A SunCam Online Continuing Education Course

National Electrical Code (NEC®)

Backup Power

NEC Special Conditions: Emergency Systems / Standby Systems / Critical Systems

by

John A Camara, BS, MS, PE, TF

Nomenclature[1]

ADA	Americans with Disabilities Act
AFCI	Arc Fault Circuit Interrupter (Interruption)
AGND	Analog Ground
AHJ	Authority Having Jurisdiction
ANSI	American National Standards Institute
ATS	Automatic Transfer Switch(es)
AWG	American Wire Gauge
BMS	Battery Management System
BOL	Beginning of Life
C	charge/discharge rate of battery in rated A-h
CAD	Computer Aided Design
COPS	Critical Operations Power Systems
DC	Direct Current
DCOA	Designated Critical Operations Area
DGND	Digital Ground
DoD	Depth of Discharge
E	Emergency Loads
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EoCV	End of Charge Voltage
EoDV	End of Discharge Voltage
EOL	End of Life
EPS	Electric Power System
EPS	Emergency Power Supply
EPSS	Emergency Power Supply System
ESS	Energy Storage System
GFCI	Ground Fault Circuit Interrupter (Interruption)
HVAC	Heating, Ventilation, and Air Conditioning
LIB	Lithium-Ion Battery

[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.

LRS	Legally Required Standby Loads
NEC	National Electrical Code
NECA	National Electrical Contractors Association
NFPA	National Fire Protection Association
OS	Optional Standby Loads
OSHA	Occupational Safety and Health Administration
p-s	parallel-series
PMAD	Power Management and Distribution
PSIA	Pounds per Square Inch Absolute
PV	Photovoltaic
s	complex “signal” frequency
s-p	series-parallel
SOC	State of Charge
UL	Underwriters Laboratories
UPS	Uninterruptable Power Supply
USCS	United States Customary System
WCA	Worst Case Analysis

Symbols

A	area
A-h	ampere-hours
AM	Air Mass
C	charge rate
I	current
ID	inside diameter
L	length
N	number
OD	outside diameter
P	power
R	resistance
s	complex frequency
t	time
T	temperature
V	voltage
W	watt
z	zenith
ρ	resistivity
λ	wavelength
ν	frequency

Subscripts

0	initial (zero value)
avg	average
BW	bundled wire
C	capacity
cmil	circular mil
d	discharge
df	diversity factor
f	final / frequency
in	inches
SW	single wire

National Electrical Code (NEC®) Backup Power
A SunCam Online Continuing Education Course

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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!

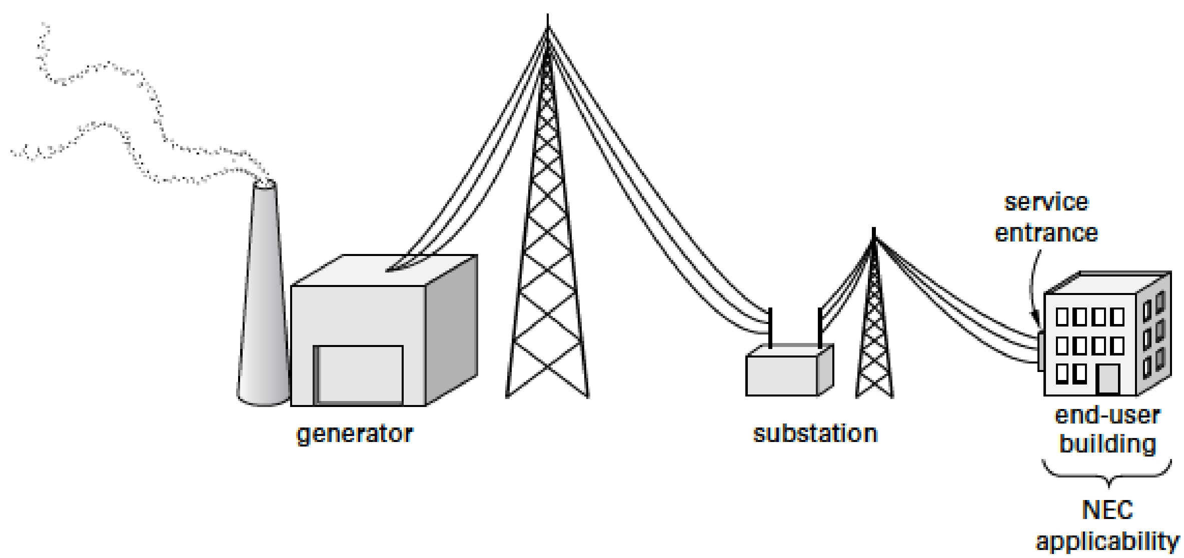

Figure 1: NEC Coverage
[Source: *Power Reference Manual for the PE Exam*]

[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.

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.
This course will focus on requirements for such buildings (residential and commercial) and their internals for items with voltages less than 1000 V—including backup 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]

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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 a backup power project, with emphasis on the specific backup power requirements in Chapter 7, *Special Conditions*, 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.

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

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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

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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 E: Types of Construction
Annex F: **Critical Operations Power Systems…**
Annex G: **Supervisory Control and Data Acquisition (SCADA)**
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.

[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.

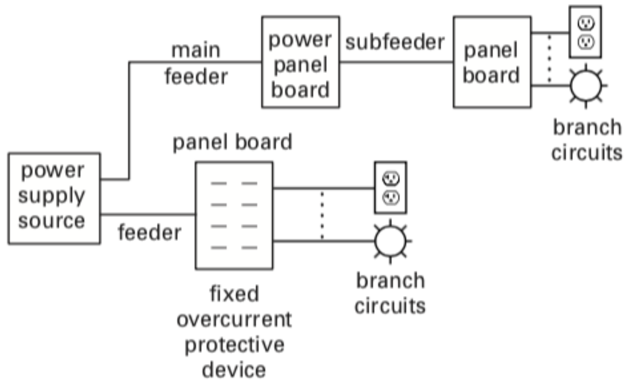

Figure 2: Typical Distribution System
[Source: *Power Reference Manual for the PE Exam*]

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. 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.

[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.

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.

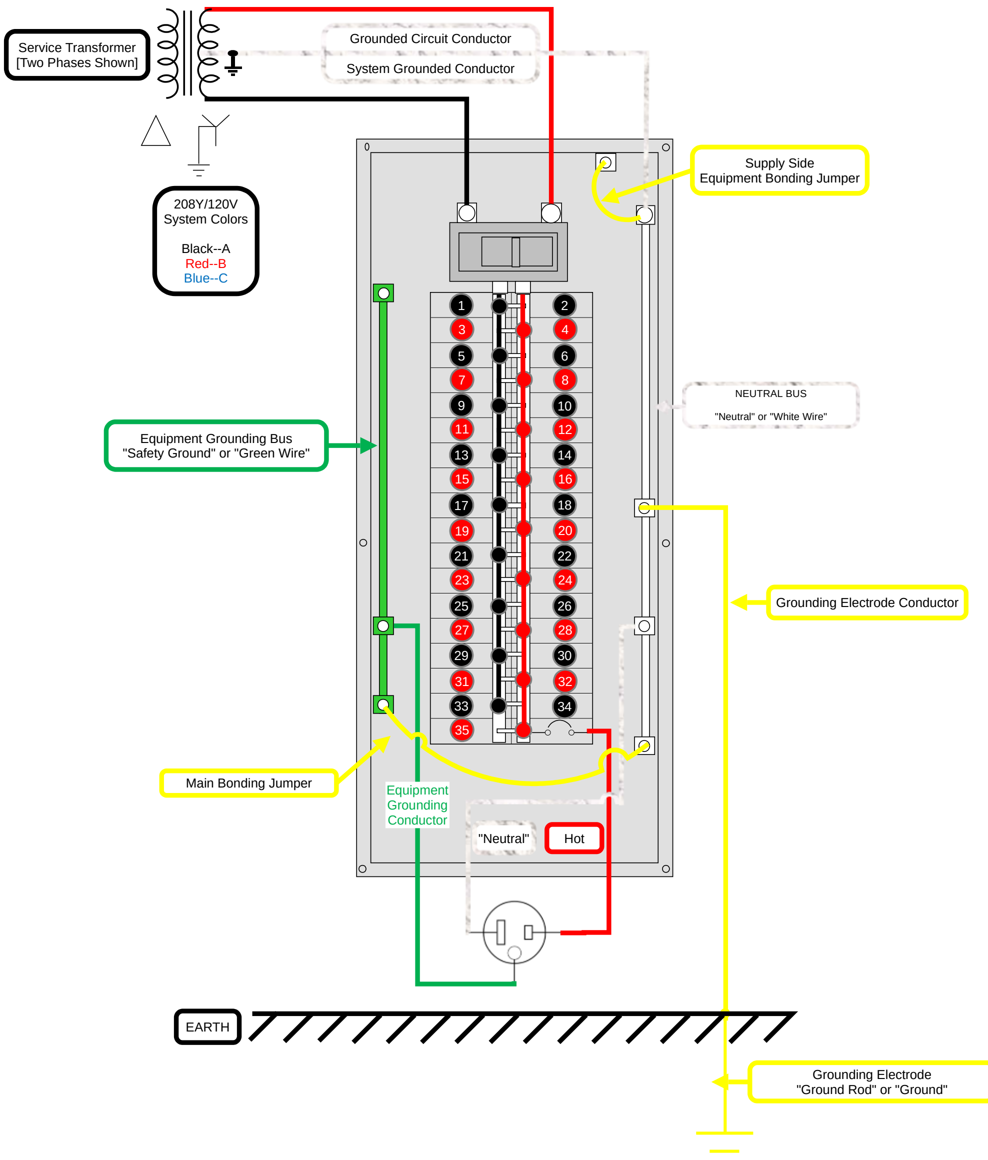

Figure 3: Bonding and Grounding Terminology

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.

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

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

(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.

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.

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

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

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

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,

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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.

whichever is greater, and must allow for 90 degree opening of hinged panels per Art. 110.26(A)(2). 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

[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.

Chapter 4 Equipment for General Use

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]

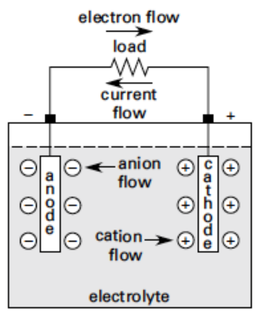

Figure 4: Battery Standard Terminology
[Source: *Power Reference Manual for the PE Exam*]

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.

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

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

Chapter 7 Special Conditions

This will be covered in-depth later in this course in the section "Backup Power", including *critical operations power systems* (COPS).

[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.

Annex C

Annex C contains fill tables for various configurations

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

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.

Special Conditions: Backup Power

Overview

In naming this course I used a colloquial term "Backup Power". The NEC uses several terms, all closely related but with differing requirements.

An *Emergency Power Supply* (EPS) is a source of electric power of the required capacity and quality for an emergency power supply system (EPSS). The *Emergency Power Supply System* (EPSS) is a complete functioning EPS system coupled to a system of conductors, disconnecting means and overcurrent protective devices, transfer switches, and all control, supervisory and support devices up to and including the load terminals of the transfer equipment…. *Emergency Systems* are those systems legally classed as emergency by municipal, state, federal, or other codes, or by any government agency having jurisdiction.[19] *Emergency Systems are required for safety of life.*

Related, *Critical Operations Power Systems (COPS) are power system(s) for facilities or parts of facilities that require continuous operation* for reasons of public safety, emergency management, business continuity, or national security.

A legally required *Standby Power System provides power to aid in firefighting, rescue operations, control of health hazards and similar operations* required by various codes or mandated by the Authority having Jurisdiction (AHJ). Further distinction comes with an *Optional Standby Power System, which is there to prevent discomfort*.[20]

[19] Although somewhat redundant or overlapping, such a definition can come into play. As an example, a compliant "emergency system" in California cannot be used for long term "maintenance power" unless additional environmental clean air requirements are met.

[20] An "optional power system" also includes those to prevent interruption of industrial processes, damage to equipment, or disruption of business—many of which may not be considered "optional" by those involved.

Article 700 Emergency Systems

700.1 Scope

This article focuses on the requirements of an emergency system or systems; that is, the installation, operation, and maintenance.[21] Per *Informational Note 1* such systems are generally installed in places of assembly where artificial illumination is required for safe exiting or panic control…or areas where interruption of power would result in serious life safety or health hazards.[22] The terminology used in this course is consistent with the Code; however, other naming conventions may be utilized.[23]

700.2 Reconditioned Equipment

Although reconditioned equipment may be used in many areas, in emergency systems reconditioned transfer switches may NOT be used.

700.3 Tests and Maintenance

Emergency system commissioning tests must be witnessed by the Authority having Jurisdiction (AHJ).[24] Such a test is known as an Acceptance Test. Additionally, the systems have to be tested periodically and maintained in accordance with manufacturer's instructions and industry standards.

NOTE

Preventative Maintenance occurs at predetermined intervals or prescribe criteria (e.g., monthly, quarterly). *Condition Based Maintenance* is based on continuous performance monitoring (motor is hot). *Risk-Based Maintenance* is based on analysis, measurement or periodic tests (e.g., past data indicates failure every 5 years or …). *Corrective Maintenance* occurs following an anomaly or failure (equipment no longer runs or runs poorly).

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[21] Whether such a system is required and how/where to install is governed by the *Life Safety Code® NFPA 101®* or the appropriate building code. See also the *Standard for Emergency and Standby Power Systems® NFPA 110®*.
[22] Thus, ventilation, fire pumps, communication systems, elevators and other systems deemed necessary or required by law or code.
[23] References [C] and [D] provides some vernacular terminology used by laymen and a bit of history for emergency and standby systems.
[24] A reference for such tests is NECA 90, *Standard for Commissioning Building Electrical Systems*. NECA is the National Electrical Contractors Association.

Written records must be kept and finally, emergency systems must have a means whereby they can be tested under an anticipated load. This is known as Operational Testing.[25]

700.4 Capacity and Rating

An emergency system must have adequate capacity in accordance with Parts I through IV of Art. 220. It must be able to handle load changes, transients, or energy requirements of any of the emergency equipment (e.g., starting surges).

To ensure adequate capacity of an emergency system if the capability to power all loads is not available, selective load pickup or load shedding must be used. The order of priority of the loads follows.[26]

1. Emergency Circuits
2. Legally Required Standby Circuits
3. Optional Standby Circuits

700.5 Transfer Equipment

Automatic Transfer Switches (ATS) are typically used in emergency and standby power systems rated for 1000 V or less. ATS devices normally don't have overcurrent protection and are generally rated at 38 kV or less. They must be "electrically operated and mechanically held".

700.6/.7/.8 Signals, Signs, Protection

Requirements for various signals (e.g., load carrying by generator, malfunctions, battery charging problems, and ground faults detection) are delineated in this section. Of note, ground fault protection is *NOT required in emergency systems* because it could interrupt power; but, detection of a fault is required (700.6). Emergency System signs are required by the service entrance and grounding connection warning signs at the alternate power source (where applicable due to removal of the grounding electrode conductor or bonding jumper occurs during the use of the alternate power source (700.7). Lastly, *Surge protection* is required to protect electronic equipment performing a critical safety function (700.8).

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[25] See for more information NFPA 70B, Recommended Practice for Electrical Equipment Maintenance.
[26] Definitions for all three types of circuits are included in this course.

700.10 Wiring

Emergency Circuits (boxes, enclosures, transfer switches, generators, power panels, receptacles) must be marked (or color coded) as belonging to an emergency system. Cables or raceways must be marked at intervals not to exceed 7.6 m (25 ft).

Wiring for emergency systems must be kept separate from all other wiring, with a few common sense exceptions (700.10(B)).

The exceptions indicated result in many possible configurations shown in Figure 5. Note the transfer switch has emergency and normal power cables together, which is a single example of the exceptions of Sec. 700.10(B). Emergency loads on diagrams/figures may be noted with an **E**, legally required standby loads may be noted as **LRS**, and optional standby loads as **OS**.

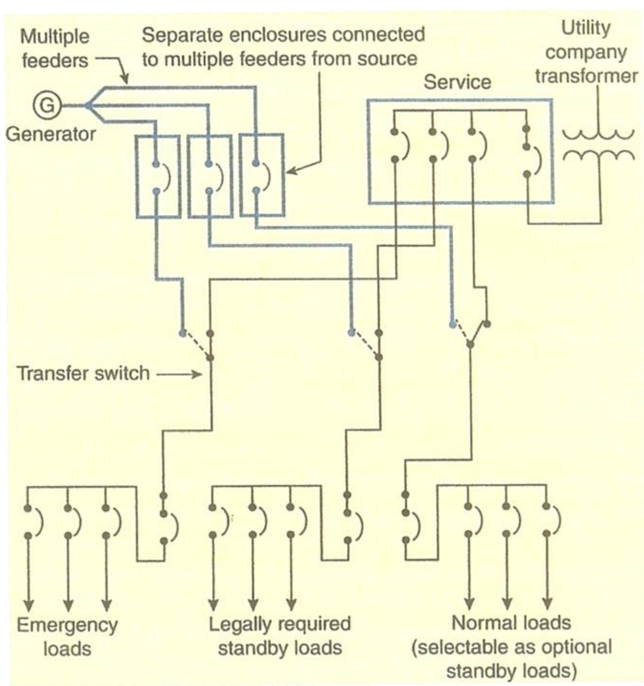

Figure 5: Emergency Generator, Multiple Feeders
[*Source: National Electrical Code Handbook, Exhibit 700.4*]

Emergency Systems installed in the following have additional requirements on wiring and should be consulted during the design phase (see 700.10(D)(2) through (D)(4)).

(1) Assembly occupancies for not less than 1000 persons

(2) Buildings above 23 m (75 ft) in height
(3) Educational occupancies with more than 300 occupants

700.12 General Requirements

The general requirements of this section apply to the *sources of power for emergency systems*.

The time required between the loss of normal power (power interruption) and the application of emergency power shall not exceed 10 seconds. (Where a power source takes longer than 10 seconds to startup, an auxiliary power supply—storage batteries or UPS (Uninterruptable Power Supply)—shall be used until the emergency generator can pickup the load.)

The emergency power source shall be of suitable rating and capacity to supply the load, but in no case shall the duration be less than 2 hours. On-site fuel must be enough for no less than two hours of operation.

Emergency systems shall NOT be solely dependent upon public utility gas systems for fuel nor municipal water systems for their cooling systems.

Storage batteries and UPS systems used for emergency illumination shall be such that they handle the total load for a minimum of 1.5 hours with voltage never going below 87.5% of nominal.[27]

Requirements for emergency lighting form the remainder of this section.

700.32 Selective Coordination

New to the 2023 Code, Overcurrent Protective Devices (OCPDs) shall be selectively coordinated with all supply-side and load-side OCPDs.[28] Examples of the results of coordination and lack thereof is shown in Figure 6.

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[27] Nominal voltages are defined in Reference [E]. One should check the portion of the standard used by the AHJ in the area of in which the emergency system is located.
[28] While new to the Code, the military (specifically, the Navy) has used this principle on ships for some time. In navy parlance, the breaker closest to the fault should trip first and the breaker furthest from the fault should trip last (if at all).

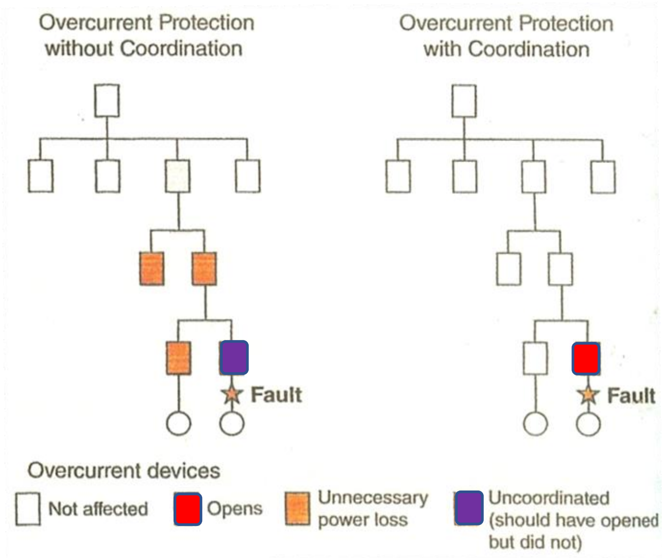

Figure 6: Overcurrent Protection Schemes
[*Source: National Electrical Code Handbook, Exhibit 700.11—Colors Modified*]

Article 701 Legally Required Standby Systems

Legally Required Standby Systems are very similar to Emergency Systems with many of the requirements being identical. However, some differences do exist with these emphasized here.

For example, wiring for such systems can be in the same raceway, boxes, cables, and cabinets as general wiring (701.10)(vice being entirely separate for emergency systems). Further, legally required standby systems have to provide power within 60 seconds of normal power interruption (701.12) (vice 10 seconds for emergency systems).

Also, power sources for emergency systems are provided with a time delay feature to avoid re-transfer to the normal power source in the event of a short-time reestablishment of the normal source with no delay time specified; however, for legally required standby systems this time delay is set as up to 15 minutes (701.12(D)).

Article 702 Optional Standby Systems

Here again requirement are very similar to Legally Required Standby Systems but when "optional" portable power generators may be used.[29]

Article 705 Interconnected Electric Power Production Services

Systems mentioned so far often operate interconnected with other power production or stored energy sources. Requirements for such connections are covered in this article. But, arguably, understanding the symbology and terminology are a vital first step in the process of applying the electrical requirements.

The terminology as well as some common components in interconnected systems are shown in the examples of Figures 7 and 8. These examples are for identification for various components. The source disconnects separates the power source from the other systems. Equipment 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.

In the figures, the interactive inverter allows power flow in one direction only while the multimode inverter allows power flow in both directions. Further, regarding symbology, the straight line on the DC side of the inverter indicates the DC value of the source while the dashed line indicates the ground connection.

If an emergency or standby system operates as a single source; that is, it is not connected to an energy storage system (think "battery") or photovoltaic (PV) system, then the requirements of this article do not apply.

[29] Permanently installed generators for household use are "optional standby systems" because they are there primarily to avoid discomfort and not because they are required by an AHJ.

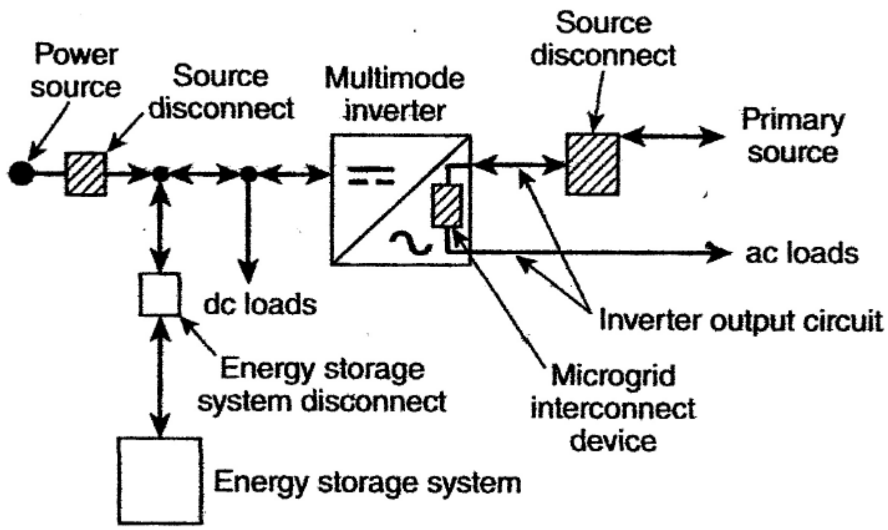

Figure 7: DC Interconnected System
[Source: *NEC® Informational Note Figure 705.1*]

Output compatibility for parallel operation is said to entail voltages, wave shape, and frequency ratings per 705.5(A).[30] 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*.

[30] 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.

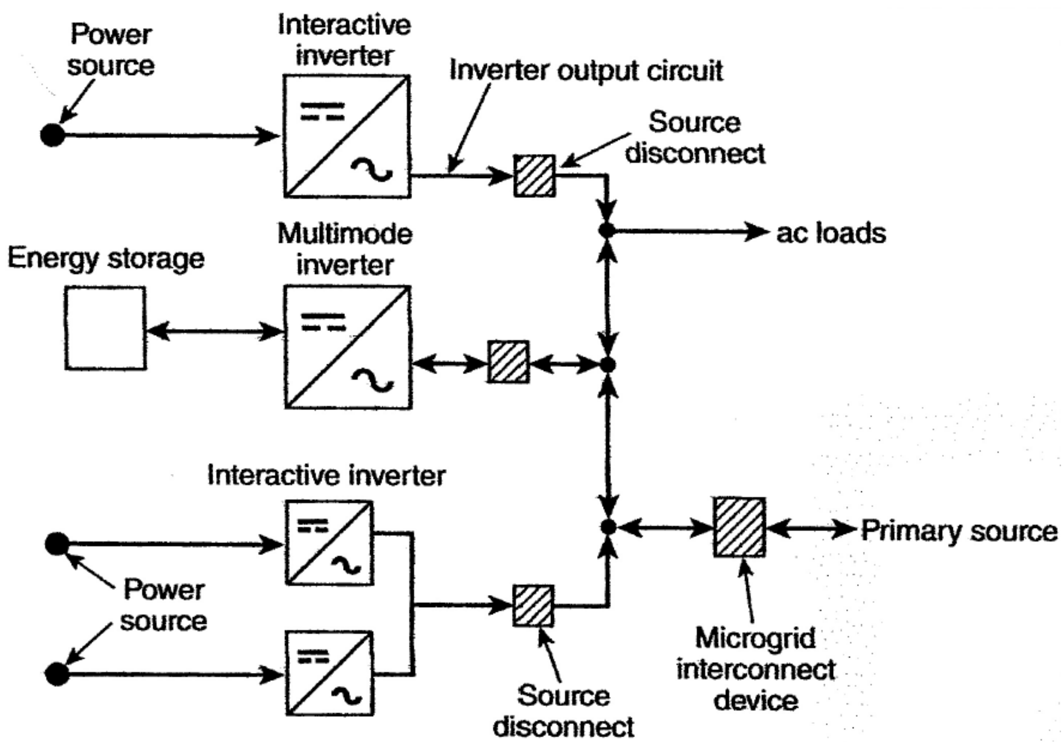

Figure 8: AC Interconnected System
[Source: *NEC® Informational Note Figure 705.1*]

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.

Article 706 Energy Storage Systems

This article applies to Energy Storage Systems (ESS) with a capacity greater than 3.6 MJ (1 kWh). These systems are primarily intended store and provide energy *during normal operations*. The systems include photovoltaic, wind, and batteries.

Article 708 Critical Operations Power Systems (COPS)

Critical Operations Power Systems are those that supply electricity to Designated Critical Operations Areas (DCOA) required by Code, the appropriate AHJ, or facility documentation stating the need for such a system. These systems can include, but are not limited to power, HVAC, fire alarm, security, communications, and signaling—in short, *vital infrastructure*.[31] To research emergency and standby systems themselves, see Reference [F][32] and the guidance for testing in the NEC Annex F and Annex G.

Requirements generally mirror those for emergency systems with a few additional items included.

708.7 Cyber Security

When a COPS is connected to a communication system, the system uses direct connection through a non-networked interface, or the system is "assessed" for cyber security. Such assessments must occur when changes are made or as a minimum every 5 years.

[31] Various reference may be consulted for more specifics: *NFPA 1600-2019, Standard on Continuity, Emergency, and Crisis Management; NFPA 110-2022, Standard for Emergency and Standby Power Systems; NFPA 101-2021 Life Safety Code.*
[32] Always look for the latest edition. For example, NFPA 110 is listed as "-2019" in the NEC but the latest is "-2022".

REFERENCES

A. Camara, John A. *PE Power Reference Manual*. Belmont, CA: PPI (Kaplan), 2021.
B. Earley, Mark, ed. *NFPA 70, National Electrical Code Handbook*. Quincy, Massachusetts: NFPA, 2020.

NOTE

Electrical refers to something related to electricity while "electric" refers to a device or machine that runs on electricity. Nevertheless, the NEC is sometimes referred to as the National Electric Code.

C. Wikipedia, The Free Encyclopedia (2023). "Emergency Power System". https://en.wikipedia.org /wiki/Emergency_power_system (accessed 7 NOV 2023).
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E. ANSI C84.1. "Electric Power Systems Voltage Ratings (60 Hz)". Washington D.C.: ANSI, 2020.
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