Chapter 12

Utility Interconnection

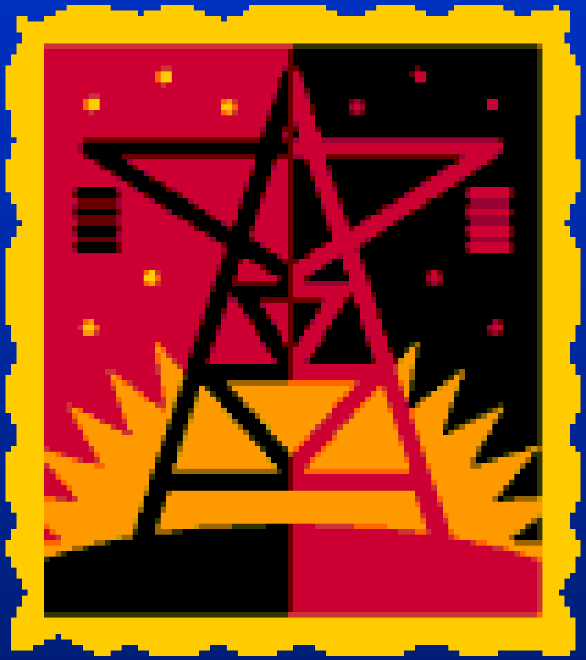
Codes and Standards ● Utility Considerations ● Supply and Load Side Connections ● Interconnection Agreements

Overview

- Identifying the codes and standards for interactive PV systems and equipment.
- Classifying types of utility-interactive photovoltaic systems.
- Understanding the requirements for supply side and load side interconnections.
- Identifying the terms and conditions for utility interconnection agreements.
- Distinguishing between net metering and other types of utility revenue metering.

Interconnection

- **Interconnection refers to the technical and procedural matters associated with operating interactive PV systems and other distributed generation sources in parallel with the electric utility system.**



Interconnection Issues

- **Technical issues include:**
  - Protections for the public and utility and other workers; power quality and impact on the utility system; installation codes.
- **Procedural and administrative issues include:**
  - Utility and government policies and laws; interconnection agreements; tariffs, rates and fees.

Utility Concerns with Distributed Generation

- **Electric utility concerns about customer-owned distributed generation include:**
  - Generation operating on their system that they do not maintain or control.
  - Protection of electrical system equipment.
  - Reliability of equipment, and impacts on the sizing and operation of utility services.
  - Power quality impacts on the utility system and other customers.
  - Impacts during utility outages and disturbances (anti-islanding protection).
  - Liability and safety of utility personnel and the public.

History of Distributed Generation and PURPA

- **The Public Utility Regulatory Policy Act (PURPA, 1978) is a federal law that created the first markets for independent power producers.**
  - Requires electric utilities to purchase energy generated from independent power producers, called Qualifying Facilities (QF).
  - Energy prices are to be based on “avoided costs”, equivalent to the utility’s cost of producing energy or wholesale rate.
  - QF rules may apply to privately-owned utility-scale PV systems larger than local net metering rules allow.

Interconnection Codes and Standards

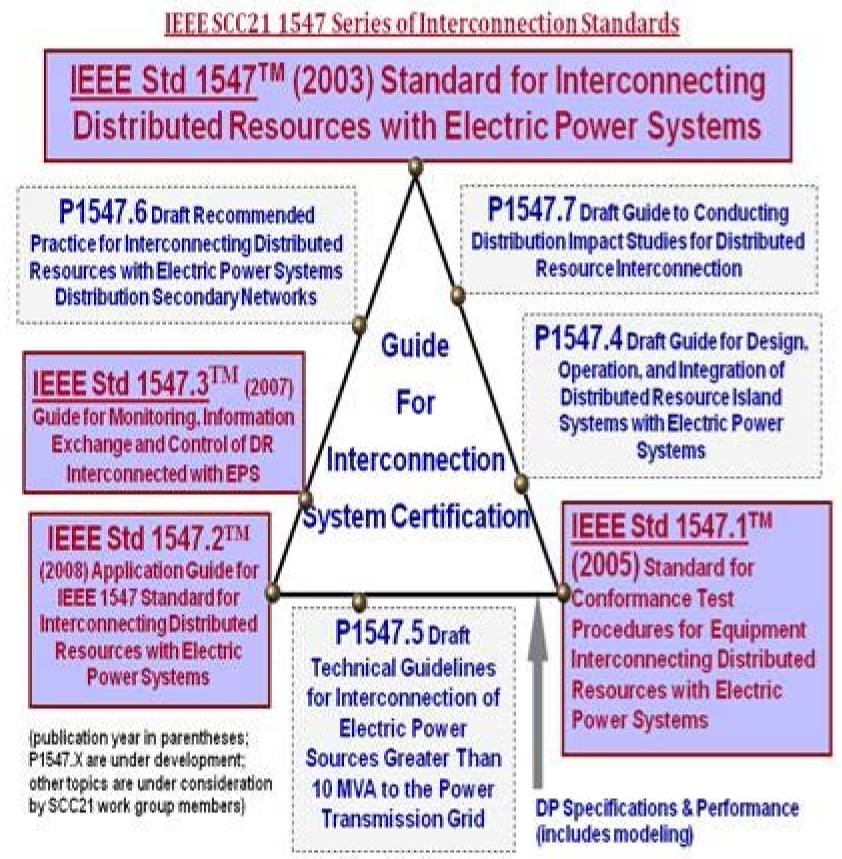
- **IEEE 1547: Standard for Distributed Resources Interconnected with Electric Power Systems**
  - Establishes technical and operational requirements.
- **UL 1741: Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources**
  - Defines equipment test procedures and product listing requirements.
- **National Electrical Code - NFPA 70**
  - Prescribes installation requirements.
    - Article 690: Solar Photovoltaic Systems
    - Article 705: Interconnected Electric Power Production Sources

IEEE 1547

- **IEEE 1547 Standard for Interconnection of Distributed Resources with Electrical Power Systems:**
  - Covers technical requirements for the interconnection of PV systems and other distributed generators.
  - Addresses personnel safety, equipment protection, power quality and islanding protection.
  - Does not address procedural or administrative details of interconnection agreements.

IEEE 1547 Series of Standards

- IEEE 1547 consists of the main standard, in addition to a series eight other standards and guidelines dealing with various aspects of interconnecting distributed power sources.
- IEEE 1547 is the basis for UL 1741 listing of interactive PV inverters.



Islanding

- Islanding is a condition where part of a utility system containing both load and generation is isolated from the remainder of the utility system but remains energized.
- Islanding of PV systems and other distributed generation is an undesirable condition, and presents two basic concerns:
  - Lack of voltage and frequency control
  - Safety for electric utility workers

Anti-Islanding Protection

- **IEEE 1547 requires PV systems and other distributed generation sources to be able to detect when an island is forming and stop supplying power to the grid until the utility system is re-energized.**

- **Listed, interactive PV inverters have integral anti-islanding protection.**
  - Inverters must disconnect their output to the grid within two seconds when an islanding condition is detected.
  - Inverters shall remain disconnected until the utility has been re-energized to acceptable voltage and frequency limits for a period of five minutes.

Monitoring and Isolation

- **IEEE 1547 requires distributed generators with an aggregate capacity of 250 kVA or more to have provisions for monitoring interconnection status, real power, reactive power and voltage at the point of connection.**
- **When required by utilities, a readily accessible, lockable, visible-break isolation device (disconnecting means) shall be located between the distributed generator and utility grid.**

Voltage

- IEEE 1547 required the following voltage regulation standards for distributed generators:
- The DG system must not cause the service voltage to go outside the requirements of ANSI C84.1, Range A. The DG system must not cause the service voltage to fluctuate more than ±5% when interconnecting.
- The DG system must de-energize its output within a specified time under abnormal voltage conditions:
  - < 50% of nominal voltage (V), 0.16 sec (~10 cycles)
  - 50% to 88% of nominal voltage, 2 sec (120 cycles)
  - 110% to 120% of nominal voltage, 1 sec (60 cycles)
  - > 120% of nominal voltage, 0.16 sec
- The service voltage must be within ANSI C84.1, Range B for 5 minutes before reconnection.

Frequency

- **IEEE 1547 requires frequency to be maintained within the following limits:**
- **For distributed generators under 30 kW, the DG system must de-energize its output within a 0.16 seconds if the frequency falls outside the range of 59.3 to 60.5 Hz.**
  - 57 to 60.5 Hz for DG systems larger than 30 kW
- **Frequency must remain in the range of 59.3 to 60.5 Hz for 5 minutes prior to reconnection.**

Power Quality

- **IEEE 1547 also requires distributed generators to conform to certain power quality standards:**
  - DC current injection must be less than 0.5%.
  - Current harmonics are limited to a specified percentage depending on the harmonic order.
  - Total demand distortion (TDD) for current must be less than 5%.

UL 1741

- **UL 1741 Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources:**
  - Covers inverters, converters, charge controllers, combiner boxes and AC modules for use in stand-alone or utility-interactive power systems.
  - Products covered by these requirements are intended to be installed in accordance with the National Electrical Code, NFPA 70.

Characteristics of Distributed Generators

- **Mechanical rotating generators and electronic inverters have different characteristics that affect their interconnection to the grid.**

- **Rotating Generators:**
  - A voltage source
  - Can deliver high fault current
  - Can act as a load
  - Synchronization and protection uses separate equipment

- **Electronic Inverters:**
  - A current source
  - Limited fault current
  - Can not act as a load
  - Synchronization and protection features are integral to inverters

Synchronizing

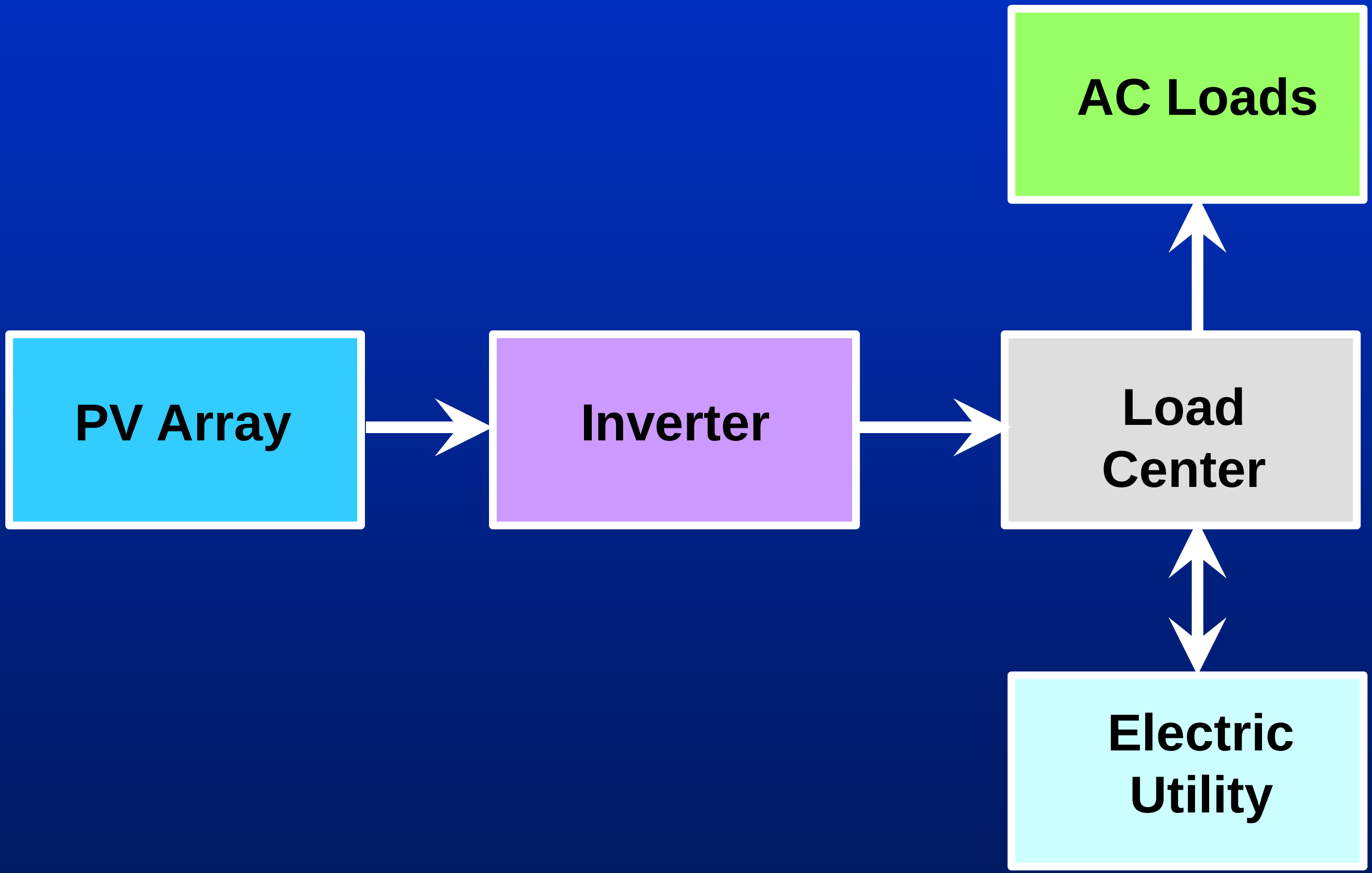
- **Synchronizing is the process of connecting a generator to an energized electrical system, and involves:**
  - Phase sequencing
  - Speed and frequency control
  - Voltage control
  - Phase matching

- **Modern electronic inverters perform all synchronizing functions internal to the inverter circuitry.**

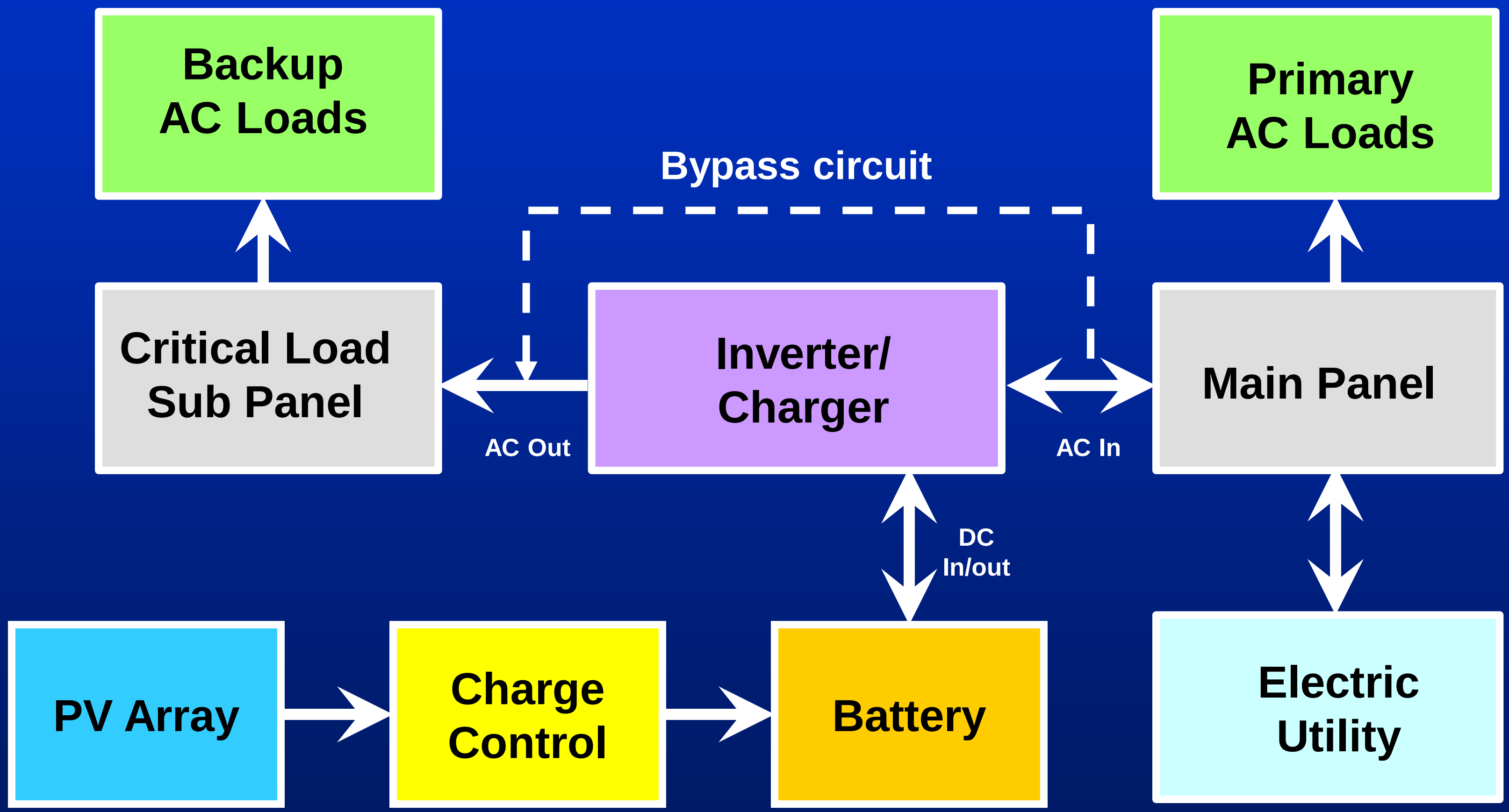
Types of Interactive PV Systems

- **Interactive Systems without Energy Storage**
  - Operate interconnected (in parallel) with the utility grid.
- **Bi-Modal Interactive Systems with Energy Storage**
  - May operate in either utility-interactive or stand-alone mode, but not simultaneously.

Utility-Interactive PV System



Utility-Interactive PV System with Energy Storage



Installation Requirements

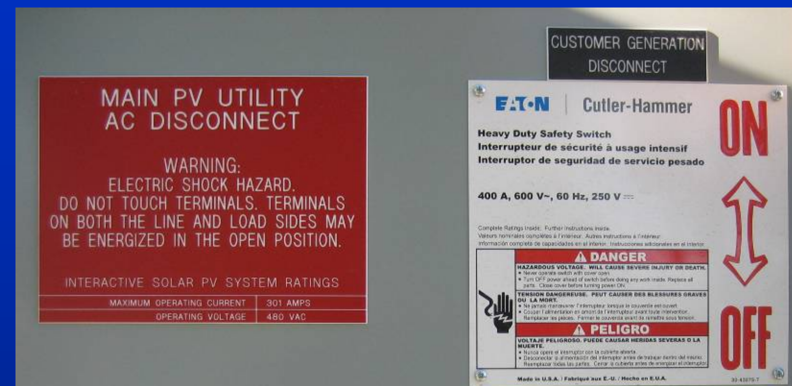
- **The installation requirements for PV systems and other interconnected distributed generators are covered by the National Electrical Code (NEC), NFPA 70.**
    - Article 690, Solar Photovoltaic Systems
    - Article 705, Interconnected Electric Power Production Sources
- **The installation and connection of distributed generators in parallel with the electric utility system must be performed by qualified persons [705.6].**

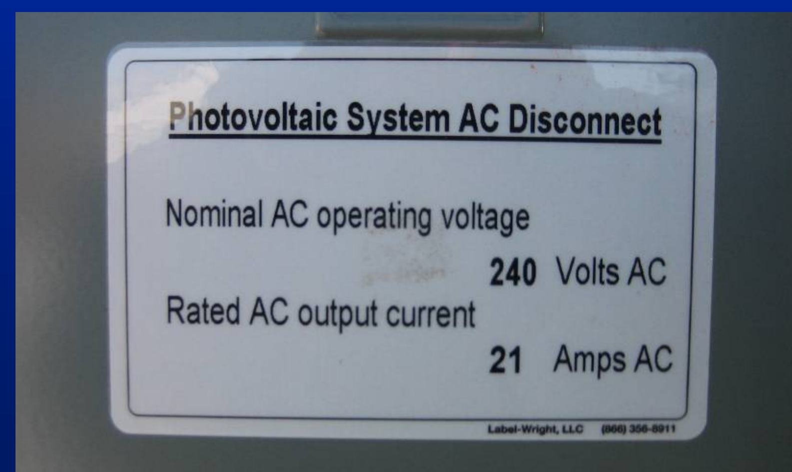
Point of Connection

- **The point of connection, or point of common coupling, is the point where a distributed generator interfaces with the electric utility system.**
  - ♦ The point of connection may be located on the load or supply side of a facility service disconnecting means.
  - ♦ Special markings and labels are required at the point of connection.

Point of Connection Markings

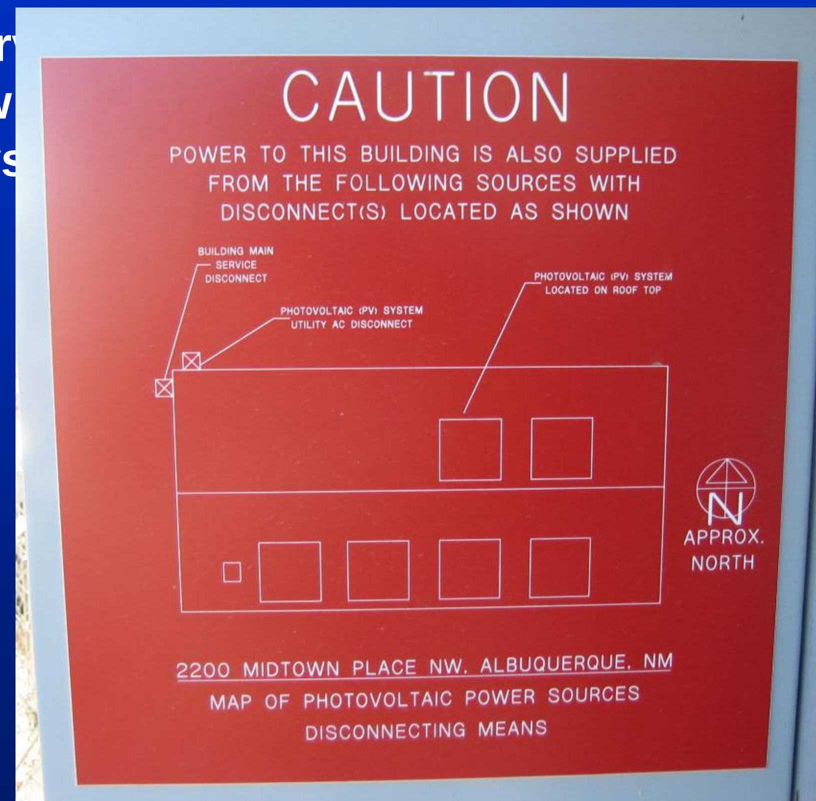
- **Markings are required for interconnected PV power sources at the disconnecting means, and must indicate the following:**
  - A PV power source
  - Nominal AC operating voltage
  - Maximum AC current





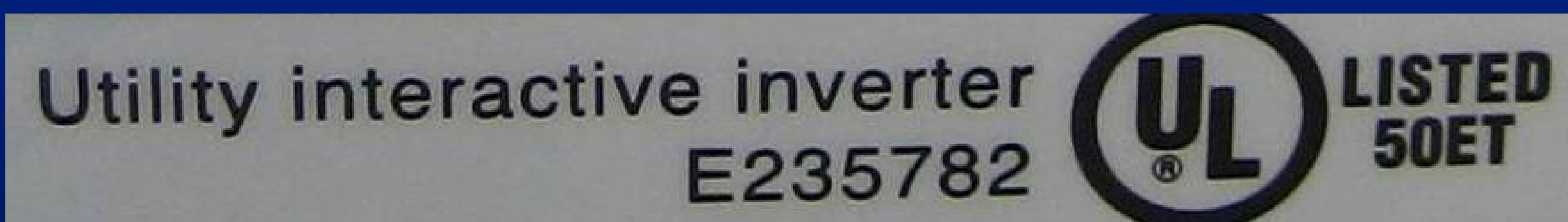
Point of Connection Markings

- **Facilities supplied by both utility ser**
  permanent plaque or directory show
  disconnecting means and the PV sys -
  located.



Identified Interactive Equipment

- Inverters and AC modules used in utility-interactive PV systems must be listed and identified for interactive operation, and special markings are required on the product listing label.



Loss of Interactive Power

- **To prevent islanding, interactive inverters and AC modules must disconnect their output from the grid upon loss of grid voltage.**
  - Prevents energizing of otherwise de-energized system conductors and is intended to prevent electric shock.
  - Addressed in the IEEE1547 standard and UL1741 inverter listing.
  - Can be demonstrated during system commissioning.
  - This feature is integral to all listed utility-interactive inverters.
- **A normally interactive PV system is permitted to operate as a stand-alone system to supply loads that have been disconnected from the utility grid.**
  - Special battery-based interactive inverters are required.

Ampacity of Neutral Conductor

- Single-phase, 2-wire inverters connected to the neutral conductor and one ungrounded conductor of a 3-wire system or of a 3-phase, 4-wire, Wye-connected system can potentially overload the neutral conductor.
- The maximum load connected between the neutral conductor and any one ungrounded conductor plus the inverter output rating must not exceed the ampacity of the neutral conductor.
- Most single-phase interactive inverters have two-wire output with no neutral connection and avoid this concern.

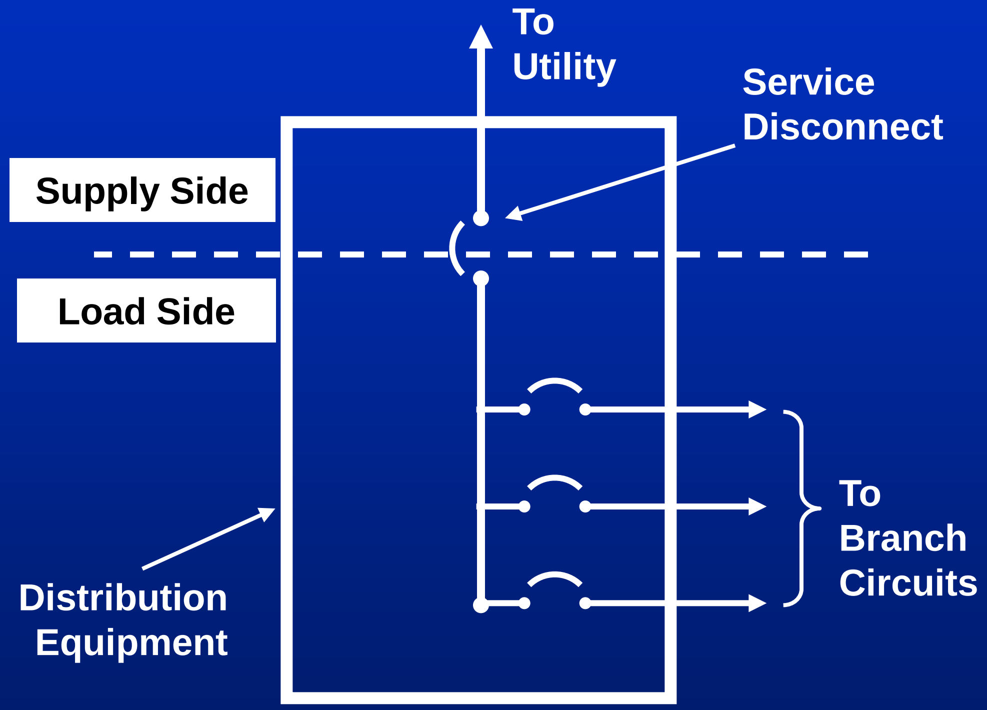
Unbalanced Interconnections

- **Single-phase inverters must not cause unbalanced phase voltages when connected to three-phase power systems.**
  - Solutions are to use three smaller single-phase inverters connected to each phase, or a larger three-phase inverter.

- **Three-phase inverters must automatically de-energize all phases upon loss of service voltage in one or more phases.**

Point of Interconnection

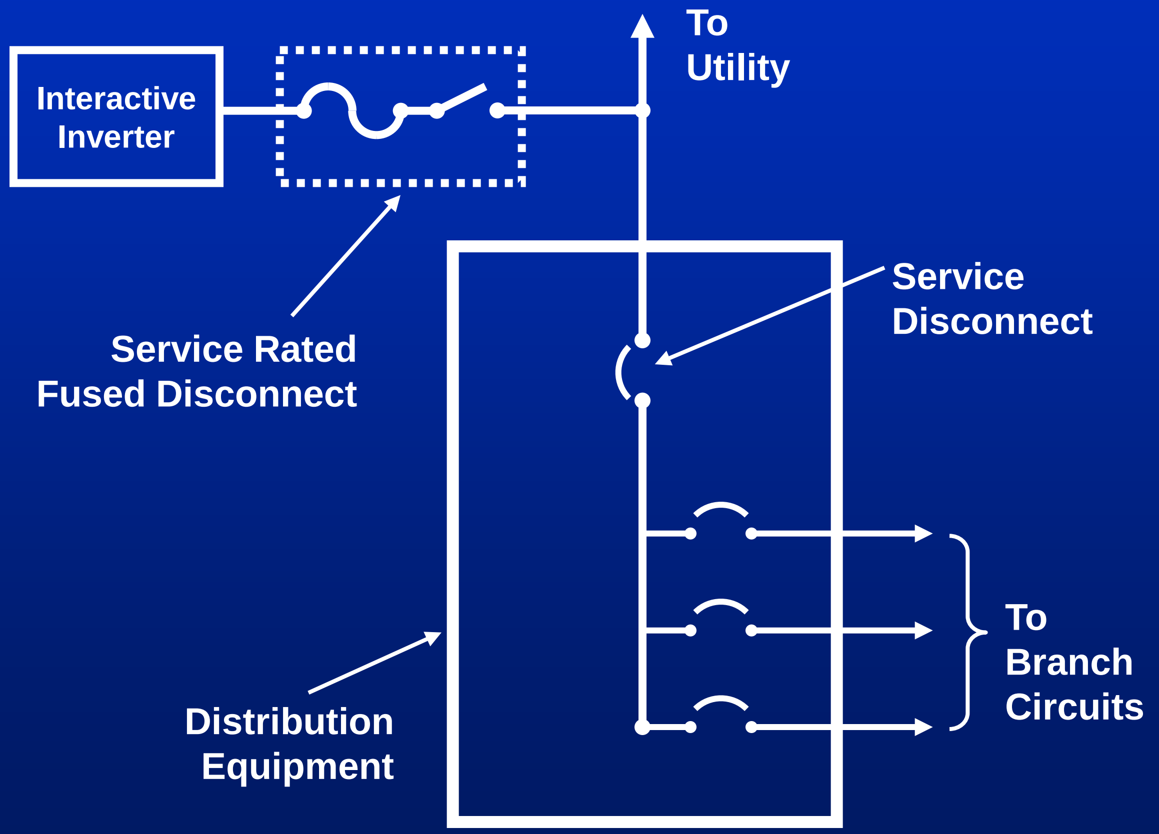
- **Interactive inverters may be connected to either the load side or the supply side of the service disconnecting means.**



Supply Side Connections

- Supply side interconnections are made on utility side of the service disconnecting means.
- Requirements are similar to installing a new service, and often used where the requirements for load side connections can not be met.
- The sum of overcurrent devices supplying the service must not be greater than the service rating.

Supply Side Connection



Supply Side Connections

- **The following requirements apply to supply side connections:**

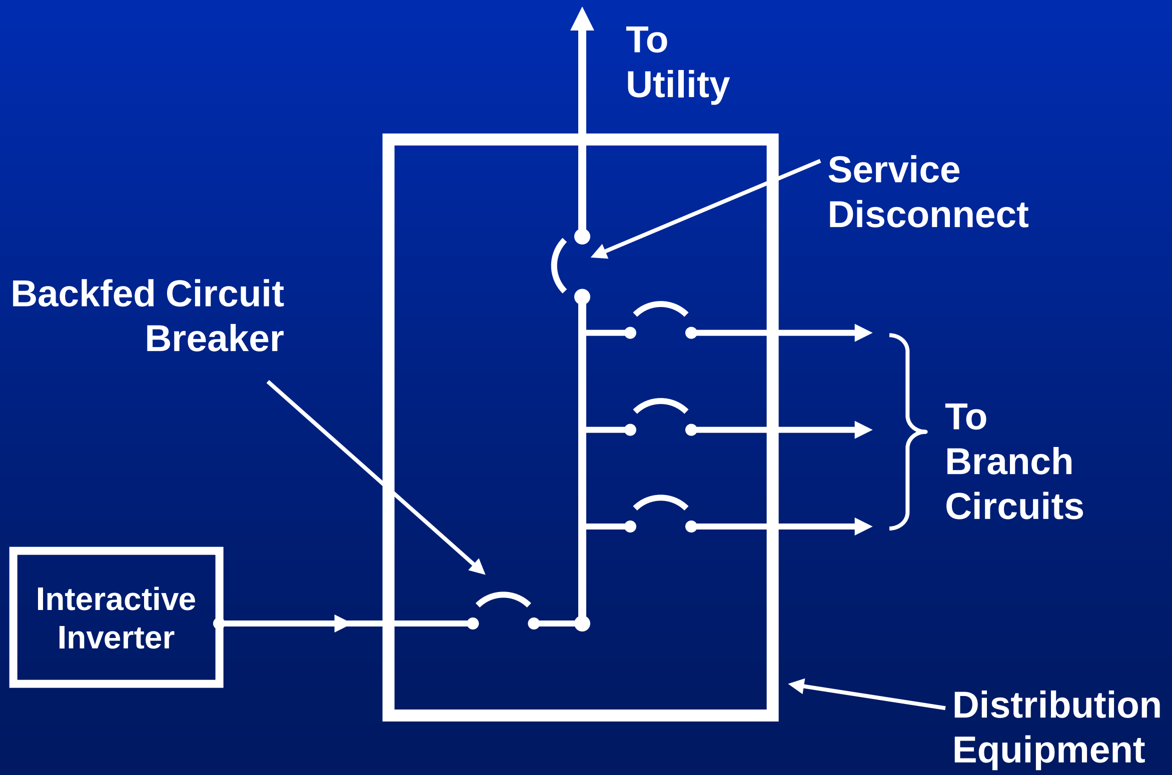
- **The disconnect and overcurrent device must be rated as service equipment, have a minimum rating of at least 60 amps, and have an interrupt rating sufficient for the maximum available fault current.**
  - Must be grouped with main service disconnect, and no more than six (6) service disconnects are allowed.
  - A service-rated fused disconnect or circuit breaker meets the requirements.
  - Disconnect may also satisfy a utility's interconnection requirements when an accessible, visible-break, lockable safety switch is used.

Tapping Service Conductors

- **Service conductors may be tapped to make supply side connections, and requires the following:**
  - Conductors should be as short as possible with the new PV disconnect mounted adjacent to the tap point.
  - Conductors should be installed in rigid metal conduit provide the highest level of fault protection.
  - Service conductors must be sized for at least 125% of the inverter continuous rated current output.
  - The new service must be properly grounded and bonded.

Load Side Connection

- The output of utility-interactive inverters are permitted to be connected on the load side of the service disconnecting means at any distribution equipment on the premises.



Load Side Interconnections

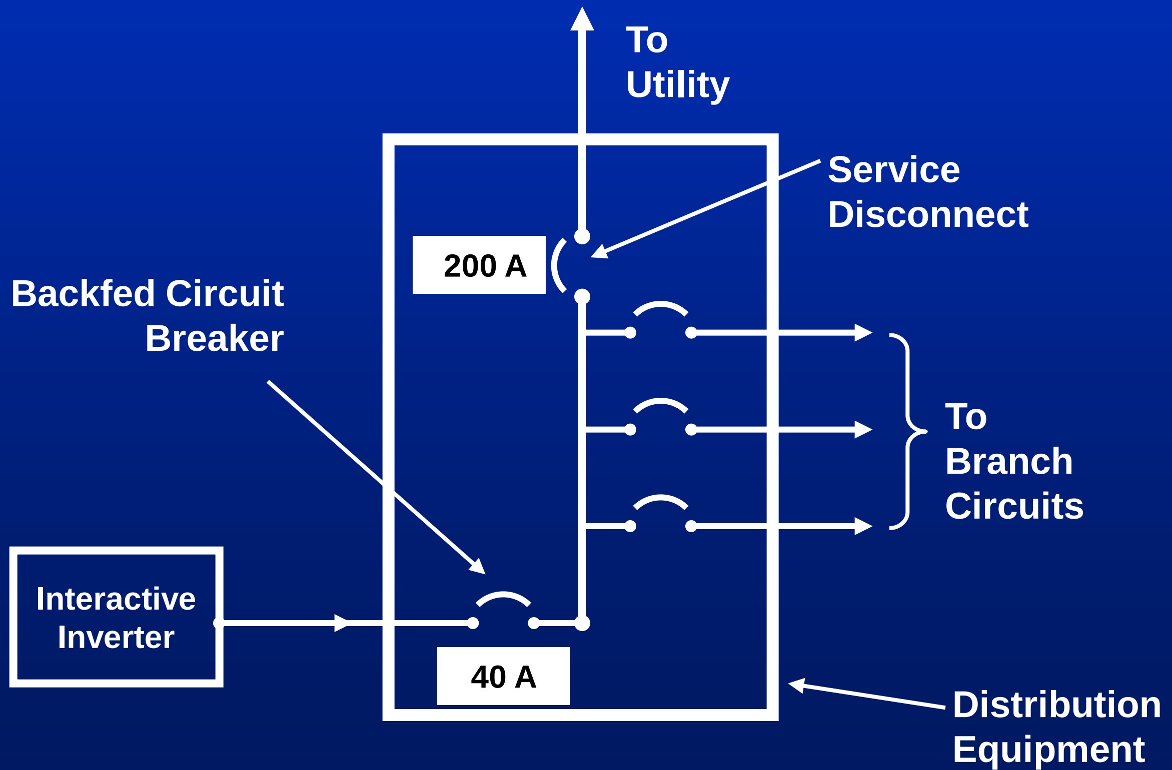
- **Load side connections for interactive inverters address the following requirements:**
  - Overcurrent protection and disconnects
  - Bus or conductor ratings
  - Ground-fault protection
  - Markings
  - Backfed circuit breakers
  - Fastening
  - Inverter output connection

Dedicated Overcurrent and Disconnect

- **Load side connections require each source (inverter) to have a dedicated disconnect and overcurrent protection.**
  - Fusible disconnect or circuit breaker; need not be service rated.
- **PV systems using more than one inverter are considered multiple sources, and require a dedicated disconnect and overcurrent device for each inverter.**
- **A single disconnecting means can be provided for the combination of multiple parallel inverters connected to subpanels.**

Bus or Conductor Rating

- Load side connections require that the sum of the ampere ratings of overcurrent devices supplying power to a busbar or conductor does not exceed 120% of busbar or conductor rating.



Bus or Conductor Rating: Example

- **What is the highest rated inverter continuous AC output current that can be interconnected to a 125 A panel supplied from the grid by a 100 A overcurrent device?**

- **The OCP devices supplying power to the panel (PV and grid) can not exceed 120% of the panel bus rating.**
  - The allowable OCP devices is 1.2 x 125 A = 150 A.
  - The allowable PV breaker would then be 150 A – 100 A = 50 A.

- **Since the PV OCP device needs to be 125% of the inverter maximum continuous output current ratings, the maximum inverter continuous output current would be 50 A / 1.25 = 40 A.**

Ground-Fault Protection

- Interactive inverters must be interconnected on the line side of all ground-fault protection equipment.
- Most ground-fault protection breakers are not listed for backfeeding, and may damage them and prevent proper operation.
- Supply side interconnections are usually required for larger facilities incorporating ground-fault protection devices at the service if they are not listed and approved for backfeeding.

Marking

- Distribution equipment used for interconnecting inverters must have marking to identify the connection for all sources.
- Requires labels for backfed PV breaker and main supply breaker.

Suitable for Backfeed

- Circuit breakers used for inverter connections must be suitable for backfeeding.
- Breakers without “Line” and “Load” side marking have been evaluated in both directions, and considered to be identified as suitable for backfeeding.

Fastening

- Fastening normally required for supply breakers is not required for breakers supplied by interactive inverters.
- Bolt-in connections, or panel covers normally render breakers not readily accessible for removal.
- The requirement for listed interactive inverters to de-energize output upon loss of utility voltage also makes these breakers safer for removal and service.

Inverter Output Connection

- **If the sum of the overcurrent device rati greater than 100% of the bus rating:**
- **The inverter output breakers must be in ne bus from the utility supply breaker, and :**
  - WARNING: INVERTER OUTPUT CONNEC OVERCURRENT DEVICE

Load Side Connection: Example

- Consider a 7 kW PV inverter with 240 V output. Can this inverter be connected to a 150 A panel supplied by a 150 A main service breaker?

Load Side Connection: Example (cont.)

- **The inverter maximum continuous output current is:**
  - 7,000 W / 240 V = 29.2 A
- **The required overcurrent device rating is:**
  - 29.2 A x 125% = 36.5 A rounded up to next standard breaker size, 40 A
- **The 150 A panelboard permits 120% x 150 A = 180 of supply breakers:**
  - 180 A – 150 A main leaves 30 A maximum allowable PV supply breakers.
- **A 7 kW inverter requires a 40 A breaker and may not be connected to this panel.**

Load Side Connection: Example (cont.)

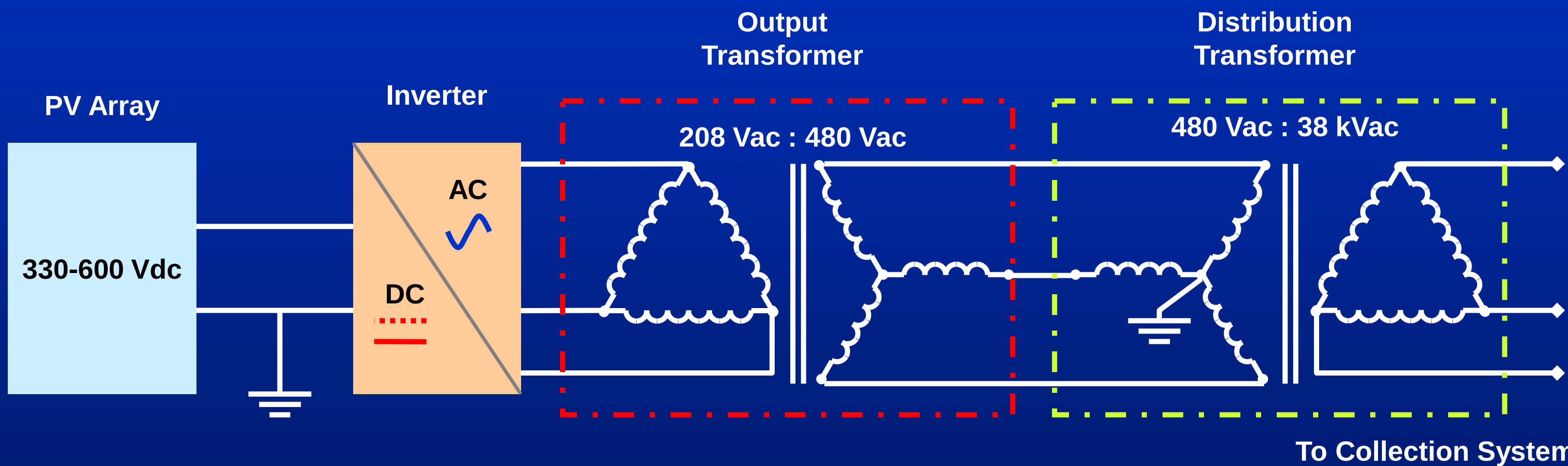
- **To allow the load side connection of a 7 kW inverter for the previous example, possible solutions include:**
- **Upgrading the panel rating to 200 A with a 200 A main breaker would allow a 40 A backfed breaker from the PV systems.**
  - Keeping the main breaker at 150 A would allow even more PV capacity to be interconnected, and not require a utility service upgrade.
- **Ultimately, the ratings of distribution equipment and overcurrent protection devices limit the size of load side interconnections.**

Inverter Subpanels

- Inverter subpanels are commonly used for multiple string inverter installations, and can be combined into a single disconnecting means.
- Each inverter has a dedicated overcurrent device and panel must be sized for load side interconnection requirements.

Utility-Scale Interconnections

- **Large PV systems 500 kW to 1 MW and larger are typically interconnected to the utility grid at distribution voltages.**



Utility Interconnection Agreements

- **Interactive PV systems require approval from the local electric utility before beginning parallel operations.**

- **Most utilities have standard procedures and agreements for customers to interconnect PV systems, and generally include the following provisions:**
  - Use of listed equipment approved for interactive operation
  - Permitting, inspection and approval by the AHJ
  - Size limits and tiers
  - Location of disconnecting means and labeling
  - Insurance and liabilities
  - Metering and billing
  - Testing and monitoring
  - Maintenance
  - Application and processing fees

Interconnection Agreements: Code Compliance

- **Electric utilities require customer-owned PV systems and other interconnected distributed generation to meet local code requirements.**
- **Listed Interactive Equipment**
  - Inverters and motor-generators must be listed and approved for interactive operations.
- **Approval**
  - PV installations must usually be permitted, inspected and approved by the Authority Having Jurisdiction (AHJ) prior to beginning interactive operations.

Interconnection Agreements: Liability Insurance

- **Electric utilities often require owners of interactive PV systems to maintain liability insurance to protect the customer and the utility in the event of any accidents, injuries or adverse effects due to the operation of a customer's PV system.**
  - Utilities may also require owners to indemnify the utility for any potential damages as a result of operation of a PV system.
- **Customer are also usually required to maintain their equipment in accordance with the interconnection agreement.**

Interconnection Agreements: Testing and Monitoring

- **Some electric utilities may require special testing or monitoring for interconnected PV systems, especially for larger installations that may impact grid operations.**
- **Utility testing and monitoring may include:**
  - Voltage and frequency output
  - Power quality
  - Anti-islanding protection

Interconnection Agreements: Disconnecting Means

- **For code compliance, interactive PV systems must already have a disconnect means to isolate the inverter output from the utility grid.**
- **Utilities may also require that PV system disconnects are:**
  - External to a building
  - Lockable by utility personnel
  - Provide a visible-break isolation from the grid
- **In some cases, small residential PV systems may not be required to have a utility-accessible disconnect.**

Interconnection Agreements: Metering and Billing

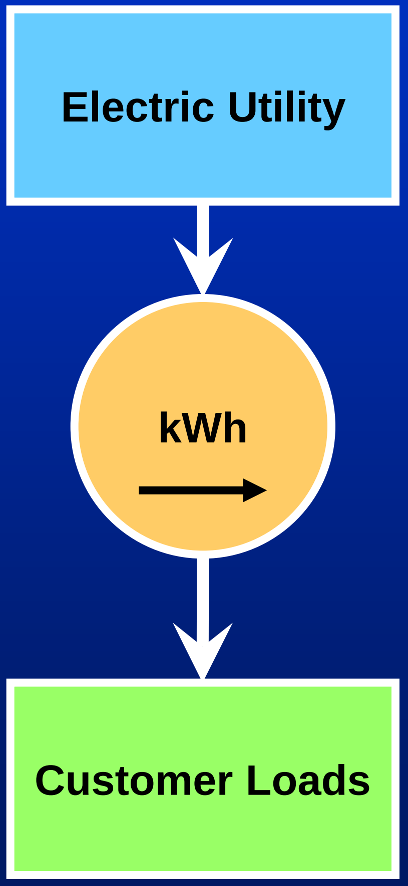
- **Different configurations and types of revenue metering may be used to record energy flows for facilities with PV systems, based on the type of billing arrangements.**
  - Demand metering
  - Time-of-use metering
  - PV output metering
  - Net purchase and sale metering (dual metering)
  - Net metering

Electronic Metering

- **Electronic utility meters can measure and record many parameters in separate registers, including:**
  - Energy delivered to a facility
  - Energy received from a facility
  - Peak power demand
  - Time-of-use consumption
  - Reactive power and energy
  - Power factor

Revenue Metering

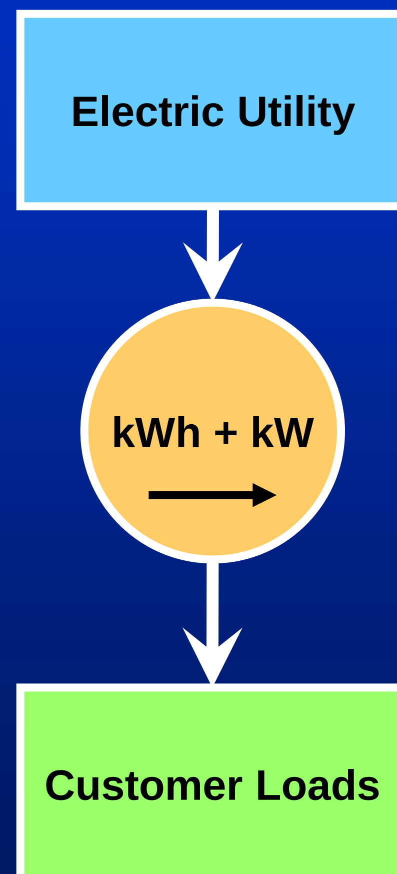
- Revenue metering is installed at the point of service entrance for utility billing purposes, and records the energy (kWh) delivered to a facility.
- Revenue metering establishes the transition between the utility and customer-owned equipment.



Meter spins in one direction, customer pays retail rate for energy

Demand Metering

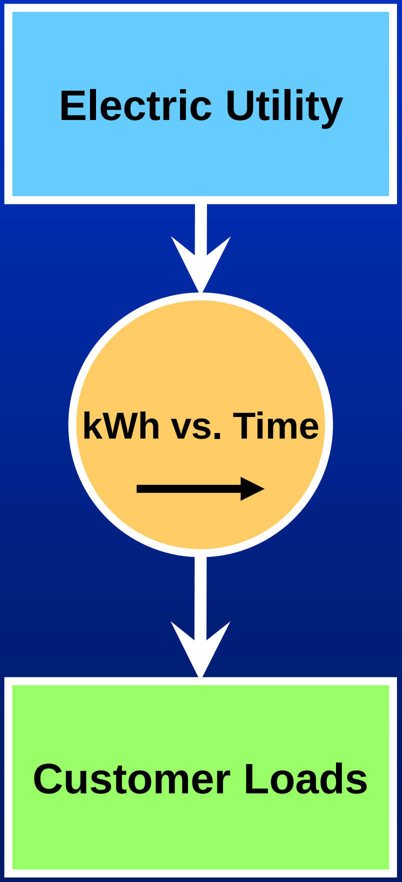
- Demand metering is often used for larger commercial and industrial facilities, and records the peak power (kW) delivered over any 15-minute interval during a month.



Customer pays for energy and peak power demand

Time-of-Use Metering

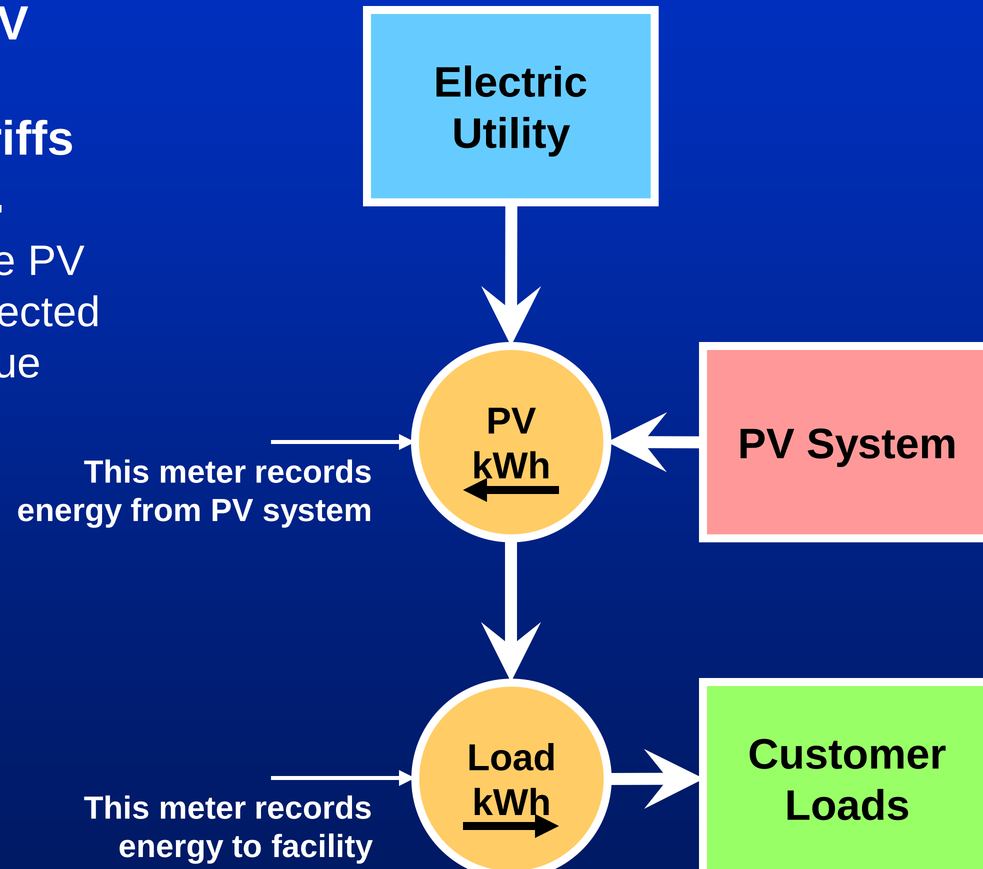
- Time-of-use metering uses electronic meters to record energy flows based on the time of day it is consumed.



Customer pays different rates for energy based on time

PV Output Metering

- **The energy production for PV systems is often metered independently for feed-in tariffs or renewable energy credits.**
  - For feed-in tariff programs, the PV output and metering are connected on the utility side of the revenue meter.

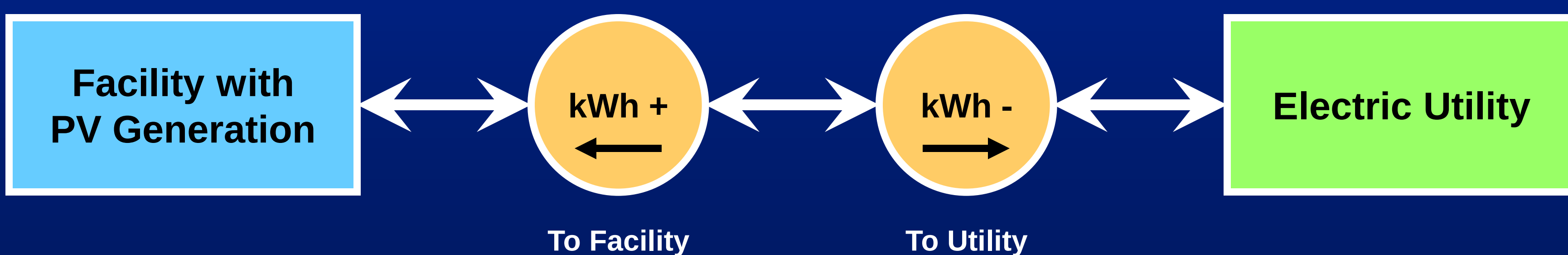


Sub Metering

- **Bimodal and hybrid PV systems with multiple AC input and output circuits may use sub metering to measure energy delivered to loads or produced by other power sources.**

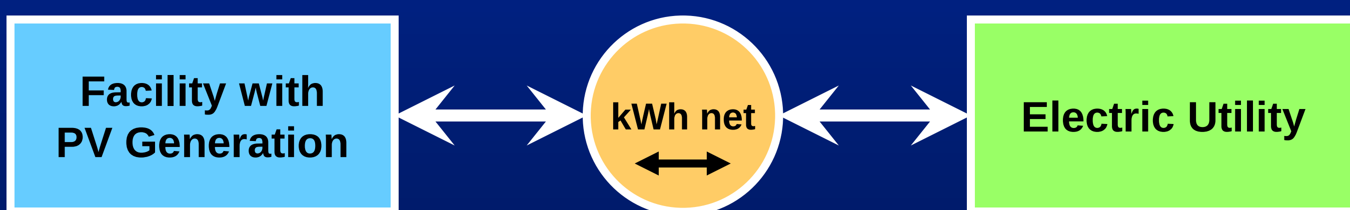
Dual Metering

- **Dual metering (net purchase and sale metering) uses two unidirectional meters (or single electronic meter) to record energy flow to and from the utility and facility with PV generation.**
  - One meter register records electricity drawn from the grid; user pays retail rate.
  - The other meter register records electricity fed back onto the grid; user is credited wholesale rate.



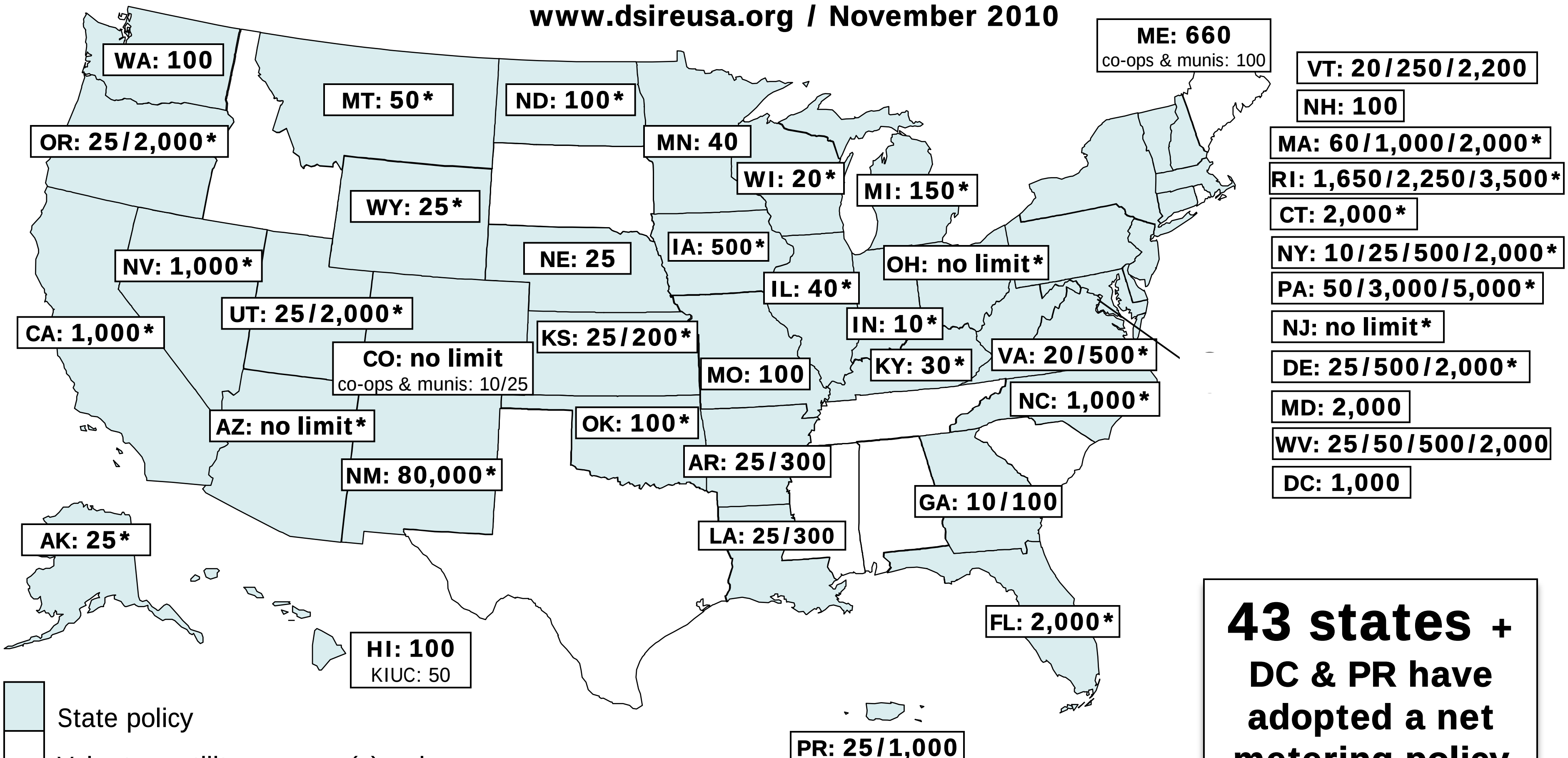
Net Metering

- **Net metering allows the utility customer to receive full retail credit for at least a portion of the excess energy produced from a PV systems and sent back to the utility grid.**
  - Utility meter spins in both directions, effectively banking excess production on the grid for future credit.



A single, bi-directional meter records net energy

Net Metering Rules



43 states + DC & PR have adopted a net metering policy

State policy

Voluntary utility program(s) only

* State policy applies to certain utility types only (e.g., investor-owned utilities)

Note: Numbers indicate individual system capacity limit in kW. Some limits vary by customer type, technology and/or application. Other limits might also apply. This map generally does not address statutory changes until administrative rules have been adopted to implement such changes.

Summary

- The technical and safety requirements for the interconnection of PV systems to the utility grid are governed by national codes and standards.
- Small PV systems can usually be connected on the load side of the service disconnect means, while larger systems are usually interconnected on the supply side.
- Policies and interconnection agreements are specific to states and utilities.

Questions and Discussion