if they are part of the PV systems or they are the inverter output conductors within the *array boundary*. That is the shutdown restrictions that follow apply to these conductors [690.12(A)].

The array boundary is defined as 305 mm (1 ft) from the array in all directions. Controlled conductors are outside the boundary or more than 1 m (3 ft) from a point of entry to the inside of the building. If inside the boundary, the voltage shall be ≤80 V DC within 30 seconds of shutdown initiation [690.12(B)(2)(2)] using a PVHCS (PV Hazard Control System) installation.[29] If outside the boundary, the voltage shall be ≤80 V within 30 seconds of shutdown initiation [690.12(B)(1)]. The *initiation device* shall be located in a *readily accessible* location 690.12(C)].[30]

## *Part III Disconnecting Means*

### *690.13 Photovoltaic System Disconnecting Means*

The disconnect(s) shall remove the PV system from all wiring systems including power, energy storage, and equipment as well as wiring on the premises. It should be readily accessible and labeled. A maximum number of six switches or breakers is allowed in one enclosure. The means used shall disconnect all conductors that are not solidly grounded.

An isolating device differs from a disconnecting means in that the former does not have an interrupting rating and is labeled, "Do Not Disconnect Under Load".[31] Requirements for both are in [690.15(D)].

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[29] Guidance for the PVHCS can be found in UL 3741.
[30] Accessible, Readily is found in Art. 100 and is defined as "capable of being reached quickly…without the use of tools…or removing obstacles…or using ladders, and so forth."
[3131] Such an isolation device would be used for maintenance.

### *Part IV Wiring Methods and Materials*

### *690.31 Wiring Methods*

Sufficient wiring length must be provided to allow for replacement. When conductors operating at ≥30 V DC are not guarded and readily accessible to unqualified personnel, they must be in type MC cable.[32]

The ampacity of the allowable conductors is determined from Table 690.31(A)(3)(1) as corrected by Table 690.31(A)(3)(2). Excerpts from said tables are provided in Tables 3 and 4.[33]

**Table 3: Ampacity, Isolated Conductors ≤2000 V**

| Wire Size | Types | |
|---|---|---|
| **AWG** | **PVC, CPE, XLPE 105°C** | **XLPE, EPDM 125°C** |
| 14 | 29 | 31 |
| 12 | 36 | 39 |
| 10 | 46 | 50 |

**Table Notes**

(1) Based on no more than three current carrying conductors in a Raceway, Cable, or Earth (directly buried)
(2) Based on Ambient Temperature of 30°C (86°F)

**Table 4: Correction Factors**

| | Conductor Temperature Rating | | |
|---|---|---|---|
| **Ambient Temperature °C** | **105°C (221°F)** | **125°C (257°F)** | **Ambient Temperature °F** |
| 31–35 | 0.97 | 0.97 | 87–95 |
| 36–40 | 0.93 | 0.95 | 96–104 |
| 41–45 | 0.89 | 0.92 | 105–113 |

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[32] Metal Clad cable is designated MC.
[33] PV cable are evaluated for exposure to direct sunlight and wet conditions.

## Example 5

An XLPE cable rated for 105°C and sized at 12 gauge is to be used for a home solar system. The system is to be installed in Hanford, CA. The design dry bulb temperature for July is 41.1°C (106°F) according to American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) data.

What is the maximum ampacity of the wire in this situation?

**Solution**

According to Table 3, the 12 AWG XLPE wire is rated for 36 A. The temperature correction factor from Table 4 for the installation location conditions of 106°F is 0.89. The maximum ampacity is as follows.

$$\begin{aligned} I_{\text{max}} &= I_{\text{capacity}} F_{\text{correction}} \\ &= (36\ \text{A})(0.89) \\ &= 32.04\ \text{A} \quad (32\ \text{A}) \end{aligned}$$

*Conductors*

PV circuit wiring, in general, should not be in the same enclosure, cable, or raceway as non-PV system wiring unless separated by a barrier or partition. There are exceptions based on the voltage applied [690.31(B)(1)].

*Identification*

PV system conductors shall be identified by color coding, marking tape, or other approved means [690.31(B)(2)]. Solidly grounded conductors are marked per Sec. 200.6(A)(5): continuous white outer finish; continuous gray outer finish; three continuous white or gray stripes on other than green insulation; or continuous insulation colored tracer thread in the braid [206.(A)(1-4)].

*Grouping*

AC and DC conductors from PV systems are to be grouped separately by cable ties or similar means at no more than 1.6 m (6 ft) [690.31(B)(3)].

*Cables*

Cable wiring methods, ampacity, and other restrictions are in 690.31(C)-(F) with >1000 V restrictions are in 690.31(G). One restriction useful in connecting solar panels with single conductors is the cables ≤8 AWG are supported and secured every 600 mm (24 in) while those >8 AWG are supported and secured every 1400 mm (54 in) [690.31(C)(b) & (c)].

### *690.33 Mating Connectors*

Connectors shall be polarized and non-interchangeable with other receptacles on the premises. Connectors rated for >30 V DC or >15 V AC shall require a tool for opening. Further, connectors shall be rated for interrupting current or be labeled, “Do Not Disconnect Under Load”.

## *Part V Grounding and Bonding*

### *690.41 PV System DC Circuit Grounding Configurations*

Allowable configurations follow [690.41(A)(1-6)]

1. Two-wire circuits with one functionally grounded conductor
2. Bipolar circuits with a functionally grounded reference (center tap)
3. Those circuits NOT isolated from the grounded inverter output
4. Ungrounded circuits
5. Solidly grounded circuits with DC Ground-Fault Detector-Interrupter [GFDI] per 690.41(B).
6. Circuits protected by listed equipment designated for such use

Circuits >30 V DC or 8 A are required to have a GFDI. This is not the same thing as a GFCI (Ground Fault Circuit Interrupter), which is used on AC systems to protect personnel. The GFDI are primarily meant to prevent fires.

Locations for the ground connections are covered in 690.42 (though this refers on back to 250.134 and 250.136) and grounding conductors are sized per 690.45 (which refers back to Table 250.122). The grounding electrode system requirements are in 690.47, but again refer back earlier articles starting with Art. 250.

## *Part VI Source Connections*

The requirements here primarily point one to Art. 705. One item of note, Fig. 11 shows a charge control circuit which is not required if: 1) the source circuit matches the voltage rating and current requirements of the battery cells, *and* 2) the maximum charge current multiplied by 1 hours is less than 3% of the battery rated capacity in A-h.[34]

## Art. 691 Large-Scale Photovoltaic (PV) Electric Supply Stations

This article covers the installation of large-scale PV electric supply stations *that are not exclusively under utility control*. As stated, the systems are large, and often called "farms", and thus are not meant to be installed on buildings. An example one-line is shown in Fig. 14. The minimum size covered by the NEC is 5000 kw or 5 MW.

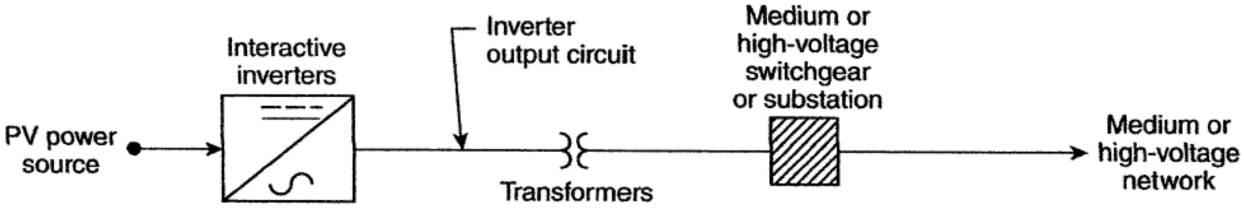

**Figure 14: Large-Scale PV Electric Supply Station**
[Source: *NEC® Informational Note 691.1*]

Such systems are to be accessible by authorized personnel. Only qualified personnel operate and maintain the system. Further, such systems are monitored by a central command center. The system must be designed by a licensed professional engineer. The fence bonding and grounding details are included in the design documentation and take into account both step- and touch-potential.[35]

## Art. 705 Interconnected Electric Power Production Services

The terminology as well as some common components in PV interconnected systems are shown in the examples of Fig. 15 and Fig. 16. These examples are for identification for various components. The source disconnects separates the power source from the other systems. Disconnecting means are not shown. System grounding and grounding equipment are not shown. Many custom designs occur, not all the components will be used in each configuration.

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[34] It's important when reading and applying the NEC that one pays attention to the words "and" and "or" as well as "one of the following" or "sum of the following".

[35] Step potential is the voltage difference between the feet of a person near an electrified (energized) object. Touch potential is the voltage difference between the energized object and the feet of a person in contact (touch) with the object.

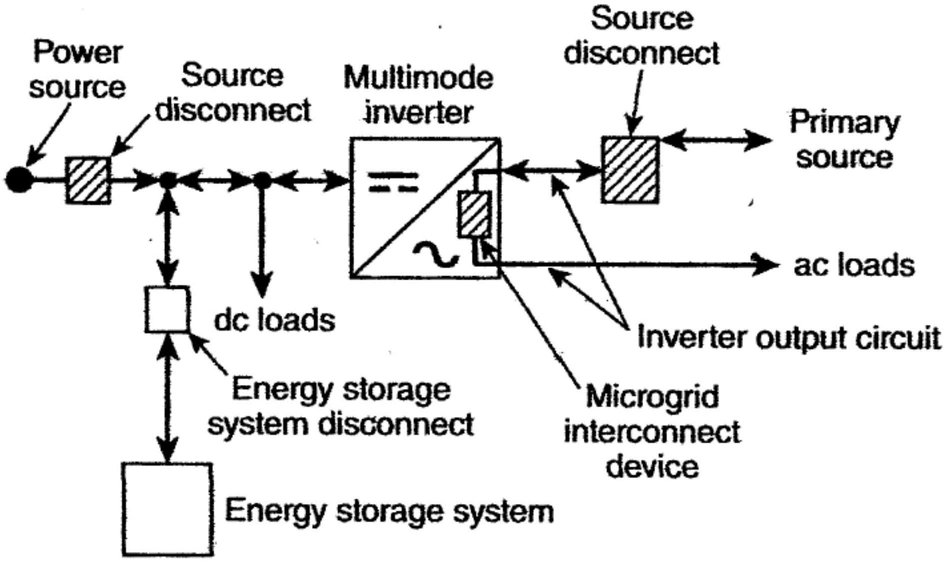

**Figure 15: DC Interconnected System**
[Source: *NEC® Informational Note Figure 705.1*]

Output compatibility for parallel operation is said to entail voltages, wave shape, and frequency ratings per 705.5(A).[36] Synchronizing equipment is to be utilized when a synchronous generator is in parallel [705.5(B)]. Guidance can be found in IEEE 1547, *Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electrical Power Systems Interfaces*. Another important reference for the solid state components is UL 1741, *Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources*.

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[36] The phase sequence, a-b-c, is hardly ever mention but must be checked during installation. Frequency controls the amount of real load shared. Voltage controls the amount of reactive load shared. The wave shape from solid state power drives contains harmonics, as such if one looks at the current wave, it appears "dirty" in layman's terms. These harmonics must be absorbed by the synchronous generator, often attached in parallel, and thus may require derating of the generator or intervening equipment.

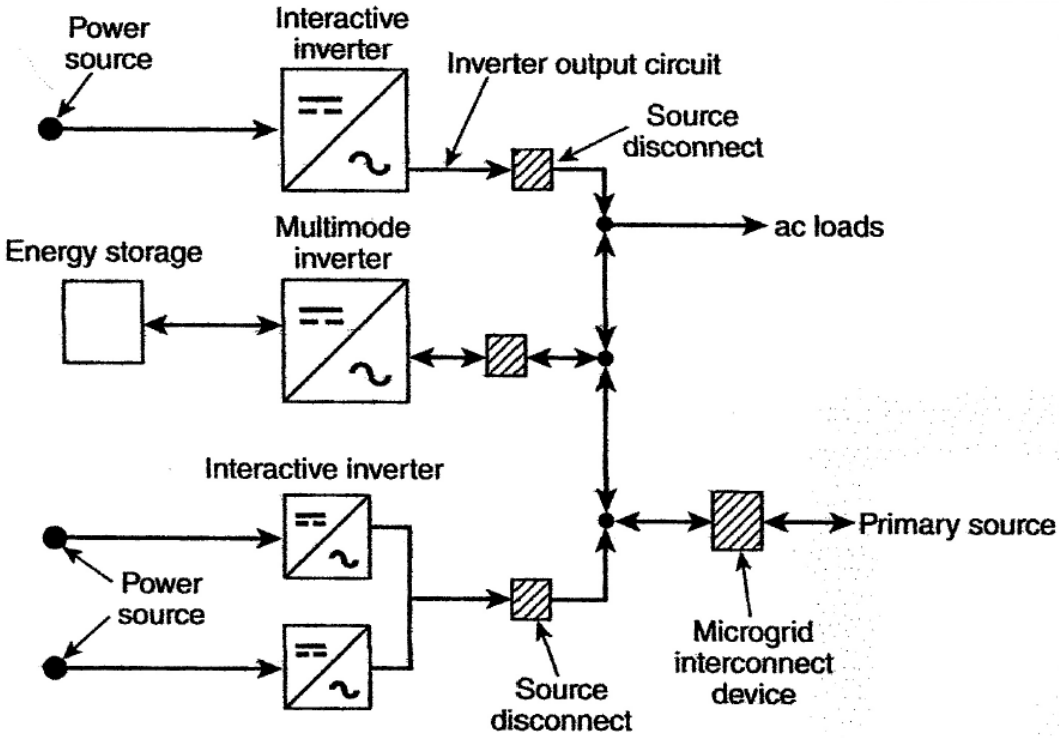

**Figure 16: AC Interconnected System**
[Source: *NEC® Informational Note Figure 705.1*]

Part I of Art.705 contains the General requirements for parallel systems. For solar system used in housing, see Part II for Microgrid Systems and Part III for Interconnected Systems operating in Island Mode.

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