

Interconnection Requirements Training

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Interconnection Engineering and Power Quality

2016



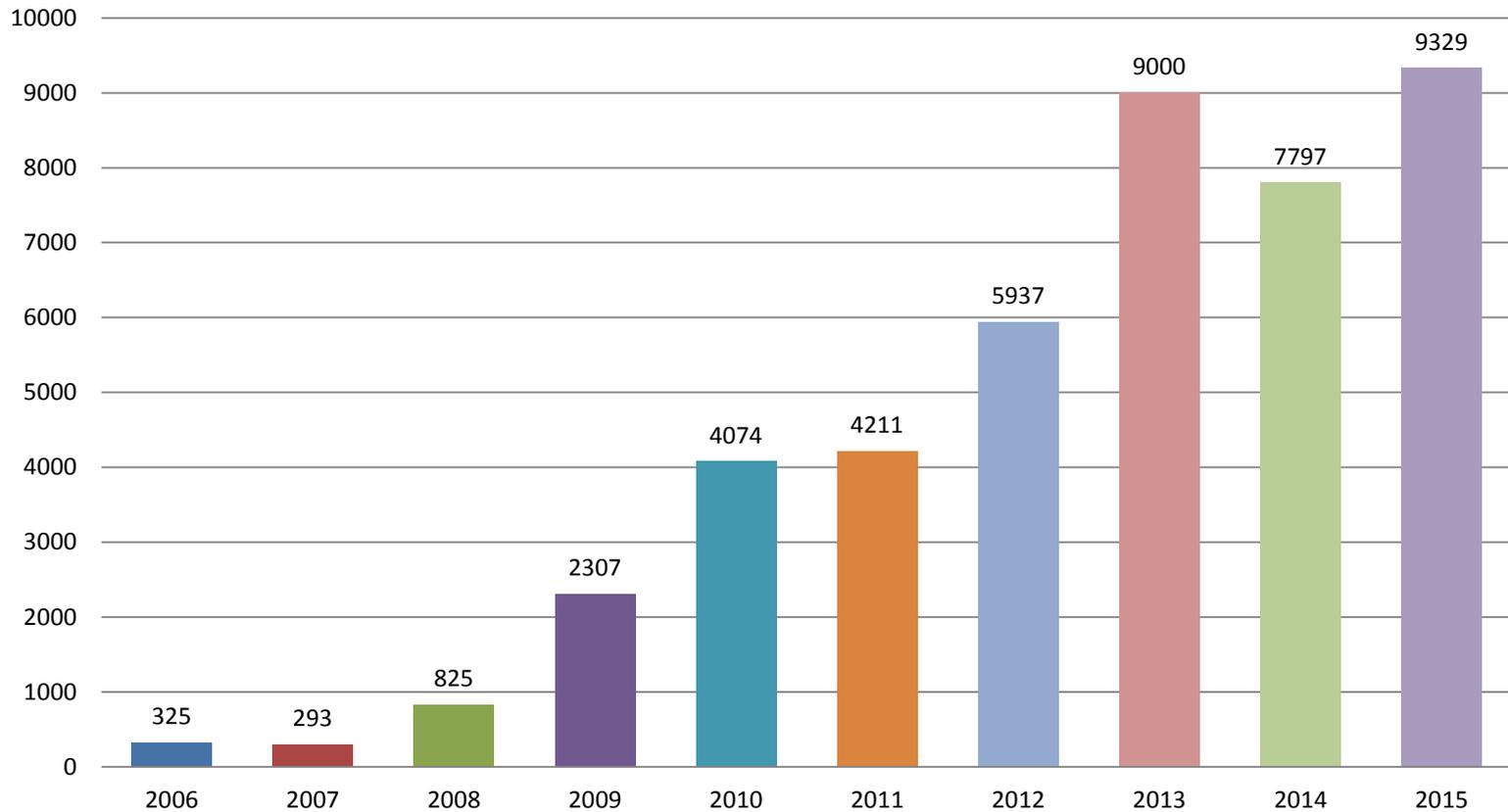
Agenda Topics

INTERCONNECTION REQUIREMENTS

- Introduction & Installation Numbers
- Typical PV System Components (Residential and Commercial)
- Required Diagrams & PV Sample One-Line
- Site Plan Diagram & System Layout Examples (Residential and Commercial)
- High Level Breaker & Wire Sizing, Helpful NEC References
- Warning Labels
- Standard Interconnection Requirements
- Supply Side Connections
- Battery Systems & Metering Considerations
- Open Delta Transformers
- Future Technology Considerations – Smart Inverters
- Lessons Learned – 2015 APS Engineering Review Audit

Distributed Generation-Photovoltaics (Residential)

Grid Tied PV Instalations by Year



Anatomy of Solar Photovoltaic System

- Components
 - Panels (UL 1703)
 - DC disconnect switch or switches
 - Inverters (UL 1741)
 - Utility AC Disconnect Switch
 - DC and AC Combiner Boxes
 - Typically interconnected with utility grid
(*stand alone PV systems with batteries are not common*)
- Codes
 - NFPA 70 / NEC 2008
 - Some Arizona Municipalities still utilizing the 2008 NEC.
 - NEC 2011
 - Many Arizona Municipalities have already adopted the 2011 NEC.
 - Section 690 has been reorganized with some sections removed and added to 705.
 - NEC 2014
 - Some AHJs have adopted 2014, note that the City of Phoenix will be skipping this NEC revision.

Required Diagrams for PV Systems

(Residential and Small Commercial Larger than 1kW, < 1MW)

- Residential

- Electrical One-Line Diagram

- Will only be reviewed by APS Engineering if system meets engineering review criteria.

- Electrical Three-Line Diagram

- Site Plan

- Commercial

- Electrical One-Line Diagram

- Electrical Three-Line Diagram & Three-Line Array

- Plant Location

- Site Plan

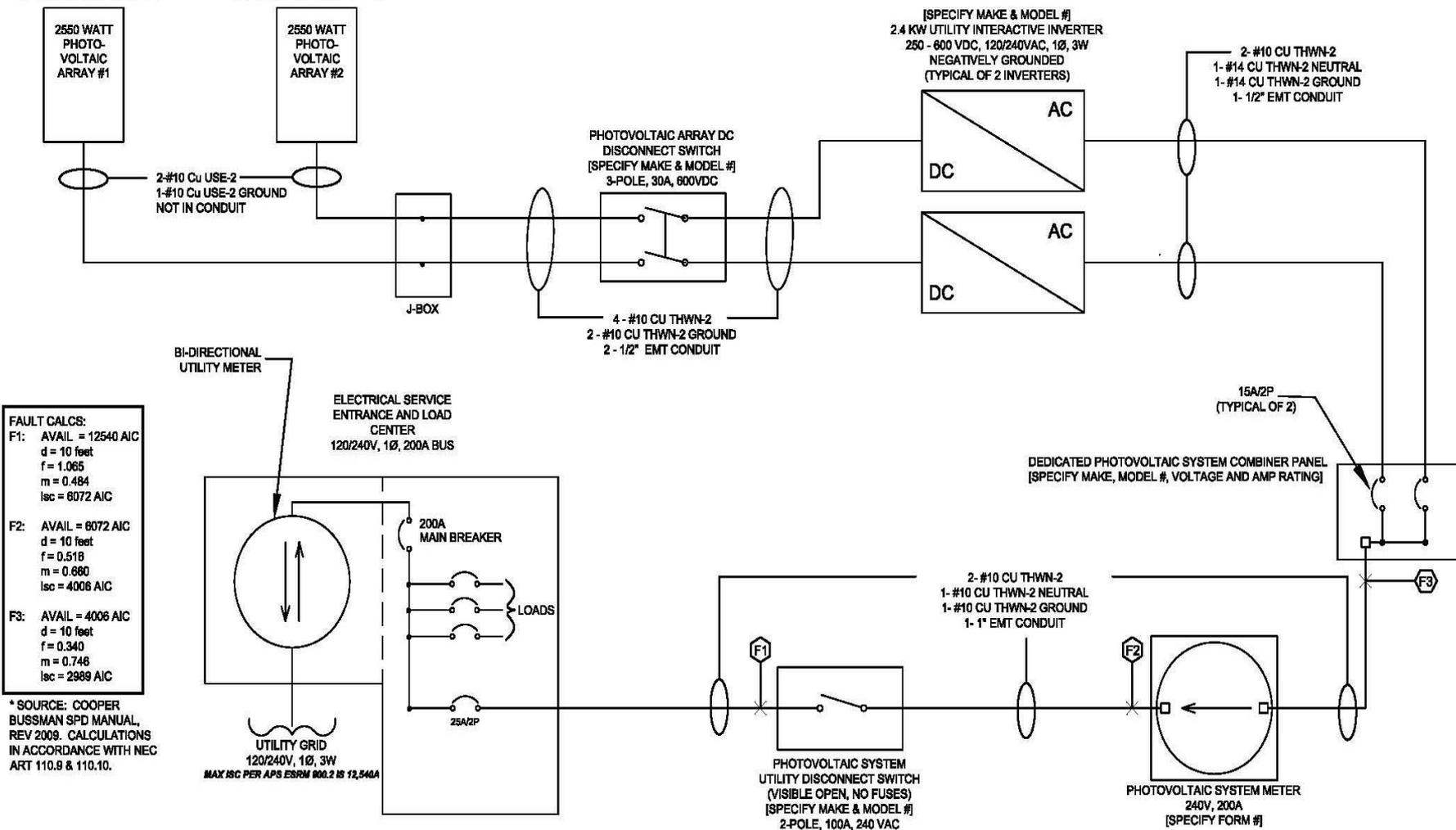
APS will not accept copyrighted, proprietary or confidential drawings. Drawings shall be site specific without any extraneous information, and shall be prepared specifically for APS use. All drawings are to be professionally drawn, using only black print on white paper, and shall be in accordance with APS Sample Diagrams. Battery Backup Systems may have other drawing requirements in addition to standard drawings as required by APS.

NOTE: Customer should discuss project plans with APS before designing its DG or purchasing and installing equipment.

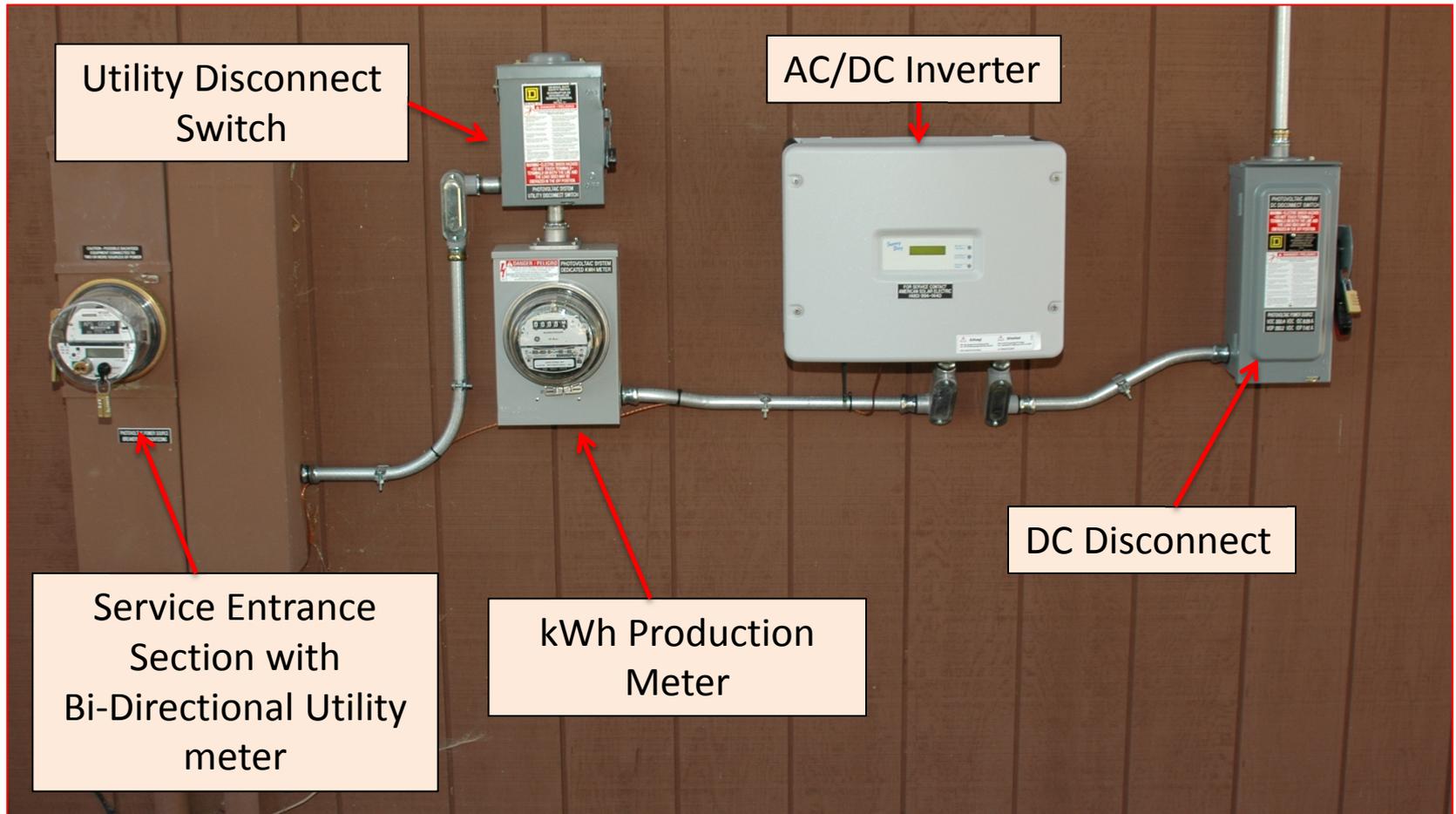
Sample 1-Line Diagram

Voc=457VDC, Isc=7.28AMP
Vmp=376VDC, Imp=6.78AMPS

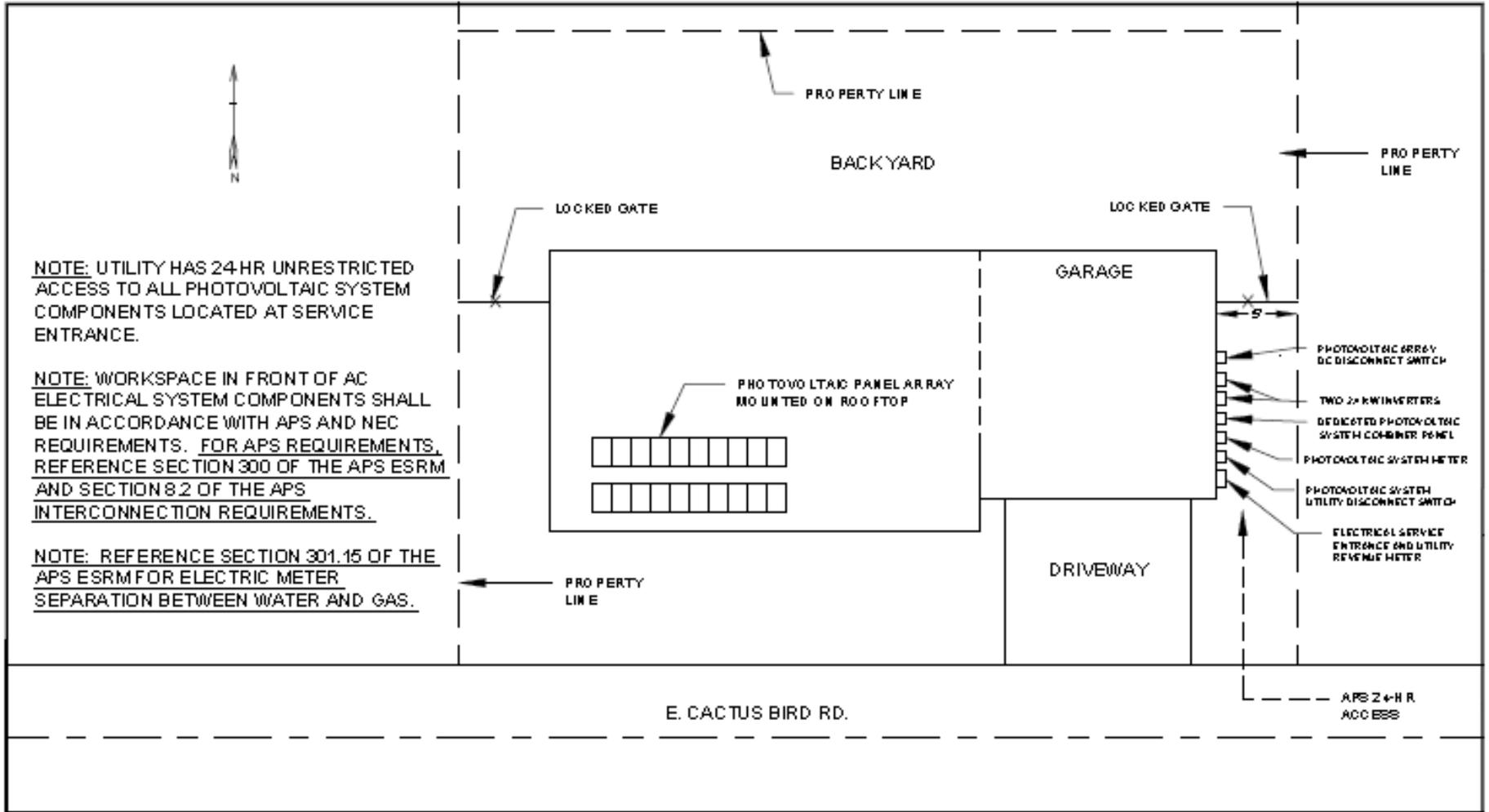
Voc=457VDC, Isc=7.28AMP
Vmp=376VDC, Imp=6.78AMPS



Example - Residential PV System



Sample Site Plan



Sample Breaker & Wire Sizing

Example: 2-8kW Static Inverters in Parallel (120/240V, 1Ø, 3W). Calculate the AC output Current, Determine the correct breaker size and wire.

— **Breaker Sizing: NEC 690.8(B)(1)(a), 240.6(A)**

Inverter AC Output Current Rating X 1.25

$$8\text{kW}/.240\text{kV} = 33.3\text{A} \times 1.25 = 41.6\text{A}$$

OCPD = 45A (combiner box)

In Parallel

$$16\text{kW}/.240\text{kV} = 66.6\text{A} \times 1.25 = 83.3\text{A}$$

OCPD = 90A (back-fed breaker)

— **Wire Sizing: NEC 690.8(B)(2), Table 310.15(B)(16) - 90°C Colum X Temp Correction [Table 310.15(B)(2)(A)]**

Assume and ambient temp of 104°F

Temp Correction = 0.87

41.6A (circuit to combiner above), Will need to use 1-#8 Cu THWN-2 per phase

In Parallel

83.3A (parallel circuit above), Will need to use 1-#2 Cu THWN-2 per phase

NOTE: If wire length is less than 10' OR less than 10% of the run is above ground, then a temperature correction factor may not be required.

Additional NEC Code References

— Six Handle Rule: NEC 230.71(A)

- In the event we have six disconnects and no main, customer wants to add a 7th breaker for a back-fed device (PV). Some AHJs consider this a violation others consider PV as a separate source and exempt from NEC 230.71(A).
- ***Systems without a main need to consider NEC 230.90(A), Exception No. 3: The sum of the ratings of CBs/fuses shall be permitted to exceed the ampacity of the service conductors provided the calculated load doesn't exceed the ampacity of the service conductors. Provide load calculations to APS, panel schedules and consider PV into the load calculations provided.***

— Main Breaker De-Rate: NEC 230.79

- If customer is in violation of the 120% Rule [NEC 705.12(D)(2)], customer may de-rate the main in order to accommodate the installation of a PV system. Load calcs will be required by the AHJ and APS prior to de-rating the main breaker. APS can provide 12 month historical load to the customer for calculation purposes [NEC 220.87].
- Note 12 Month historical Loads are provided in kW. To convert from kW to kVA, we assume a 0.91PF for residential and 0.85PF for commercial
- A placard/label is required per APS Requirements.

— GEC: NEC 250.66, NEC 250.166

- For new services, customers shall review APS ESRM 701.0.
- PV Systems requiring a GEC installed back to the SES, may consider NEC 250.166, 690.47(C)(2).

— Non-isolated (Transformerless) Inverters

- Not addressed very well in the 2011 NEC, typical practice is to install ONLY an EGC in accordance with NEC 250.122.
- Some inverters are shipped with a GEC terminal, some are not. Decision as to install a GEC is left up to the AHJ for these types of Inverters.
- ***2014 NEC covers this topic in better detail [NEC 690.47(C)(3)]: For ungrounded systems, this conductor shall be sized in accordance with 250.122 and shall not be required to be larger than the largest ungrounded phase conductor.***

Example of PV System Warning Labels (cont.)

Utility Disconnect switch
(Orange with Black Lettering)

WARNING
ELECTRIC SHOCK HAZARD
- DO NOT TOUCH TERMINALS -
TERMINALS ON BOTH LINE AND
LOAD SIDES MAY BE ENERGIZED
IN THE OFF POSITION

Combiner box
(Blue with White Lettering)

NOTICE
DEDICATED PHOTOVOLTAIC SYSTEM
COMBINER PANEL
DO NOT ADD LOADS TO THIS PANEL

Backfed Breaker
(Orange with Black Lettering)

WARNING
INVERTER OUTPUT CONNECTION
DO NOT RELOCATE THIS OVERCURRENT
DEVICE

Main Bkr De-rate
(Black with White Lettering)

BREAKER HAS BEEN DE-RATED
PER NEC 705.12(D)(2)

Amp Rating of Main if De-rated
(Black with White Lettering)

MAX XXX AMPS

NEC 705.10 – Requirements for Directory

From NEC 705.10:

“A permanent plaque or directory, denoting all electric power sources on or in the premises, shall be installed at each service equipment location and at locations of all electric power production sources capable of being interconnected.

Exception: Installations with large numbers of power production sources shall be permitted to be designated by groups.”

This requirement has not been uniformly enforced.

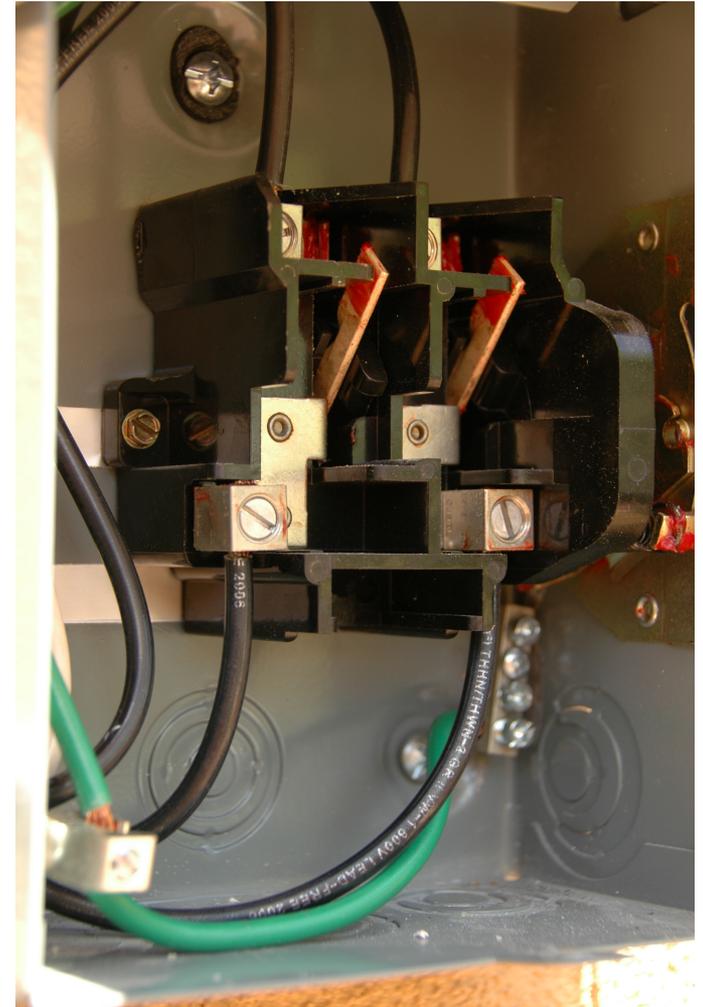
Standard Interconnection Requirements:

- **Disconnect Switch (Utility Disconnect): Section 8.2**
 - Must be locked with an APS Padlock with a 3/8" shank.
 - Must be placed in a safe, unobstructed location, available 24 hours a day.
 - Shall be installed in accordance with the NEC and APS requirements, and the center of the pivot handle of the switch shall be located between 36" and 60" above grade and include a 36" square clear working space.
 - If the Disconnect switch is not located within close proximity to the SES, APS requires a placard at the SES with explicit directions as to the location of the disconnect switch:

WARNING
OTHER POWER SOURCE CONNECTED IS A PHOTOVOLTAIC SYSTEM.
UTILITY DISCONNECT SWITCH FOR THIS SOURCE IS LOCATED APPROX
40 FEET FROM THIS LOCATION ON NORTH WEST SIDE OF DETACHED
GARAGE

Standard Interconnection Requirements:

- **Disconnect Switch (cont.)**
 - The “Utility Disconnect Switch” **blades, jaws and air gap** between them shall be clearly **visible** when the switch is in the open position.
 - Blades shall always be on the Inverter Side, and shall be de-energized in the open position in accordance with NEC 404.6(C)
 - Arc shields are acceptable only if they do not impede our ability to verify a visual open. **NOTE: Arc shields may not be removed in order to verify the visual open.**
 - Multiple Utility Disconnects are allowed in the event of a system expansion just as long as the disconnect switches are properly labeled and contain switch numbers (i.e. 1 of 2, 2 of 2).
 - **Note that APS requires a fused disconnect ahead of the APS required unfused disconnect to meet fault current requirements (Refer to APS ESRM 800.2):**
 - The required fused disconnect shall be locked by the customer/installer, and does not need to meet APS visual open requirements like the APS required Utility Disconnect Switch.

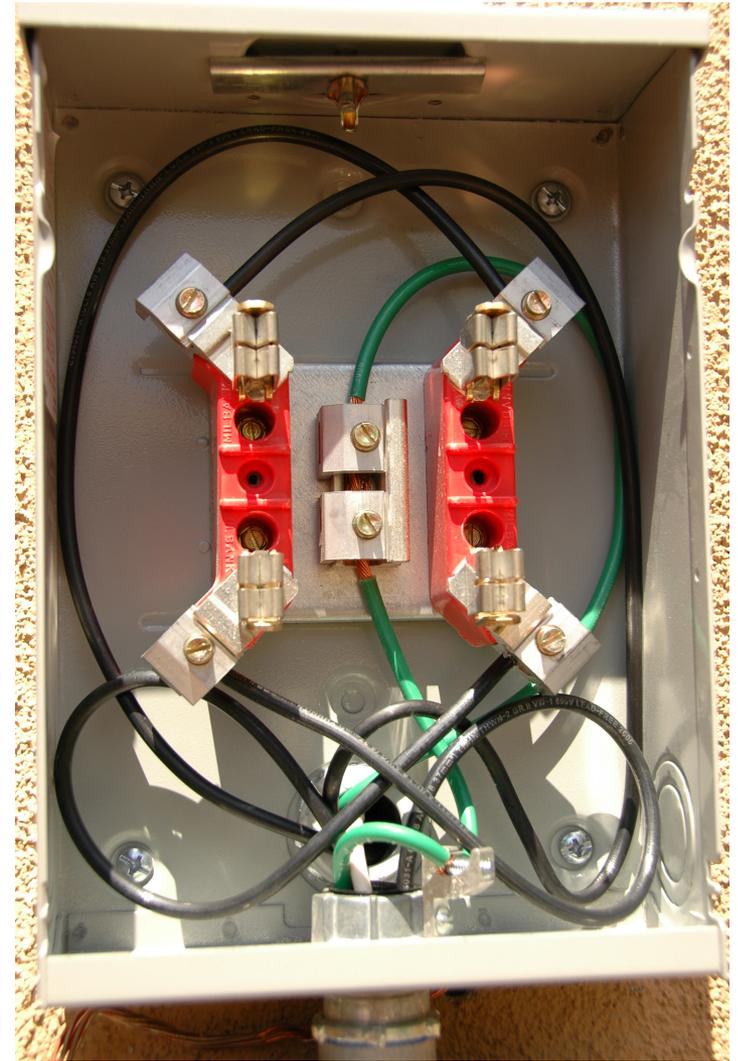


Standard APS Interconnection Requirements:

Production Metering

Customer must provide and install, at Customer's expense, meter sockets and metering cabinets in accordance with APS service standards, in locations acceptable to APS

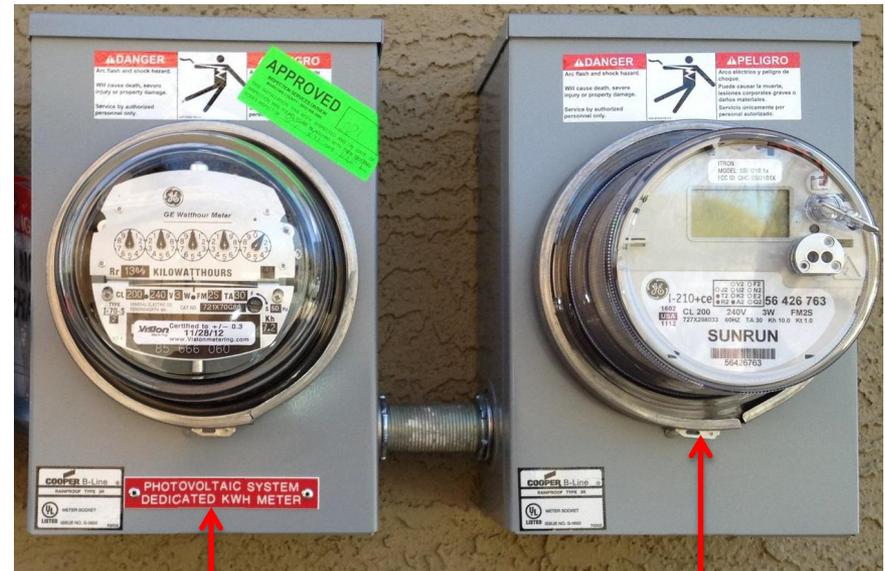
- Shall be ring-type. Ring-less is not permitted.
- 36" X 36" working space
- Meter height must be between 48" and 75" from finished grade to the center of the meter socket.
- CT rated production metering sections shall have suitable visual open disconnecting means, subject to APS approval.
- All CT rated metering enclosures shall have the bus identified with reference to the generation source side prior to metering installation with a temporary tag labeled "Generation Source".



Standard APS Interconnection Requirements:

Production Metering (cont.)

- 3rd Party Production Metering
 - Customer's installing 3rd party production meters, may do so just as long as the 3rd party meter is correctly labeled and is located on the inverter side of the APS Production Meter.
- Multiple Production Metering
 - An example would be a system expansion in which the Customer has an existing Incentive and wishes to expand the system by adding a non-program system. Production Meters shall be properly labeled with meter identification (i.e. 1 of 2, 2 of 2).



APS Production Meter labeled "Photovoltaic System Meter" or "Photovoltaic System Dedicated kWh Meter."

3rd Party Production Meter labeled "Leasing Company PV Production Meter"

Standard APS Interconnection Requirements:

Production Metering (cont.)

- Meter Cover vs. Test Meter
 - Residential customers may verify PV/Solar production with use of a test meter. **Note that flats or jumpers are not permitted.**
 - Additionally, for residential customers, In lieu of providing a Production Meter, Customer may install a commercially available meter cover over the Production Meter Socket.



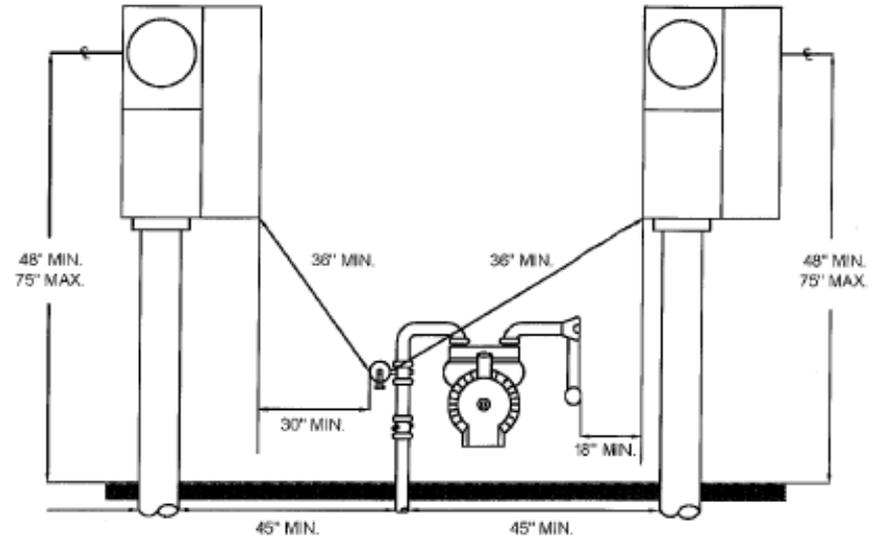
NOTE: Cardboard is not an acceptable cover material. Cover material shall be fiberglass, plastic, glass or Plexiglas.

Standard APS Interconnection Requirements:

Production Metering (cont.)

ESRM 301.15: ELECTRIC METER SEPARATION BETWEEN WATER AND GAS

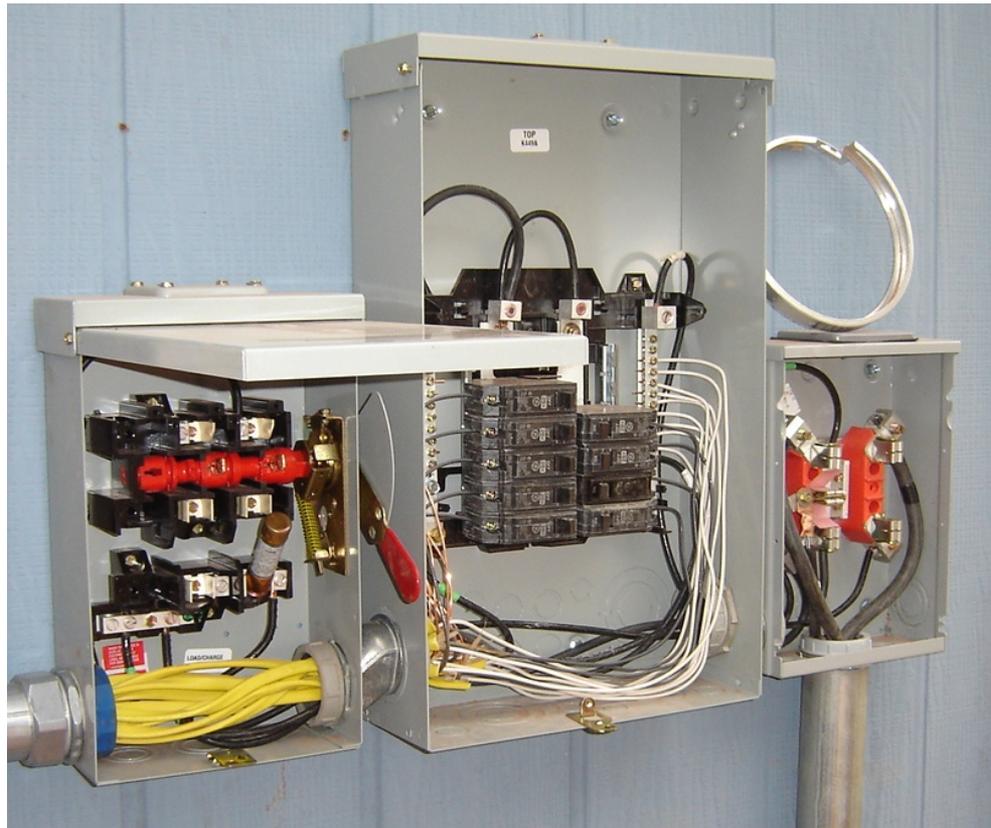
- The Production Meter is subject to this requirement.
- Based on the NFPA Gas Code & the Arizona Gas Pipeline Standards
 - Require a 36" radial clearance from a "venting source" of a gas system to any "potential source of ignition."
 - APS interprets the "potential source of ignition" the edge of the meter panel, and the "venting source" the gas regulator.
 - Working Clearance shall be a minimum of 36" wide. If electric panels extend wider than the 36" minimum, working clearance shall be the width of the entire assembly. Working space extend out from the face of electric meter panel a minimum of 36".



- Water valves or hose bibs within the 36"X36" Safe Work Area are prohibited.
- Drain pipes or soffits are prohibited above the meter enclosure to ensure the 36"X36" Safe Work Area remains safe and dry.

Standard APS Interconnection Requirements:

“Under no circumstances shall any metering or disconnect switch enclosure be used as a raceway for any conductors other than those phase conductors being switched.”



Standard APS Interconnection Requirements:

The Utility Disconnect Switch and Production Metering Enclosure shall be installed in a Readily Accessible location:

Readily Accessible as defined by APS: Capable of being reached quickly and conveniently on a **24-Hour** basis without requiring climbing over or removing obstacles, obtaining special permission, keys or security clearances.

- **Commercial Applications:** If access is restricted for security reasons, subject to APS approval, a lock-box may be provided to gain access to the Utility Disconnect Switch and/or Production Metering as long as the lock box is installed within 36” of the door/gate and located between 36” and 60” from finished grade.
- The Utility Disconnect Switch and/or Production Metering Shall not be:
 1. Located behind an electrically operated gate or door unless the electric operator is backed up by a UPS to ensure it can be operated in the event of a utility power outage.
 2. Installed under a breezeway, patio, porch or any area that can be enclosed.
 3. installed behind a gate, fence, wall or other barrier **unless expressly agreed to by APS (we may grant exceptions to Commercial customers).**

Supply Side Connection

- Allowed per 2011 NEC 705.12 (A):
 - “The output of a utility-interactive inverter shall be permitted to be connected to the supply side of the service disconnecting means as permitted in 230.82 (6)”(similar to installing a second service per APS ESRM 104.11.2).
- RMC (Rigid Metal Conduit) between the connection and the fused disconnect.
- Ampere rating of conductors between fused disconnect and connection shall not be less than the ampere rating of the disconnect.
- Neutral to ground bond must be re-established in the fused disconnect, and tied to GEC.
 - Note that if the SSC is made via a breaker or fused disconnect located within the SES, then the existing N-G bond will suffice (i.e. Solar Ready Panels).
- Fused Disconnect must be within 10’ of SES, subject to ESRM 301.12 requirements, NEC 225.32, 230.79(D) & 240.24(B).
- MFG approval in writing or UL field evaluation and certification for SSC is required (i.e. letter of compliance and approval sticker).

Supply Side Connection (cont.)

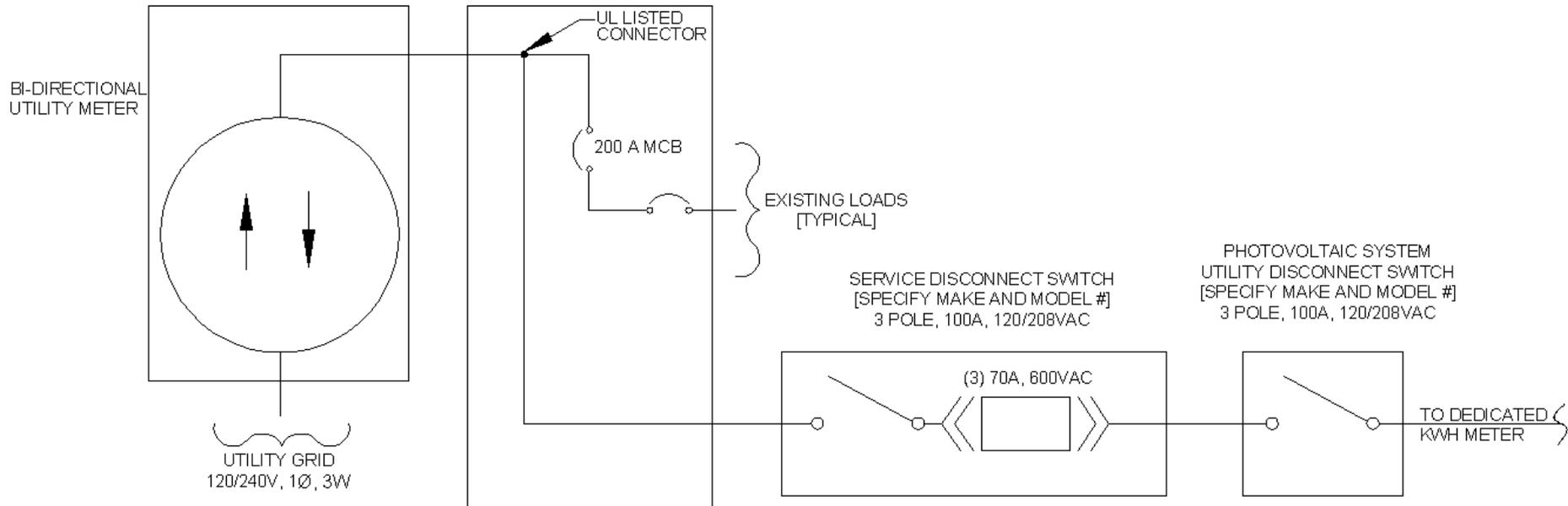
- No connections allowed inside the APS Sealed CT/Metering Compartments.
- Fused and unfused conductors shall not occupy the same raceway unless they are isolated from each other via a firewall barrier in a manner acceptable to APS.
- ***Disconnecting/opening the main breaker will not disconnect the PV system.***
- Warning label shall be located at the main service with the following language:

WARNING A GENERATION SOURCE IS CONNECTED TO THE SUPPLY (UTILITY) SIDE OF THE SERVICE DISCONNECTING MEANS. FOLLOW PROPER LOCK-OUT/TAG-OUT PROCEDURES TO ENSURE THE PHOTOVOLTAIC SYSTEM UTILITY DISCONNECT SWITCH IS OPENED PRIOR TO PERFORMING WORK ON THIS DEVICE

- APS will only operate the Photovoltaic System Utility Disconnect Switch, as this is our clearance point.
- For most applications, APS will require two disconnect switches (exception to this would be an approved “Solar Ready” panel)

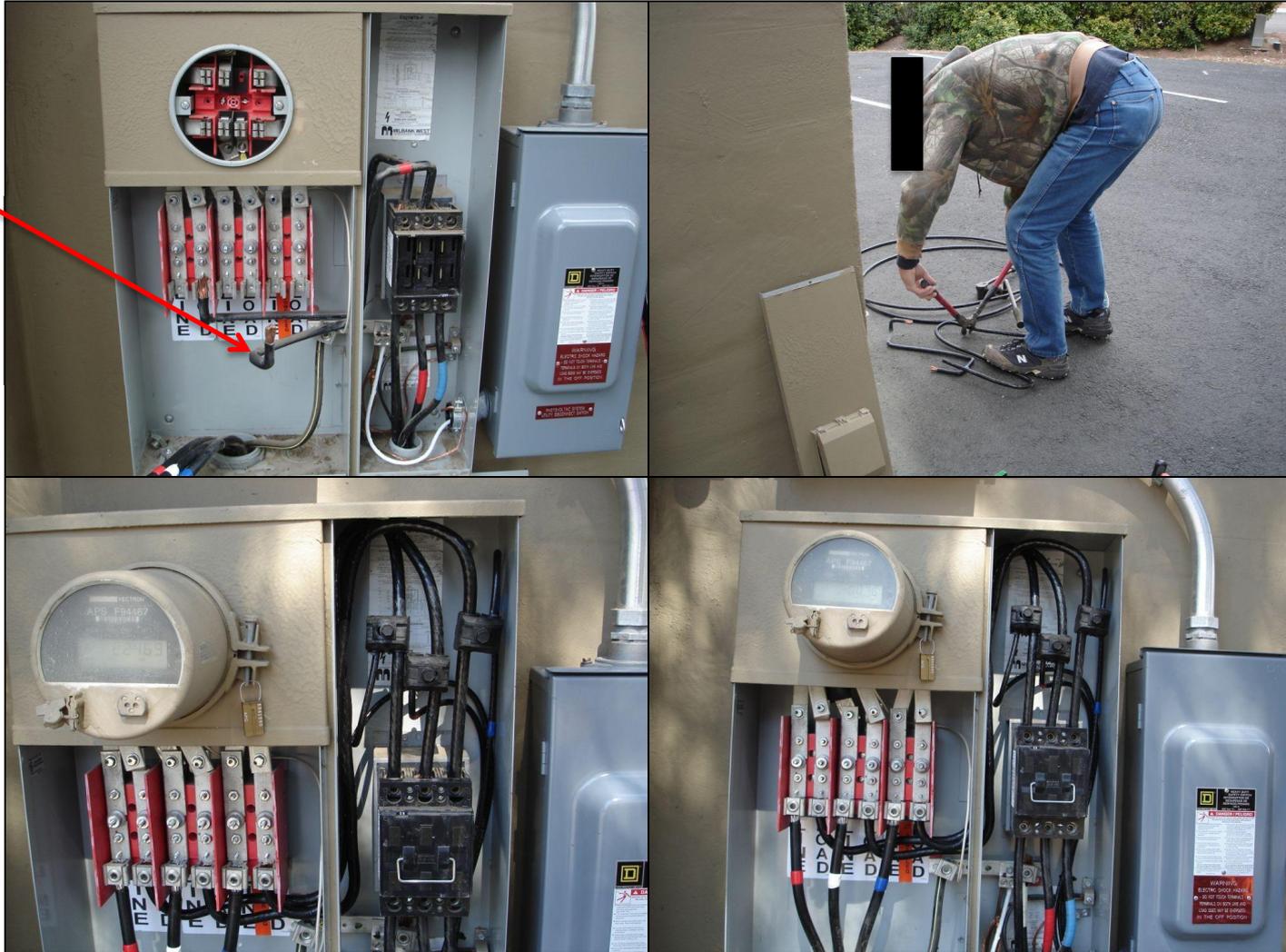
Supply Side Connection (cont.)

ELECTRICAL SERVICE ENTRANCE SECTION AND LOAD CENTER
120 / 240V, 1Ø, 200A BUS



Supply Side Connection – Don't Do This

Don't
remove
factory
installed
conductors



UL Listing of
panel was
violated -
entire
service
entrance
panel had to
be replaced
in order to
pass city and
APS
inspections

Battery Back-Up Systems

- Sometimes installed in conjunction with Photovoltaic Systems.
- In the event there is an APS outage (planned or unplanned), the customer's critical loads are powered by the battery back-up system.
- ***Opening the Utility Disconnect Switch may not kill all AC power feeding the Home.***
- Customer's may opt to activate "Grid-Sell" or "Battery Charger" modes. Either option is acceptable to APS.
- The installation of a bypass switch (manual or automatic transfer switch) is acceptable just as long as proper warning signs and written procedures/instructions are provided.
- Some battery backup applications require specific metering ("Grid Sell" mode) if the customer wishes to net out any load.
- Installer is required to provide operating instructions for proper isolation of AC power to the home as well as isolation instructions for the inverters for home owner, First Responders and maintenance personnel that may work on the system from time to time.

Battery Back-Up Systems (cont.)

- This is an example of two 2S production meters installed for a 120/240V battery backup system (Outback Type).
 - Meters need to be **electro-mechanical** and labeled “3rd Party Owned Battery Production Metering”
 - Each Meter is comprised of a utility energy component and an output circuit component.
 - APS may change out meters to AMI type metering for remote reads.
 - ACC mandates that APS accounts for all customer owned power production sources that nets out load that otherwise would be served by APS.

GF Meters and Utility Disconnect Switch (Common for 240V Systems)

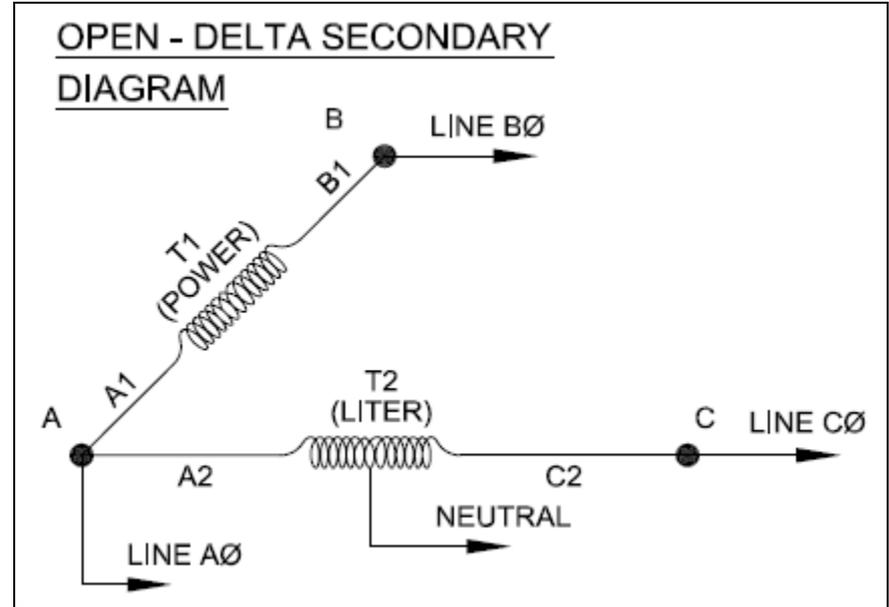


- Customer's shall apply NEC 300.3(B): All conductors of the same circuit (including the neutral and ground) shall be contained within the same raceway, conduit, gutter, cable tray, etc..

Note: SMA Sunny Island systems only require a single production meter.

Open Delta Transformers

- Installed in older areas of APS service territory (i.e. North-Central Phoenix, Downtown Phoenix, Rural areas, Tempe, Chandler, Paradise Valley and Central Scottsdale)
- Secondary voltage of 120/240V, limited to 25 horsepower motor load and 50kVA 3-phase load
- Comprised of two transformer configuration made up of a power pot and a liter pot.
 - Power pot is where two pole loads can be connected (no center tap neutral on the power pot, so connecting single phase load is not permitted).
 - Liter pot can have a combination of single pole and two pole loads.
 - Three phase loads are connected across all three phases.



- Customer load is generally not balanced for these configurations.
- Liter Pot sees 100% of the 1-phase load + 58% of the 3-phase load.
- Power Pot sees 58% of the 3-phase load
- **APS recommends installing inverters across A-B and A-C. Keep in mind not to over-duty the APS transformers tied across A-B and A-C.**

Future Technology Considerations

- Smart Inverters/Systems installed in rooftop solar applications (<10MW).
 - Utilize the newly adopted IEEE 1547 Amendment.
 - This standard allows for regulating the voltage at the Point of Interconnection (POI) if the utility (area EPS) allows and/or requires it.
 - Response to how an abnormal voltage and/or frequency event shall be handled.
- Frequency Event Table:

Table 2—Interconnection system default response to abnormal frequencies

Function	Default settings		Ranges of adjustability	
	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s) adjustable up to and including
UF1	< 57	0.16	56 – 60	10
UF2	< 59.5	2	56 – 60	300
OF1	> 60.5	2	60 – 64	300
OF2	> 62	0.16	60 – 64	10

Future Technology Considerations (Cont.)

- Voltage Event Table:

Table 1—Interconnection system default response to abnormal voltages

Default settings ^a		
Voltage range (% of base voltage ^b)	Clearing time (s)	Clearing time: adjustable up to and including (s)
$V < 45$	0.16	0.16
$45 \leq V < 60$	1	11
$60 \leq V < 88$	2	21
$110 < V < 120$	1	13
$V \geq 120$	0.16	0.16

^a Under mutual agreement between the EPS and DR operators, other static or dynamic voltage and clearing time trip settings shall be permitted

^b Base voltages are the nominal system voltages stated in ANSI C84.1-2011, Table 1.

Some Challenges:

- Building the infrastructure to control numerous different Distributed Resources (DR).
- Creating customer awareness and developing new rate structures.
- Training APS Operations Personnel on how to utilize the DR to help the APS System.
- ***Rate structure design: if APS requires voltage regulation/curtailment compromising real power output.***

Residential Drawing Engineering Audit - 2015

At the end of 2015, APS Interconnection Engineering was asked to assist with roughly 200 Residential Roof-top solar reviews. These applications were a combination of supply side taps, battery backup, 12kW or larger, and/or systems with more than three inverters. Some of the issues identified:

1. **Drawings were not per APS Samples:** i.e. block drawings vs. schematic drawings, production meter on line side of the Disconnect Switch, text not legible at 11X17, etc..
2. **Grounding and bonding issues:** case ground for individual equipment not shown, bond jumpers as required by NEC 250.64(E)(1) & 690.47(C)(3), and supply side connection grounding.
3. **Wire sizing issues:** ensure compliance with NEC 240.4(B), identify insulation and if Cu or Al.
4. **Fault Current Calculations:** APS requires compliance with recently updated ESRM 800.2, NEC Art 110.9 & NEC Art 110.10.
 - a. If a fused disconnect is not shown on the line side of the APS required Utility Disconnect Switch, APS will require fault current calculations to verify compliance.
 - b. Note that most unfused disconnect switches are rated for only 10k AIC.
5. **NEC and APS Required Labels Missing:** Refer to APS Equipment Labels (Interconnection Requirements & Equipment Labels available via www.aps.com/dg) & various NEC code references. Label references shall be identified on diagrams.
6. **Required Keyed Notes:** in many cases this page was created, but not provided. In the future APS Engineering will reject applications missing this information.
7. **Access/Workspace Notes:** Provide 24-hr access, workspace clearance and meter separation between water and gas notes.
8. **Production Meter orientation:** APS requires the Utility Disconnect switch to be located on the line/utility side of the APS production meter.
 - a. If a leasing company production meter is installed, it shall be located on the load/inverter side of the APS required production metering.

References and Sources for Further Information

APS Commercial Renewables

Phone: (602) 371-6160, email: commercial-renewables@aps.com

web: <http://www.aps.com/dg>

NEC 2008: National Electrical Code, Section 690 “Solar Photovoltaic Systems”

NEC 2011: National Electrical Code, Section 690 “Solar Photovoltaic Systems”

NEC 2011: National Electrical Code, Section 705 “Interconnected Electric Power Production Sources”

“Understanding NEC Requirements for Solar Photovoltaic Systems” – Mike Holt

IEEE Std 1547a-2014: IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems Amendment 1:

APS Requirements:

1. APS “Interconnection Requirements for Distributed Generation”
<http://www.aps.com/dg> http://www.aps.com/main/green/choice/choice_79.html
2. APS “Electric Service Requirements Manual” (ESRM)
http://www.aps.com/main/services/construction/corner/corner_66.html

Questions?