1 Exam Prep
Photovoltaic Systems
Tabs and Highlights

These 1 Exam Prep Tabs are based on the *Photovoltaic Systems, 3rd Edition*.

Each Tabs sheet has five rows of tabs. Start with the first tab at the first row at the top of the page; proceed down that row placing the tabs at the locations listed below. Place each tab in your book setting it down one notch until you get to the last tab (usually the index or glossary).

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4	**Photovoltaics:** Photovoltaics is a solar energy technology that uses the unique properties of certain semi-conductors to directly convert solar radiation in electricity. A photovoltaic (PV) system is an electrical system consisting of a PV module array and other electrical components needed to convert solar energy into electricity usable by loads. **Advantages:** the PV system may save the consumer a great deal of money Photovoltaics is an environmentally friendly technology that produces energy with no noise or pollution. Since there are no moving parts, PV systems are extremely reliable and last a long time with minimal maintenance. PV system reduces the consumer's vulnerability to utility outages, and a stand-alone system eliminates it. **Disadvantages:** Currently, the most significant issue is the high initial cost of a PV system.
5	**Typical Utility-Connected PV System**
6	Distributed generation is a system in which many … A distributed generation system may serve as the only source of power for the consumer (a stand-alone system), or as backup or supplemental power for a utility connection.
11	**PV Applications:** Today, PV systems can be used in almost any application where electricity is needed and can support DC loads, AC loads, or both. **Portable Applications:** Portable PV systems power mobile loads such as vehicles, temporary sign and lighting, and handheld devices.
12	**Remote Applications.** Remote PV systems power loads that are permanently fixed but too distant to be connected to the utility power grid.

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12	**Lighting.** The availability of low-power DC lamps makes PV energy ideal for remote lighting applications.
13	**Utility-Interactive Applications:** Systems that are connected to the utility grid and use PV energy as a supplemental source of power offer the greatest flexibility.
	A PV system may or may not save in money in the short-term when competing against relatively inexpensive utility power.
14	PV systems can be used to provide supplemental power to any utility-connected building … and institutions.
	Utility-Scale Applications: The only moving parts of a PV system are in the tracking system, if one is used. Unfortunately, PV electricity still costs considerably more in the United States than electricity generated by conventional plants.
15	**Figure 1-14** The PV industry is composed of several levels of businesses and organizations.
	Manufacturers: A balance-of-system (BOS) component is an electrical or structural component, aside from a major component, that is required to complete a PV system. BOS systems include the conductors, … array, inverter and battery system.
	Integrators: An integrator is a business that designs, builds, and installs complete PV systems for particular applications by matching components from various manufactures.
16	Silicon is the primary raw material for producing PV cells.
	All PV system installers should meet the following criteria: (14 bullets).
17	**Figure 1-15:** Quality PV installation relies on the quality of the selected components, system design, and installation practices.
21	**Collectors:** A solar energy collector is a device designed to absorb solar radiation and convert it to another form.
	Flat-plate collector: A flat-plate collector is a solar energy collector that absorbs solar energy on a flat surface without concentrating it, and can utilize solar radiation … Nearly all commercial and residential solar energy installations use flat-plate collectors.
22	**Concentrating collectors:** A concentrating collector is a solar energy collector that … through reflective surfaces or lenses.
23	**Solar Thermal Energy:** Solar thermal energy systems convert solar radiation into heat energy.
	Solar Thermal Heating: Solar thermal heating systems can be classified as passive or active. In passive systems, …are used to circulate the fluid.

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24	**Solar Thermal Cooling:** The heat energy is used to compress a gas … cools a set of coils.
	Solar Thermal Electricity: Concentrating solar power (CSP) is a technology that uses mirrors and/or lenses to reflect … large area onto a small area.
30	**The Sun:** An astronomical unit (AU) is the average distance between Earth and the sun (93 million mi).
	Solar Radiation
	Solar Irradiance (Solar Power): Solar irradiance is the power of solar radiation per unit area … expressed in units of watts per square meter or kilowatts per square meter.
31	Solar irradiance is used as a reference input condition … utilization equipment such as PV modules.
	Figure 2-3. Solar irradiance is solar power per unit area.
	Figure 2-4: The inverse square law states that irradiance is reduced in proportion to the inverse square of the distance from the source.
32	**Solar Irradiation (Solar Energy):** Solar irradiation is the total amount of solar energy accumulated on an area over time.
	Solar irradiation is commonly expressed in units of watts-hours per square meter or kilowatts per square meter. Solar irradiation quantifies … and is the principal data needed for sizing and estimating the performance of PV systems.
	Solar irradiation can be calculated from average solar irradiance by applying the following formula: [formula].
	Figure 2-5. Solar irradiation equals the total solar irradiance received over time.
34	**Figure 2-6.** The electromagnetic spectrum is the range of all types of electromagnetic radiation, which will vary with wave length.
	Direct Radiation: Direct radiation is solar radiation directly from the sun that reaches Earth's surface without scattering.
	Diffuse Radiation: Diffuse radiation is solar radiation that is scattered by the atmosphere and clouds.
	Albedo Radiation: Albedo radiation is solar radiation that is reflected from the Earth's surface back up through the atmosphere.
35	**Figure 2-8.** Solar radiation in the earth's atmosphere includes direct, diffuse, and albedo radiation.
	Air Mass. Zenith is a point in the sky directly overhead a particular location. The zenith angle is the angle between the sun and the zenith.
36	**Figure 2-9.** Air mass is a representation of the amount of atmosphere radiation that must pass through to reach Earth's surface.
37	**Terrestrial Solar Radiation:** Terrestrial solar radiation is solar radiation reaching the surface of the Earth.

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	Peak sun hours is the number of hours required for a day's total solar irradiation to accumulate at peak sun condition.
	The total irradiation for a day may be expressed in units of peak sun hours by dividing by 1000 W/$m2$ (peak sun irradiance).
	Figure 2-10. Peak sun hours is an equivalent measure of total solar irradiation in a day.
	Knowing the average number of peak sun hours on a given surface at a given location is used to determine PV system performance.
40	**Solar Radiation Measurement**:
	- **Pyranometers.** Solar irradiance is typically measured with a pyranometer. A pyranometer is a sensor that measures the total global solar irradiance in a hemispherical field of view.
41	- **Pyrheliometers.** Direct solar radiation is measured with a pyrheliometer. A pyrheliometer is a sensor that measures only direct solar radiation in the field of view of the solar disk.
	They must be pointed directly at the sun.
42	**Reference Cells.** A reference cell is an encapsulated PV cell that outputs a known amount of electrical current per unit of solar irradiance … the output current can be used to indirectly measure irradiance.
	Reference cells are highly accurate precision instruments … used to measure the output of PV modules.
	Sun-Earth Relationships: Earth axis is tilted at 23.5. The amount of solar radiation received at a particular location on Earth's surface is a direct result of Earth's orbit and tilt.
42-43	**Earth's Orbit:** Perihelion is the point in Earth's orbit that is closest to the sun … The equatorial plane is the plane containing earth's equator and extending outward into space. Because Earth's tilt, the angle between these planes is 2.5 and remains constant as Earth's makes its annual orbit around the sun.
43	**Solar Declination:** Solar declination is the angle between the equatorial plane and the rays of the sun. The angle of solar declination changes continuously as Earth orbits ranging from -23.5˚ to +23.5˚.
	Figure 2-18. The ecliptic plane is formed by Earth's elliptical orbit around the sun.
	Figure 2-19. The equatorial plane is tilted 23.5˚ …this orientation produces a varying solar declination.
44	**Solstices:** A solstice is the Earth's orbital position when solar declination is at its minimum or maximum. The summer solstice is at its maximum solar declination (+23.5˚) and occurs around June 21.
	The winter solstice is a at minimum solar declination (-23.5˚) and occurs around December 21.

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	Figure 2-20. The summer solstice occurs when the Northern Hemisphere is tilted towards the sun. The winter solstice occurs when the Northern Hemisphere is tilted away from the sun.
	Equinoxes. An equinox is the Earth's orbital position when solar declination is zero … The spring (vernal) equinox occurs around March 21 and the fall (autumnal) equinox occurs around September 23.
	Figure 2-21. The fall and spring equinoxes occur when the sun is directly in line with the equator.
45	**Solar Time:** Solar time is a timescale based on the apparent motion of the sun.
	Standard Time: Standard time is a timescale based on the apparent motion of the sun crossing standard meridians. A standard meridian is a meridian located at a multiple of 15˚ east or west of zero longitude.
	Figure 2-22. Standard time organizes regions into time zones.
46	The Equation of Time is the difference between solar time and standard time at a standard meridian. This difference varies over the course of a year and can be as much as +16 min or -14 min.
	The longitude time correlation is calculated with the following equation: (equation).
	Using both time correlations, local standard time can be converted to solar time, or vice versa, with the following equations: (equation).
	Figure 2-23. The Equation of Time adjusts for variations in the Earth's orbit and rotation that affect solar time.
47	**Sun Path:** An analemma is a diagram of solar declination against the Equation of Time.
	Figure 2-24. An analemma shows how sun position, at the same time of day, changes throughout the year.
	Sun Position. The solar altitude angle is the vertical angle between the sun and the horizon.
	The solar azimuth angle is the horizontal angle between a reference direction and the sun.
	Figure 2-26. The sun's path across the sky at various times of the year.
49	**The Solar Window:** The solar window is the area of sky between sun paths at summer solstice and winter solstice for a particular location. Knowing the solar window at a given site is critical … to achieve optimal energy performance and to prevent shading from trees and other obstructions.
	Array Orientation: The array tilt angle is the vertical angle between horizontal and the array surface. The array azimuth angle is the horizontal angle between the reference direction and the direction an array surface faces.
	Figure 2-27. The solar window is the area of the sky containing all possible locations of the sun throughout the year for a particular location.

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	Figure 2-28. The orientation of an array surface is described using azimuth and tilt angles.
50	**Array Tilt Angle**
51	**Array Azimuth Angle**
	Sun Tracking: Sun tracking is continuously changing the array tilt angle, the array azimuth angle, or both, so the array follows the position of the sun.
	Single-axis tracking is a sun-tracking system that rotates one axis to approximately follow the position of the sun.
	Dual-axis tracking is a sun-tracking system that rotates two axes independently to follow the position of the sun.
53	**Solar Radiation Data Sets:** Solar radiation data indicates how much solar energy trikes a surface at a particular location on Earth during a period of time.
	Figure 2-31. The NREL provides solar radiation data for various locations, times of the year, and south-facing array orientations.
54	**Solar Radiation for flat-Plate Collectors Facing South at Fixed Tilt:** The section on flat-plate collectors at fixed tilt is applicable to most installations.
56	**Solar Radiation for Flat-Plate Collectors with Two-Axis Tracking:** The section on two-axis trackers represents solar irradiation on a surface that always faces the sun.
	Two-axis tracking enables greater receiving of solar irradiation than either fixed or single-axis tracking surfaces.
62	**Customer Development:** Sales persons, designers, and installers of PV systems must identify customer needs, concerns, and expectations.
	Solar Resource: The solar radiation resource should be researched before visiting the site.
	When reviewing the solar resource data, the installer should note the differences for various array tilt angles … This is important when evaluating potential mounting orientations for PV arrays.
64	**Hazard Assessment and Safety Training**
	Personal Protective Equipment (PPE). PPE is the equipment and garments worn by workers to protect them from work hazards.
	Safety glasses, hard hats, safety shoes, gloves, hearing protection, and fall protection gear are common types of PPE required for PV system work.
65	**Electrical Safety.** Preventing injury due to electrical hazards involves wearing appropriate PPE, including a Class E hard hat and electrical (EH) rated footwear ... work on electrical systems and equipment should be conducted in a de-energized state, using lockout and tagout procedures.
66	Flexible extension cords must be of the three-wire type.

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	Fall Protection. OSHA requires fall protection for work taking place more than 6’ above a lower level.
	A personal fall arrest system (PFAS) is a fall prevention system that prevebts a worker from falling and consists of anchorage and connectors, a body harness, and lanyard, and a deceleration device.
67	**Ladder Safety.** OSHA requires that a stairway or ladder be used at points of access on a construction site with an elevation change of 19” or more.
67-68	**Hand and Power Tools Safety**. All power tools must be fitted with guards and safety switches.
68	**Site Surveys:** Site surveys identify suitable locations for the array and other equipment. The most appropriate array locations … and are not necessarily shaded.
	Site Survey Equipment
70	**Solar Shading Calculator.** A solar shading calculator is a device that evaluates the extent of shading obstruction interfering in the solar window for a given location.
71	**Array Location:** The primary task of the site survey is to determine whether there is a suitable location for a PV array.
	Array Area. The required overall area for any given array is based on the desired peak-rated output, the efficiency of the modules, and how densely the modules are installed for the array.
	For an initial site survey, the required array area can be estimated with the following formula: (formula).
72	Allowing for space between the modules for access and maintenance … per kilowatt of peak array power. (Found in blue box in top left cornet).
	Array Orientation. The roof slope orientation must be measured during a site survey for a rooftop installation. The easiest way to measure the slope is with an angle finder.
	The slope is then calculated from the following formula: (formula).
73	The azimuth orientation of the roof is the direction …that the sloped surface faces, and is determined with a compass.
75	**Shading Analysis:** Arrays should be installed in location with no shading at any time.
	At a minimum arrays should have an unobstructed solar window from 9 am to 3 pm (solar time) throughout the summer … string inverters can help improve system performance under partial shading.
77	**Solar Shading Calculators.** The solar pathfinder consists of a latitude specific solar shading diagram ... it is leveled and oriented to true south with the built in compass and bubble level.
	The SunEye directly acquires a digital photo of the sky … that photographs the entire hemisphere of the sky and surroundings in one image.
	Using the location information, the SunEye generates and displays a solar window diagram specific to local latitude ... It then calculates the total monthly solar access.

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79	**Altitude Angle Method.** A simple method to evaluate shading at a particular location is by measuring or calculating the altitude angle of each obstruction.
	Altitude angles can be calculated with the following formula: (formula).
80	**Figure 3-23.** Altitude angles can be determined using a calculator, protractor, or by calculations from measurements.
	Profile Angle Method. The profile angle is the projection of the solar altitude angle onto an imaginary plane perpendicular to the surface of the obstruction.
	The profile angle is calculated with the following formula: (formula).
81	**Figure 3-25.** The profile angle is the projection of the solar altitude … This angle is used to calculate the length of shadows.
82	**Figure 3-26.** Profile angle calculations are particularly useful … at certain time of the day.
83	**Accessibility.** Accessibility to rooftop mounted PV arrays is a critical concern for firefighters in allowing access pathways and ventilation opportunities on the roof in the event of a fire.
83-84	**Roofing Evaluation.** Arrays are installed on many types of roof surfaces … The expected life of the roof covering is also very important.
84	A primary concern is the condition of the roof covering, particularly its weather sealing.
	For conventional asphalt shingles, deterioration includes … Asphalt shingles generally are the least expensive, but have the shortest life.
	For slate, clay, or concrete roof tiles problems include … Slate and tile roofs have a long expectancy, but are moderately expensive.
	Metal roofing also has a long life but is expensive. Signs of aging include … and pitting on aluminum roofs.
	The thickness of the roof decking dictates the appropriate length of the fasteners needed to install the array. The thickness can usually be determined by looking under the eave drip edge or flashing along the edge of the roof.
85	**Structural Support.** First, a visual inspection determines the flatness of the roof surface. A string … dips wherever there is a gap between the string and the roof surface.
	Next, the installer should walk carefully across the roof and check for movement of the surface.
	Arrays must be securely attached to the roof's underlying structural members in order to resist wind and other loads.

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	Electrical Assessment.
86	Most inverters can be installed either indoors or outdoors, as long as they have the appropriate enclosure ratings … Inverters should be kept out of direct sunlight or other environments that can raise operating temperatures.
	Batteries should be installed within well-ventilated and protective enclosures.
	Site Layout Drawings: Site layout diagrams and sketches should identify the shape and dimensions of the structure, and the locations between major system components.
	Energy Audit: Some PV installations require a detailed electrical load analysis … average daily time of use, and total energy consumed.
87	**Figure 3-32.** A site layout drawing shows basic building dimensions and locations of major components.
	Figure 3-33: A load analysis is part of an energy audit … sizing PV systems using batteries.
90	**Installation Planning:** The installer completes the final design' prepares construction drawings … to complete the installation in the most efficient and timely manner.
98	**Modules and Array:** An array consists of individual PV modules that are electrically connected to produce a desired voltage, current, and power output. Modules and arrays produce DC voltage … or can be converted to AC power by inverters.
	Energy Storage Systems: Energy storage systems balance energy production and demand.
	Batteries, particularly lead-acid types are by far the most common means of energy storage in PV systems.
99	**Batteries.** A battery bank is a group of batteries connected together with … Batteries in a PV system are charged by the array when sunny and discharged by loads when cloudy or at night.
	Batteries provide short surge currents for loads with special starting requirements, which PV modules cannot provide.
	Flywheels. Flywheels are large, spinning rotors and are commonly used to transfer power from motors and engines to pumps and other rotational loads.
100	**Supercapicitors.** Capacitors store energy in an electrical field developed by two oppositely charged a parallel conductive plates separated by a dielectric material.
	Supercapacitors are a suitable replacement for batteries in many low-power applications.

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	Power Conditioning Equipment: Power conditioning equipment converts, controls, and otherwise processes DC power produced by a PV array to make the power compatible with other power loads.
101	**Inverters.** An inverter is a device that converts DC power to AC power. In PV systems, inverters convert DC power from battery banks or PV arrays to AC power for AC loads. to export to the utility grid.
	Battery-based inverters are used in stand-alone PV systems and operate directly from the battery banks to their input source.
	The AC output is typically 120V or 240V single-phase power, with power ratings from a few hundred watts to over 10 kW.
102	Utility-interactive inverters draw power directly from PV arrays and operate in parallel with the utility grid.
	Typically output voltages are 120 V or 240 V single-phase units with power outputs up to 10 k W, while 208 V and 480 V three-phase … a few MW. Utility-interactive inverter output is determined by the DC input from the array, unlike battery based inverters.
	Charge Controllers. A charge controller is a device that regulates battery charge by controlling the charging voltage and/or current from a DC power source, such as a PV or array.
103	Charge controllers regulate battery charging by terminating or limiting the charging current when the battery bank reaches a full state of charge.
	Rectifiers and Chargers. A rectifier is a device that converts AC power to DC power. A charger is a device that combines a rectifier with filters, transformers, and other components to condition DC power for the purpose of battery charging.
	DC-DC Converter. A DC-DC converter is a device that converts DC power from one voltage to another.
	Maximum Power Point Trackers. A maximum power tracker (MPPT) is a device or circuit that introduces electronics to continually adjust the load on a PV device under changing temperature … to keep it operating at its maximum power point.
104	**Electrical Loads.** An electrical load is any type of device, equipment, or appliance that consumes electricity.
105	**DC Loads.**
	The most common DC Loads used in PV systems are lighting fixtures and motors for fans and pumps. Many DC loads operate at 12 V, 24 V, and 48 V.
	AC Loads. Most residential and commercial loads are AC loads, including refrigerators, air conditioners, televisions, lighting, and motors.

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	Balance-of System Components: Balance-of-system components are all the remaining electrical and mechanical components needed to integrate and assemble the major components of a PV system.
	Mechanical BOS Components. Mechanical BOS components include fasteners, brackets, enclosures, racks, and other structural support.
	Electrical BOS Components. Electrical BOS components include conductors, cables, conduits, junction boxes, enclosures, connectors, and terminations needed to make circuit connections between modules, controllers … and equipment.
106	**Electrical Energy Sources:** Besides the PV array, an electric utility grid is the source of electricity that is far by far most commonly connected to PV systems.
110	**PV System Configurations:** The simplest PV system configuration is a PV module or array connected directly to a DC load.
	Stand-Alone Systems. A stand-alone system is a type of PV system that operates autonomously and supplies power to electrical loads independently of the electric utility. Stand-alone PV systems are most popular for meeting small to intermediate size electrical loads.
	Direct-Coupled System Systems. A direct –coupled PV system is a type of stand-alone system where the output of a PV module or array is directly connected to a DC load.
	Direct-coupled PV systems are common for pumping potable water and agricultural water supplies.
	DC motors are the most common loads for direct-coupled systems.
	While direct-coupled systems are the simplest form of any PV system in terms of equipment, they are perhaps the most complex to design properly dues to lack of energy storage or system control.
111	**Self-Regulated Systems.** A self-regulating PV system is a type of stand-alone PV system that uses no active control systems to protect the battery, except through careful design and component sizing.
	To protect the battery from over charge, the battery system must be oversized in relation to the size of the array.
	Charge-Controlled Systems. If loads are variable or uncontrolled, charge control is required to prevent damage to the battery from overcharge or discharge. Charge control typically involves … to prevent overcharge.
	Charge control is required by the NEC if the maximum array current is equal to 3% or more of the rated battery capacity.
113	**Utility-Interactive Systems.** A utility-interactive system is a PV system that operates in parallel with and is connected to the electric utility grid.

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	These systems are the simplest and least expensive PV systems that produce AC power because they require the fewest components and do not use batteries. The primary component of a utility-interactive system is the inverter.
	Net Metering. Net metering is a metering arrangement where any excess energy is exported to the utility is subtracted from the amount of energy imported from it. Using this system, energy supplied … credited to the customer at full retail value.
114	**Figure 4-19.** Utility-Interactive System
	Dual Metering. Dual metering is the arrangement that measures energy exported to and imported from the utility grid separately.
115	**Multimode Systems.** A multi-mode system is a PV system that can operate in either utility-interactive or stand-alone mode and uses battery storage.
	The key component … is the inverter, which draws DC power from the battery system instead of the array.
	Multimode systems are typically used to back up critical loads … different times of the day in order to reduce electricity bills.
116	**Figure 4-21**. Multimode System
118	**Hybrid Systems:** A hybrid-system is a stand –alone system that includes two or more distributed energy sources.
	Hybrid systems offer several advantages over PV-only … flexibility in meeting variable loads.
	Hybrid systems are perhaps the most complex of all PV system in terms of equipment, system design, and installation.
	A DC bus hybrid system is a hybrid system that combines … for charging the battery bank.
	An AC bus hybrid system is a hybrid system that supplies loads with AC power from multiple energy sources.
	Figure 4-22. Hybrid Systems
124	**Photovoltaic Cells.** A photovoltaic cell is a semiconductor device that converts solar radiation into direct current electricity.
	Semiconductors. A semiconductor is a material that can exhibit properties of both an insulator and a conductor.
125	**Photovoltaic Effect:** The basic physical process by which a PV cell converts light into electricity is known as the photovoltaic effect. The photovoltaic effect is the movement of the electrons … energy above a certain level.

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	A PV cell is a thin, flat wafer consisting of a … semiconductor materials in contact with one another.
	Figure 5-3. Photovoltaic Effect
126	**Cell Materials:** PV cells can be produced from a variety of semiconductor materials, though crystalline silicon is by far the most common.
	Crystalline silicon (C-Si) cells currently offer the best ratio of performance … semiconductor industry.
	Gallium arsenide (GaAs) cells are more efficient than c-Si cells … space application.
	A multifunction cell is a cell that maximizes efficiency … wavelengths of solar energy.
	A thin-film module is a module level PV device … and make electrical connections between cells.
	A photoelectrochemical cell is a cell that relies on chemical processes to produce electricity from light, rather than using a semiconductor.
	Figure 5-4. PV Cell Material Efficiencies.
131	**Current Voltage (I-V) Curves:** The current-voltage (I-V) characteristic is the basic electrical output of a PV device.
	An I-V curve is the graphic representation of all possible voltage and current operating points for a PV device at a specific operating condition.
	A PV device can operate anywhere along its I-V curve, depending on the electrical lOad.
	Figure 5-10. I-V Curve
	Certain points on an I-V curve are used to rate module performance and are the basis for the electrical design of arrays.
132	**Open-Circuit Voltage:** The open-circuit voltage is the maximum voltage on an I-V curve and is the operating point for a PV device under infinite …and no current output.
	The open-circuit voltage of a PV-device can be measured by exposing the device to sunlight and measuring across the output terminals with a voltmeter or multimeter set to measure DC voltage.
	The open-circuit voltage of a PV device is determined by the semiconductor material properties and temperature.
	Short-Circuit Current: The short-circuit current is the maximum current on a n IV-curve and is the operating point for a PV device …and no voltage output.
132-133	The short-circuit current of a PV device is used to determine maximum circuit design … measuring current with an ammeter or multimeter.

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133	**Figure 5-12.** Short-Circuit Current Measurement
134	The current of a PV device is directly proportional to the surface area … doubling the solar irradiance on the device surface will double the current.
	Maximum Power Point: The maximum power point is the operating point on an IV-curve where the product of current and voltage is at a maximum.
	The maximum power voltage is the operating voltage on an I-V curve … Maximum power is calculated using the following formula: (formula).
135	Maximum power voltage and current can be measured only while the PV device is connected to a load that operates the device at maximum power.
	Efficiency. The efficiency of PV devices compares the solar power input to the electrical power output.
136	Efficiency is expressed as a percentage and is calculated with the following formula: (formula).
	Operating Point: PV cells operate most efficiently at their maximum power points.
137	The electrical load resistance required to operate a PV device at any point can be calculated … the formula is: (formula).
138	**Solar Irradiance Response:** Changes in solar irradiance have a small effect on voltage but a significant effect on the current output of PV devices. The current of a PV device increases proportionally with increasing solar irradiance.
139	**Temperature Response:** For most types of PV devices, high operating temperatures significantly reduce voltage output.
139-140	**Cell Temperature.** The cell temperature of a PV device refers to the internal temperature at the p-n junction. Cell temperature is influenced by …. Cell temperature can be estimated by either directly measuring the cell or module surface temperature or applying the temperature rise coefficient.
140	**Temperature Coefficients.** A temperature coefficient is the rate of change in voltage, current, or power output from a PV device due to changing cell temperature.
142-143	**Modules and Arrays:** A module is a PV device consisting of a number of individual cells connected electrically, laminated, encapsulated, and packaged into a frame.
	An array is a complete PV power generating unit consisting of a number of individual electrically and mechanically integrated modules with structural supports, trackers, or other components.
144	**Electrical Connections**

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	Series Connections. Individual cells are connected in series by soldering thin metal strips … Modules are connected in series with other modules by connecting conductors … to the positive terminal of another module.
	Only PV devices having the same current output should be connected in series.
	PV devices with different voltage outputs can be connected in series without loss of power as long as each device has the same current output.
	Figure 5-25. Series Connections
146	The maximum number of modules that can be connected in a series string … voltage rating of the modules and other components.
	Parallel Connections: Parallel connections involve connecting the positive terminals … together at common terminals or busbars.
151	**Module Selection:** Electrically, the voltage, current, and power output values are the most important considerations because they define the total number of modules needed to meet the desired energy production requirement.
152	On the physical side, among factors that may be considered for module selection are … the means for structural attachments.
	Arrays: Groups of modules are combined electrically and mechanically … The result is a complete array that integrates all the modules into a single power-generating unit.
	Most complete arrays are monopole arrays. A monopole array is an array that has one positive terminal and one negative terminal.
160	A cell is the basic unit in a battery that stores electrical energy in chemical bonds and delivers this energy through chemical reactions.
161	**Steady-State:** A cell or battery that is not connected to a load or charging circuit is at steady-state. Steady-state is an open-circuit condition where essentially no electrical or chemical changes are occurring.
	The open-circuit voltage is the voltage of a battery or cell when it is at steady-state. The open-circuit voltage of a fully charged lead-cell is about 2.1 V.
162	**Capacity:** Capacity is commonly expressed in ampere-hours (Ah), but can also be expressed in watt-hours (Wh).
	Discharging
163	**State of Charge (SOC).** The state of charge (SOC) is a percentage of energy remaining r in a battery compared to its fully charged capacity.
	Depth of Discharge (DOD). Depth of discharge (DOD) is the percentage of energy withdrawn from a battery compared to its fully charged capacity.

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	The depth of discharge and state of charge of a battery add of to 100%.
164	**Allowable DOD.** The allowable depth of discharge is the maximum percentage of total capacity that is permitted to be withdrawn from a battery.
	Autonomy. Autonomy is the amount of time a fully charged battery system can supply power to system loads without further charging.
	Charging. A cycle is a battery discharge followed by a charge.
165	Charge rate is the ratio of nominal battery capacity to the charge time in hours.
167	Overcharge is the ratio of applied charge to the resulting increase in battery charge.
169	**Battery Life:** Battery life is expressed in terms of cycles or years.
170	**Battery Types.** A primary battery is a battery that can store and deliver electrical energy but cannot be recharged.
	A secondary battery is a battery that can store and deliver electrical energy and can be charged by passing a current … to the discharge current.
171	**Battery Classifications**
172	**Flooded-Electrolyte Batteries**
	Captive-Electrolyte Batteries
173	**Lead-Acid Batteries**
174	**Nickel-Cadmium Batteries**
175	**Battery Systems**
	Battery Selection: Considerations includes lifetime, deep cycle … overcharge, and maintenance requirements.
	Battery Banks: A battery bank is a group of batteries connected together with series and/or parallel connections to provide a specific voltage and capacity.
176	**Series Connections.** Batteries are first connected in a series string by connecting the negative terminal of one battery, to the positive terminal of the next battery, in order to build voltage.
	For batteries of similar capacity and voltage connected on series, the circuit voltage … circuit capacity is the same as the capacity of the individual batteries.
177	**Parallel Connections.** Batteries are connected in parallel by connecting all the positive terminals together and all the negative terminals together.

Page #	Highlight
	The current of the parallel circuit is the sum of the current from the individual batteries. The voltage across the circuit … the sum of the capacities of each battery. If batteries or cells with different capacities … limited by the lowest capacity battery.
179	**Battery Installation**
	Battery Bank Voltage: Battery banks installed in dwellings must be less than 50 V nominal … This usually limits the voltage of lead-acid batteries to no more than 48 V nominal.
180	**Grounding:** Battery systems over 48 V are permitted to be ungrounded but have several requirements. The PV array … overcurrent protection for each ungrounded conductor.
	Wiring Methods: Battery systems are permitted to use flexible conductors of 2/0 AWG and larger.
	Conductor insulation types RHW and THW also meet the requirements for most battery installations in PV systems.
188	**Charge Controller Features:** A charge controller is a device that regulates battery charge by controlling … from a DC power source, such as a PV array. A charge controller in a PV systems maintains … overdischarge by system loads.
	Battery Charging: Charge controllers manage the array current delivered to a battery Charge acceptance is the ratio of the increase in battery charge to the amount of charge supplied to the battery.
190	**Overcharge Protection:** Overcharge is the condition of a fully charged battery … A charge controller protects a battery from overcharge through charge regulation.
	According to the NEC, any PV system employing batteries shall have equipment to control … This equates to a maximum charge rate of C/33.
191	**Overdischarge Protection:** Overdischarge is the condition of a battery state of charge declining to the point where it can no longer supply discharge current … without damaging the battery.
	A charge controller protects a battery from overdischarge through load control, disconnecting … reaches a low voltage condition.
193	**Charge Controller Types**
	Shunt Charge Controllers: A shunt charge controller is a charge controller that limits charging current to a battery system by short-circuiting the array.
194	**Series Charge Controllers:** A series charge controller is a charge controller that limits charging current to a battery system by open-circuiting the array.
196	**Maximum Power Point Tracking Charge Controllers:** A maximum power point tracking charge controller is a charge controller that operates the array … as well as regulates the battery charging.

Page #	Highlight
	Diversionary Charge Controllers: A diversionary charge controller is a charge controller that regulates charging current … to an auxiliary load.
197	**Hybrid System Controllers:** A hybrid system controller is a controller with advanced features for managing multiple energy sources.
	A principle feature of some hybrid controllers is the additional ability to start and control an engine generator.
198	**Ampere-Hour Integrating Charge Controllers:** An ampere-hour integrating charge controller … based on a preset amount of overcharge.
	Charge Controller
199	**Charge Controller Setpoints:** A charge controller setpoint is a battery condition, commonly the voltage, … switching functions.
	Charge Regulation Setpoints
200	**Load Control Setpoints**
205	**Charge Controller Installation**
	Figure 7-19: Charge Controller Selection Criteria
206	**Location:** To minimize their operating temperature, charge controllers should be installed out of direct sunlight and with unobstructed airflow around the heat sinks.
209	**Self-regulating PV Systems:** A self-regulating PV system is a type of stand-alone PV system that uses … component sizing.
	Self-Regulating PV systems must be designed so that the battery is never overcharged or discharged under any operating conditions.
210-211	**Battery and Array Sizing:** Any PV system with batteries must employ a charge control whenever the charge rate exceeds C/33.
218	**AC Power:** Direct current (DC) is electrical current that flows in one direction, either positive or negative.
	PV modules, and some other power generating technologies, produce DC power. However … Alternating current (AC) is electrical current that changes between positive and negative directions.
	Waveforms: A waveform is the shape of an electrical signal … used to represent changing electrical current and voltage.
220	**Three-Phase AC Power:** Three-phase AC power includes three separate voltage and current waveforms occurring simultaneously 120 apart.
223	**Power Factor.** True factor is the product of in-phase voltage and current waveforms and produces useful work … represented in units of watts (W).

Page #	**Highlight**
224	Reactive power is the product of out-of-phase voltage and current waveforms and results in no net power flow. Power factor is the ratio of true power to apparent power and describes … Apparent power is a combination of true and reactive power and is given in units of volt-amperes (VA). **Inverters:** When a PV system must supply power for AC loads, an inverter is required. An inverter is a device that converts DC power to AC power. Inverters provide convenience by being able to integrate a PV system with existing electrical systems. Static (solid-state) inverters change DC power to AC power using electronics and have no moving parts. Inverters used in PV systems are exclusively static inverters.
226	**Stand-Alone Inverters:** Stand-alone inverters are connected to batteries as the DC power …independently of the PV array and the utility grid. **Utility-Interactive Inverters:** Utility-interactive PV inverters are connected to, and operate in parallel with, the electric utility grid.
229	**Multimode Inverters:** Multimode inverters can operate in either interactive or stand-alone (though not simultaneously).
231	**Square Wave Inverters**
233	**Power Conditioning Units:** The physical enclosure that is referred to as an inverter … Power conditioning units perform one or more power processing …and maximum point tracking.
234	**Rectifiers:** A rectifier is a device that converts AC power to DC power. Rectifiers are used in battery chargers and DC power supplies operating from AC power. **Transformers:** A transformer is a device that transfers energy from one circuit to another through magnetic coupling. Transformers cannot convert between DC and AC … or change the frequency of an AC source.
235	**DC-DC Converter:** A DC-DC converter is a device that changes DC power from one voltage to another. Many PV inverters use DC-DC converters to change the DC input from low voltage to high voltage prior to the power-inverting process.

Page #	Highlight
	Maximum Power Point Trackers: A maximum power point tracker (MPPT) is a device or circuit … to keep it operating at its maximum power point .. all interactive inverters include MPPT circuits.
236	**Power Ratings.** For an interactive inverter, the output power rating limits the power it can handle at the its DC input, which limits the size of the PV array.
	Temperature Limitations. Solid-state switching devices are capable of handling only so much current before they overheat and fail. Parallel switching devices in the design increases the power rating of an inverter.
237	Temperature is the primary limiting factor for inverter power ratings.
	Interactive inverters control high temperatures by limiting the array power delivered to the inverter.
	Voltage Ratings
	AC Output. For interactive inverters, AC voltage output must be maintained at -10% to +5% of the nominal system voltage. In the case of nominal output, this range is from 108V to 126 V.
238	**DC Input.** DC input voltage ratings are based on the operating characteristics of wither a battery bank or a PV array.
	The required array voltage increases with increasing grid voltage … to permit MPPT operation.
	The DC voltage from the array is also affected by ambient temperature which complicates sizing.
239	**Frequency Rating:** For nominal 60 Hz operation the, the AC output frequency must be maintained between 59.3 Hz and 60.5 Hz.
	Current Ratings: For the DC side, current ratings limit the PV array or battery current that can be applied to the inverter. On the AC side, current ratings … output for interactive inverters.
240	**Efficiency:** Inverter efficiency is the ratio of an inverter's AC power output to its DC power input.
	Inverter efficiency is calculated with the following formula: (formula).
	Inverter efficiency is primarily affected by the inverter load. In stand-alone, the AC load defines the inverter load, and for interactive inverters the PV array defines the load.
248	**Sizing Methodologies:** 236 **Power Ratings.** For an interactive inverter, the output power rating limits the power it can handle at the its DC input, which limits the size of the PV array.

Page #	Highlight
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248	**Sizing Methodologies:** When sizing a PV system, it is necessary to consider the energy demand before considering the supply … The objective is to first determine the size of the inverter, battery bank, and array that are needed to meet the requirements.
	Sizing Utility-Interactive Systems: The sizing for interactive systems without energy storage generally involves determining the maximum array power output … 80% to 90% of the array maximum-power rating at standard test conditions (STC).
249	**Figure 9-2.** Interactive System Sizing
	Sizing interactive systems begins with the specifications of PV module chosen for the system.

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	The size of an interactive system is primarily limited by the space available for an array and the owner's budget.
250	**Sizing Stand-Alone Systems:** Stand-alone systems are designed to power specific on-site loads … directly proportional to the load requirements.
	Sizing stand-alone systems is based on meeting specific load requirements and involves the following key steps: 1-4.
251	**Sizing Multimode Systems**: Multi-mode systems are typically sized according to the stand-alone technology.
	The stand-alone sizing methodology determines the minimum size of a multimode system.
	Sizing Hybrid Systems: The array and battery bank for a PV array and engine generator hybrid system are sized similarly to those for a stand-alone system with three differences. First … Finally, battery banks can be sized for a shorter autonomy period than for PV-only stand-alone systems, also because the generator power is available on demand.
	Sizing Calculations: Sizing PV systems for stand-alone operation involves four sets of calculations. First … Finally the PV array is sized to fully charge the battery bank under the critical conditions.
252	**Load Analysis:** Analyzing electrical loads is the first and most important step in PV-system sizing. The energy consumption dictates the amount of electricity that must be produced.
	A detailed load analysis completed during the site survey lists each load, its power demand and daily energy consumption.
253	**Power Demand.** Peak-power information is usually found on appliance nameplates … peak power demand can be estimated by multiplying the maximum current by the operating voltage.
	Energy Consumption. Electrical energy consumption is based on the power demand over time.
254	The daily energy consumption for each load is determined by the load's power demand multiplied by the daily operating time.
	Inverter Selection. If the system includes AC loads, an inverter must be selected. Several factors must be considered when selecting an inverter. First, … as the largest single AC load.
	Inverter voltage output is another consideration.
255	The inverter DC-input voltage must also correspond with either the array voltage or the battery-bank voltage.

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	Inverter Efficiency. Both the AC and DC energy requirements from the load analysis are used to determine how much total DC energy will be required.
	The total amount of DC energy required by the loads is calculated using the following formula: (formula).
256	**Critical Design Analysis:** Systems are sized for the worst-case scenario of high load and low insolation.
	The critical design ratio is the ratio of electrical energy demand to average insulation during a period.
257	**Array Orientation.** If multiple orientations are possible, separate analyses are performed for each orientation.
	The orientations most commonly used in a critical design analysis are tilt angles equal to the latitude.
	The greater array tilt angle maximizes the received solar energy in winter months … in summer months.
260	**DC-System Voltage:** This voltage dictates the operating voltage and rating for all other connected components … inverters, and the array.
	The selection of the battery-bank voltage affects system currents.
	Lower current reduces the required sizes of conductors, overcurrent protection … and other equipment.
	As a rule of thumb, stand-alone systems up to 1 kW use a minimum 12 V battery-bank voltage, which limits DC currents to less than 84A.
	System Availability. System availability is the percentage of time over an average year that a stand-alone PV system meets the system load requirements.
	System availability is determined by insulation and autonomy.
	Autonomy is the amount of time a fully charged battery can supply system can supply power to the system loads without further charging.
261	**Battery-Bank Sizing**
	Battery-Bank Required Output. Batteries for stand-alone PV systems are sized to store enough … without further charge or energy contributions from the PV array.
	Figure 9-13. Battery-Bank Sizing
262	The required battery-bank capacity is determined from electrical-energy requirements to operate loads … The required battery-bank rated capacity is calculated using the following formula: (formula).

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	Battery-Bank Rated Capacity. Most PV systems use deep-cycle lead-acid batteries, which can be discharged to about 80%. This is the maximum fraction of the total rated capacity … at any time.
	Most battery rating are specified for operation at 25 C (77 F) at a certain discharge rate.
263	Using the daily operating time calculated in load analysis … average discharge rate is calculated using the following formula: (formula).
	To calculate the total rated capacity of the battery bank … The required capacity is calculated using the following formula: (formula).
264	**Battery Selection.** The number of parallel battery connections should be limited to 3- 4 strings.
	The nominal DC-system voltage divided by the nominal battery voltage determines the number of batteries in a string.
265	**Battery-Bank Operation.** First, the daily load fraction supplied by the battery bank is estimated.
	The load fraction is the portion of load operating power that comes from the battery bank over the course of a day.
	Instead, of load-fraction estimate of 0.75 is a common rule of thumb used for most PV systems.
	With the load fraction estimate, the average battery-bank daily depth … estimated with the following formula: (formula).
266	**Array Sizing:** For stand-alone systems, the array must be sized to produce enough electrical energy to meet … while accounting for normal system losses.
	Figure 9-18. Array Sizing
	Required Array Output: The required array current is calculated using the following formula: (formula).
267	**Array Rated Output**
268	Soiling is the acumination of dust and dirt on an array surface that shades the array and reduces electrical output.
	The rated array maximum-power current is calculated using the following formula: (formula).
	High temperature reduces array voltage output.
	The rated array maximum-power voltage is calculated using the following formula: (formula).

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269	**Module Selection.** For each module, three parameters are needed for sizing: the maximum power … and the maximum-power (operating) voltage.
	The number of parallel strings of modules required … rounding up to the next whole number.
	The number of series-connected modules in each string is determined … rounding up to the next whole number.
	The rated array maximum power is calculated by multiplying the rated module maximum power by the total number of modules.
278	The installed nominal operating cell temperature (INOCT) is the estimated temperature of a PV array operating in a specific mounting system design.
281	**Array Mounting Systems:** the simplest most common type of array mount for modules is the fixed-tilt type. A fixed-tilt mounting system … An adjustable mounting system is an array mounting system that permits the manual adjustment of the tilt.
	Building Mounting Systems
	Direct Mounts. A direct mount is a type of …finished rooftop or other building surface.
	Temperature-rise coefficients for direct mounts can be as high as 40 to 50 C/kW/m^2.
282	**Roof-Rack Mounts.** A rack-mount is a type of fixed- or adjustable-tilt array mounting system with a triangular-shaped structure to increase the tilt angle of the array.
	INOCT for rack-mounted arrays is the lowest among building mounting systems … 15 to 20 C/kW/m^2.
	Standoff Mounts. A standoff mount is a type of fixed-tilt array mounting system where modules … slightly above the roof surface.
283	In general, standoff mounts should be installed between 3" to 6" from the top of the module to the roof surface … are around 20 to 30 C/kW/m^2.
284	**Ground Mounting Systems**
286	**Sun-Tracking Systems:** A sun-tracking mount is an array mounting system that automatically orients the array to the position of the sun.
287	An active tracking mount is an array mounting system that uses electric motors and gear drives to automatically direct the array toward the sun.
288	A passive track mount is an array mounting system that uses nonelectrical means to automatically direct an array toward the sun.
	Mechanical Integration

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	Materials. Any material used should match the expected 20- to 30-year service lifetime of the overall system.
	Stainless steel alloys recommended for most fasteners.
	Aluminum structural alloys 6061 and 6063 ….and relatively inexpensive.
289	**Structural Loads:** Arrays and their attachment points must be designed and installed to withstand the forces from a combination of structural loads. A design load is a calculated structural load used to evaluate the strength of a structure to failure.
290	**Dead Load:** A dead load is a static structural load due to the weight of permanent building members, supported structure, and attachments.
	Live Load: A live load is a dynamic structural load due to …occupying the structure.
291	The basic wind speed is the maximum value of a 3 sec gust at 33' elevation, which is used in wind load calculations.
294	**Attachment Methods**
295	Mounting system attachments should be made through the roof cladding and into building structural members, such as rafters.
	Lag Screws. Lag screws are the most common fastenings for attaching array mounts to rooftops.
	Figure 10-22. Allowable Withdrawal Loads
309	**Voltage and Current Requirements**
310	**Maximum PV Circuit Voltage**: The maximum voltage of a PV source circuit is determined … lowest expected ambient temperature**.**
311	The maximum PV source-circuit or output-circuit voltage is calculated using the formula: (formula).
312	**Maximum PV Circuit Currents:** For PV source circuits, the maximum current is 125% of the sum … parallel-connected modules.
	For PV output circuits, the maximum current is the sum of the maximum currents of the parallel-connected source circuits.
	Maximum Inverter input Current: Maximum inverter input current is calculated with the following formula: (formula).
313	**Maximum Inverter Output Current:** The maximum current for the inverter output is equal to … output current rating.
	Conductors and Wiring Methods:

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314	**Figure 11-4.** Conductor Sizes
315	**Figure 11-5.** National Ampacities of Insulated Cooper Conductors
317	**Voltage Drop.** Voltage drop and the associated percentage of the voltage drop of conductors are calculated using Ohm's law: (formula).
318	**Conductor Insulation**
319	**Figure 11-10.** Recommended Insulation Types for PV Systems
321	**Wiring Connections**
322	The following are basic requirements for terminating electrical conductors: (6 bullets).
	Module Connectors. These connectors must meet the following five requirements from Section 690.33: (5 bullets).
324	**Junction Boxes**
328	**Overcurrent Protection**
329	**Overcurrent Protection Devices.** Overcurrent protection devices include fuses and circuit breakers.
330	**PV System Overcurrent Protection**
331	Circuits must be protected from every source of power.
	Every undergrounded conductor must be protected.
	Array Overcurrent Protection. Generally, all undergrounded array conductors must include overcurrent protection. The grounded conductors must not normally include overcurrent protection.
332	**Inverter-Output Overcurrent Protection.**
	Figure 11-25. Overcurrent protection in the inverter output circuit depends … accomplished by using circuit breakers or fused disconnects.
333	**Disconnects:** A disconnect is a device used to isolate equipment and conductors from sources of electricity from the purpose of installation, maintenance, or service.
334	**Array Disconnects:** A disconnect must be provided to isolate all current-carrying conductors … in a building or structure.
	AC Disconnects: A disconnect must also be installed on the AC side of the PV system to isolate the system from the rest of a building's electrical system.
335	**Equipment Disconnects**: If equipment is connected to one or more power source, each power source must have disconnecting means.

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	Grounding
336	**AC Grounding**
	DC Grounding. The DC grounding connection must be made at a single point on the PV output circuit, usually within the inverter.
337	**AC and DC Grounding.**
	Figure 11-30. The DC grounding system and the AC grounding system must be … require a separate grounding electrode system.
338	**Ground-Fault Protection.** Ground-fault protection is the automatic opening of conductors involved in a ground fault.
340	**Equipment Grounding.**
341	**Figure 11-35.** Grounding Conductor Sizing
343	**Surge Arrestors:** A surge arrestor is a device that protects electrical devices from transients (voltage spikes).
345	**Battery Systems.**
	Battery Banks Less Than 50 V
	Battery Banks Greater Than 50 V: Battery systems of greater than 48 V must include a disconnect to divide the system into segments of 48 V or less for maintenance.
346	**Charge Control:** In the case of self-regulated systems, charge control is accomplished through careful sizing and the matching of the array to the battery bank. Most systems … must include active means of charge control.
	Diversion loads are commonly used for charge control …The loads voltage rating must be greater than the maximum battery voltage … the power rating must be at least 150% of the array's power rating.
354	**Utility-Interactive Systems.** The most common type of utility interactive PV system is one that does not use energy storage. The array is connected to the DC input of the utility- interactive inverter.
	When on-site power demand exceeds the supply from the PV system, the power is drawn from the utility.
	Multimode Systems. Multimode systems are interactive systems that include battery storage … water pumps, or lighting.
	The inverters serve the on-site loads or send excess power back to the grid while the array keeps the battery bank fully charged.

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355	Multimode inverters are programmed to supply electrical loads … minimizing the use of high-priced utility energy.
358	**Interconnection Concerns.**
	Islanding. Islanding is the undesirable condition where a distributed-generation power … continues to supply power to the utility grid during a utility outage.
360	**Point of Connection**: The point of connection is the location at which the interactive distributed-generation system makes its interconnection with the electric utility system.
	Load-Side Interconnections. The NEC permits load-side connection for utility interactive inverters … following the seven conditions are satisfied: 1 -7.
363	**Supply-Side Interconnections.** When PV systems are too large to interconnect on the load side … a supply side interconnection must be used.
366	**Utility Interconnection Policies**
383	**Permitting**
	Permit Applications. Permit applications for PV systems should contain site drawing s … and array mounting information.
	Site Drawings. A simple drawing of the site should indicate the locations of major PV system components … and other features.
	Electrical Diagram
385	**Figure 13-5.** Permit applications usually require either a one-line or a three-line electrical diagram.
	Array Mounting Design. Most permit applications for PV systems require descriptions … and that the array will be well secured.
387	**Inspection**
388	**Working Space:** PV system inspections also ensure that there is adequate access and safe working space around all electrical equipment.
389	**Live Parts.** Live parts are energized conductors and terminals. Live parts must be protected … 50 V or more.
390	**Labels and Marking**
400	**System Functional Testing**
	Verification Testing
402	**System Performance Testing**
404	**Maintenance**

Page #	Highlight
405	**Array Maintenance**
408	**Battery Maintenance**
413	**Monitoring**
417	**Troubleshooting**
426	**Incentives**
431	**Cost Analysis**
433	**Life-Cycle Costs**
438	**Life-Cycle Cost Analysis:** The life-cycle cost for any energy system is the sum of the present values … This is represented in the following formula: (formula).