

Interconnection Engineering Updates

Frankie Greco, Shelly Born and Julio Zavala

Interconnection and Power Quality Engineering

2019



Agenda Topics

- Typical PV System Components (Residential and Commercial)
- Required Diagrams & PV Sample One-Line
- Site Plan Diagram & System Layout Examples (Residential and Commercial)
- Warning Labels
- Standard Interconnection Requirements
- Supply Side Connections - Revised
- Advanced Inverter Requirements - Revised
- Electrical PE Stamp – Revised
- Battery Systems & Metering Considerations
- NFPA 855 Energy Storage Location Requirements
- Do Batteries need to be UL Listed?
- Example Calculations
- Common Code Violations
- Q/A
- Appendix – NEC, Rapid Shutdown, etc.....

Required Diagrams for PV Systems

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

- Residential
 - Electrical One-Line Diagram*
 - 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.

**** Electrical one line diagrams are only required for three phase DG systems.***

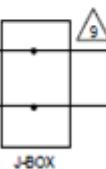
Sample 1-Line Diagram

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

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

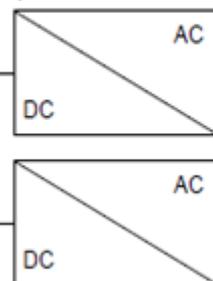


2-#10 CU USE-2
1-#10 CU USE-2
GROUND NOT IN CONDUIT



4 - #10 CU THWN-2
2 - #10 CU THWN-2 GROUND
2 - 1/2" EMT CONDUIT

[SPECIFY MAKE & MODEL #]
2.4 KW UTILITY INTERACTIVE INVERTER
250 - 600 VDC, 120/240VAC, 18, 3W
NEGATIVELY GROUNDING
(TYPICAL OF 2 INVERTERS)



2- #10 CU THWN-2
1- #10 CU THWN-2 NEUTRAL
1- #10 CU THWN-2 GROUND
1- 1/2" EMT CONDUIT

FAULT CALCS:

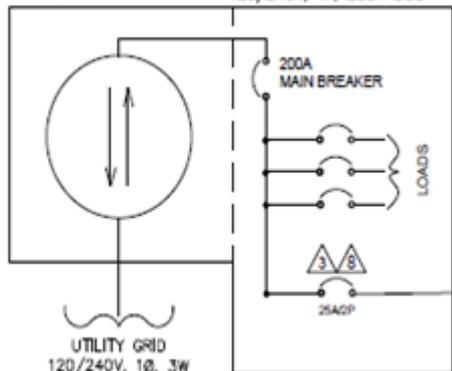
F1: AVAIL = 14,318 AIC
d = 5 feet
f = .383
m = 0.723
Isc = 10,355 AIC

F2: AVAIL = 10,355 AIC
d = 5 feet
f = .277
m = 0.783
Isc = 8,110 AIC

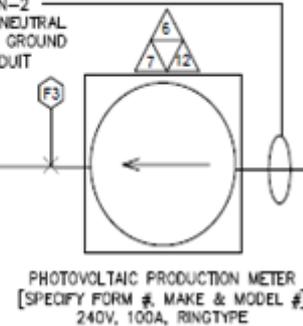
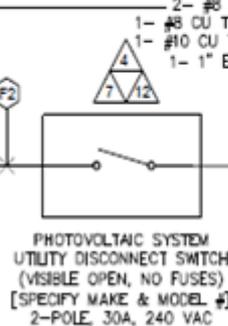
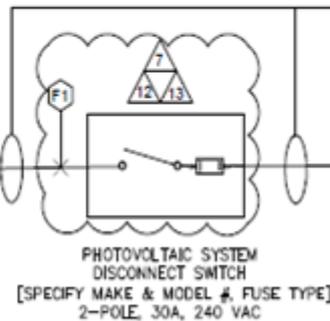
F3: AVAIL = 8,110 AIC
d = 5 feet
f = .217
m = 0.822
Isc = 6,665 AIC

F4: AVAIL = 6,665 AIC
d = 5 feet
f = .178
m = 0.849
Isc = 5,657 AIC

*SOURCE: COOPER BUSSMAN
SPD MANUAL, REV 2009.
CALCULATIONS IN ACCORDANCE
WITH NEC ART 110.9 & 110.10.



MAX ISC PER APS ESRM 800.2-1 IS 14,318A



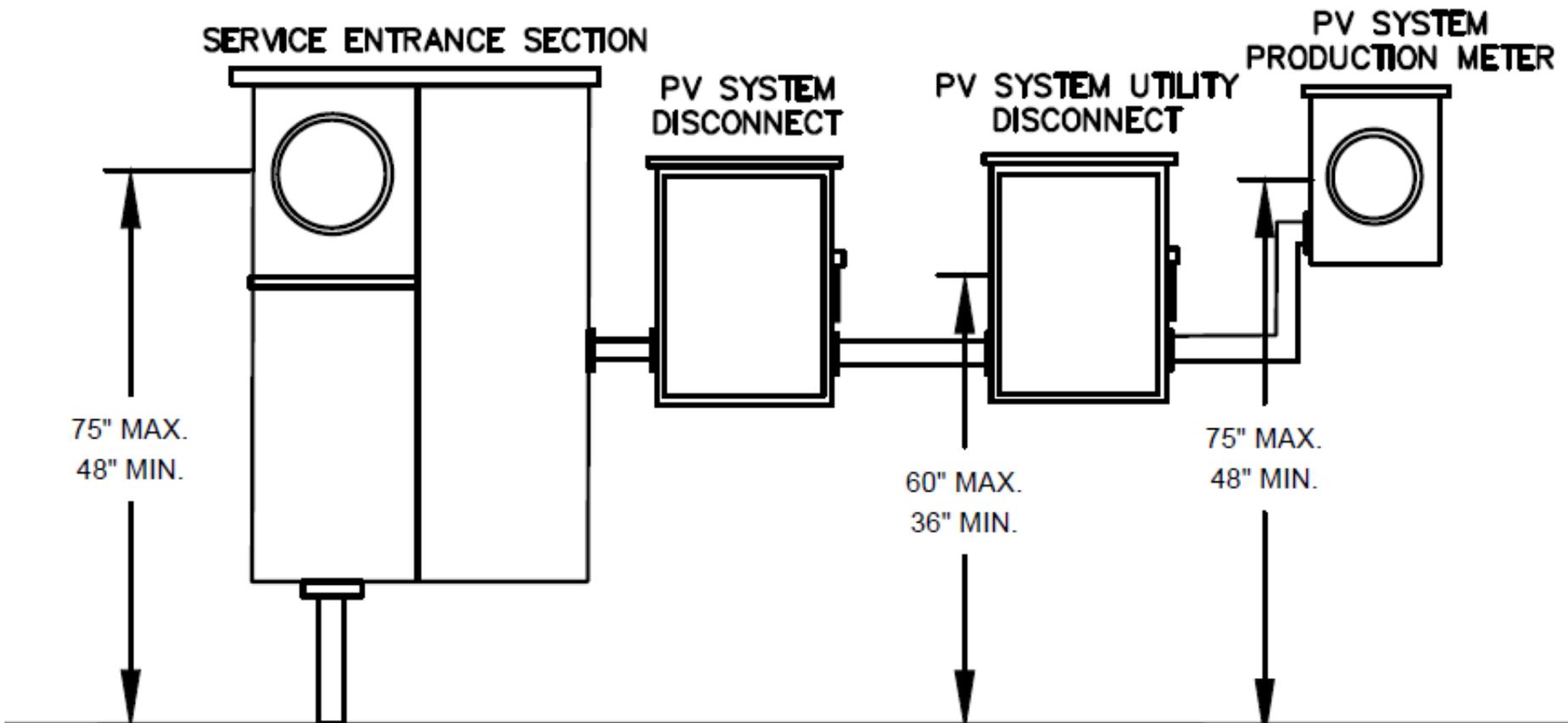
DEDICATED PHOTOVOLTAIC SYSTEM COMBINER PANEL [SPECIFY MAKE, MODEL #, VOLTAGE AND AMP RATING]

15A/2P
(TYPICAL OF 2)

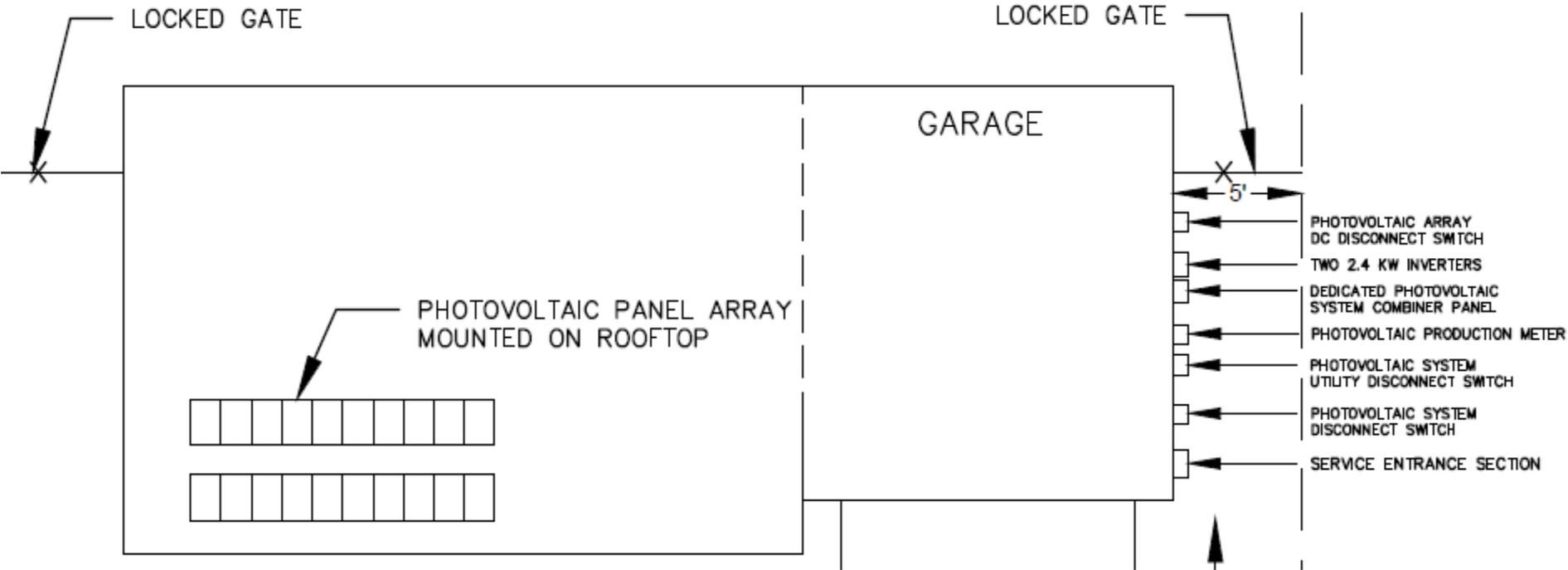
NOTES:

Example - Residential PV System

ELEVATION VIEW



Sample Site Plan

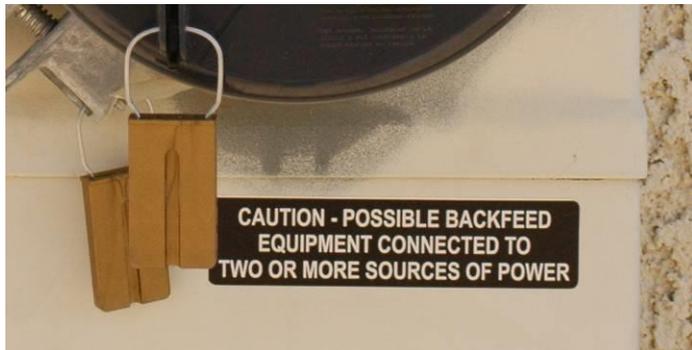
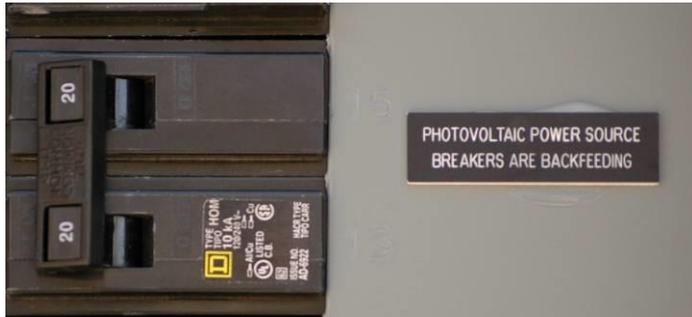


NOTE: UTILITY HAS 24-HR UNRESTRICTED ACCESS TO ALL PHOTOVOLTAIC SYSTEM COMPONENTS LOCATED AT SERVICE ENTRANCE.

NOTE: REFERENCE SECTION 301.15 OF THE APS ESRM FOR ELECTRIC METER SEPARATION BETWEEN WATER AND GAS.

NOTE: WORKSPACE IN FRONT OF AC ELECTRICAL SYSTEM COMPONENTS SHALL BE IN ACCORDANCE WITH APS AND NEC REQUIREMENTS. FOR APS REQUIREMENTS, REFERENCE SECTION 300 OF THE APS ESRM AND SECTION 8.2 OF THE APS INTERCONNECTION REQUIREMENTS.

Example of PV System Warning Labels



NOTE: Typical APS Equipment Labels Handout is located at www.aps.com/dq. ANSI color standards may be used, but isn't required by NEC or APS.

Example of PV System Warning Labels (cont.)

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

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

WARNING
WARNING: MULTI POWER
PRODUCTION SOURCES
INTERCONNECTED TO THIS
ELECTRICAL SERVICE.

APS LABEL FOR 705.12(D)(2)(3)(d)

CAUTION
DUAL POWER SOURCES
SECOND SOURCE IS
PHOTOVOLTAIC SYSTEM

CAUTION
DO NOT MOVE BREAKERS OR ADD
NEW CIRCUITS WITHOUT
ELECTRICAL ENGINEER APPROVAL

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

PHOTOVOLTAIC POWER SOURCE
BREAKERS ARE BACKFEEDING

BREAKER HAS BEEN DE-RATED
PER NEC 690.64(B)(2)

DENOTE LOCATION OF "UT PV SYS DISC" (2 OF 2)
OR
DENOTE LOCATION OF CRITICAL SUB-PANEL

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

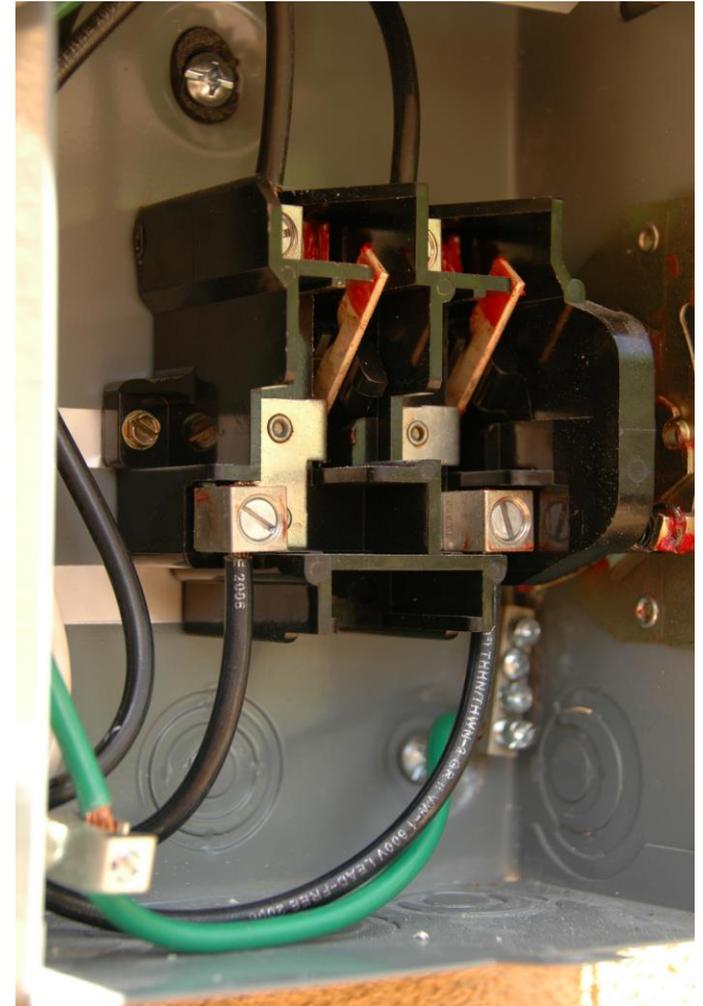
- Must be locked with an APS Padlock with a 3/8" shank.
- Must be placed in a safe, unobstructed location, available 24 hours a day.
- Shall be installed in accordance with the NEC and APS requirements, and the center of the pivot handle of the switch shall be located between 36" and 60" above grade 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:



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) and OSHA 1926.405(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

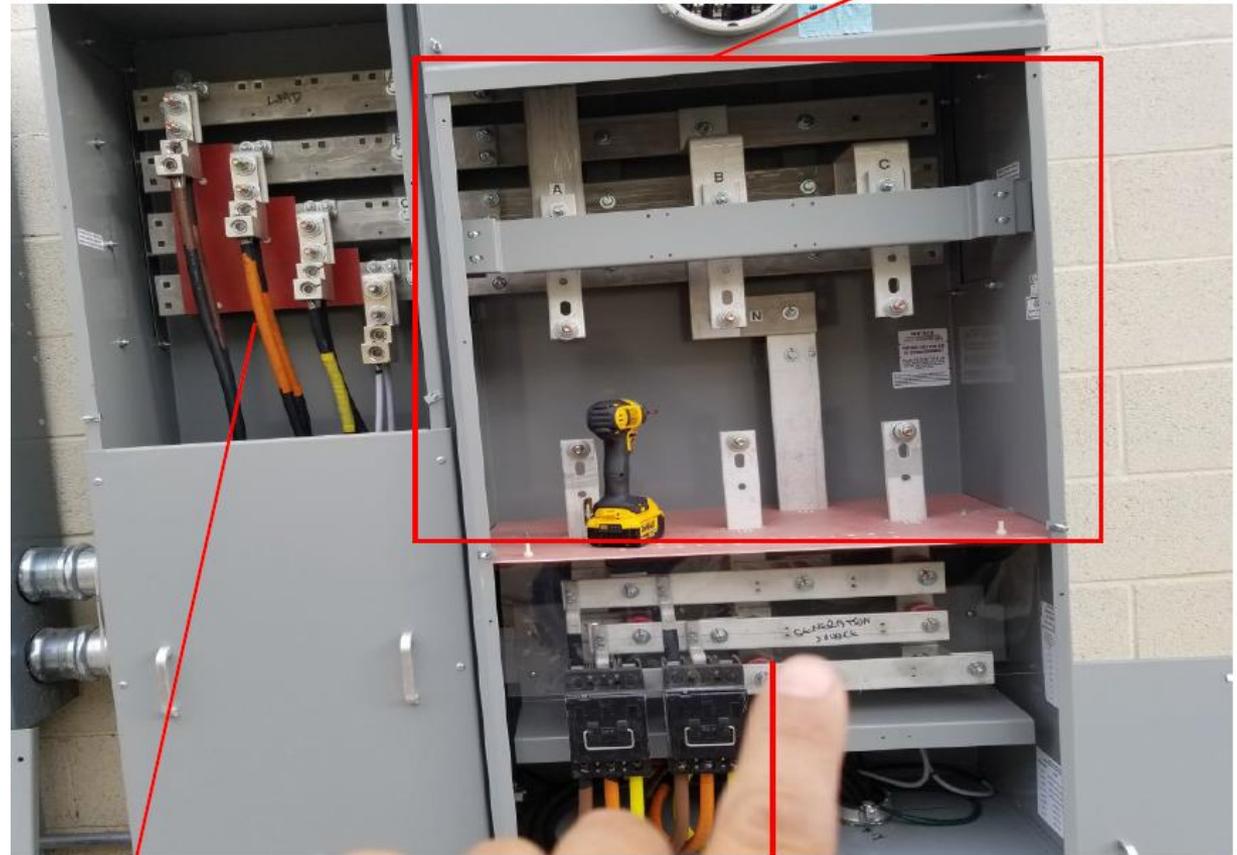
- Shall be ring-type. Ring-less is not permitted.
- 36" X 36" working space
- Meter height must be between 48" and 75" from finished grade to the center of the meter socket.
- CT rated production metering sections shall have suitable visual open disconnecting means, subject to APS approval.



Standard APS Interconnection Requirements:

Production Metering

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".



Meter Section (ONLY LABEL
HERE)

Pull Section (DO
NOT label here)

Load Section (DO
NOT label here)

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.



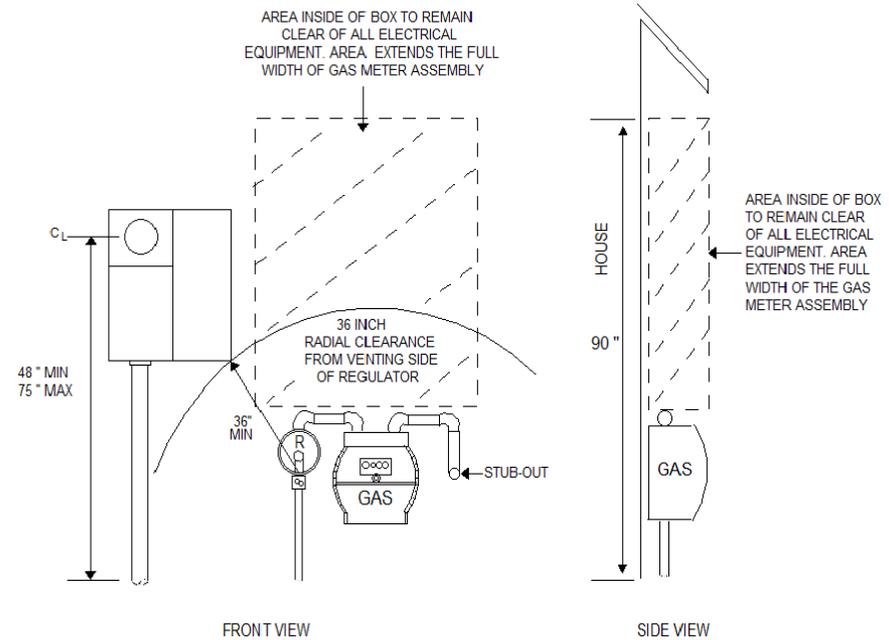
NOTE: Cardboard is not an acceptable cover material. Cover material shall be fiberglass, plastic, glass or Plexiglas.

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:

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.

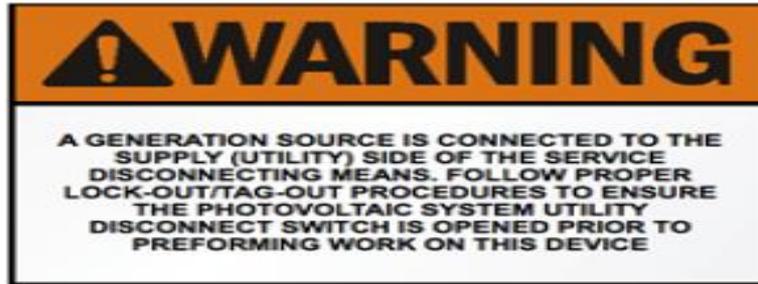
- **Commercial Applications:** If access is restricted for security reasons, subject to APS approval, a lock-box may be provided to gain access to the Utility Disconnect Switch and/or Production Metering as long as the lock box is installed within 36” of the door/gate and located between 36” and 60” 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 for Commercial customers).**

Supply Side Connection

- Allowed per 2011/2014/2017 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 adjacent (within 10’) to 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).

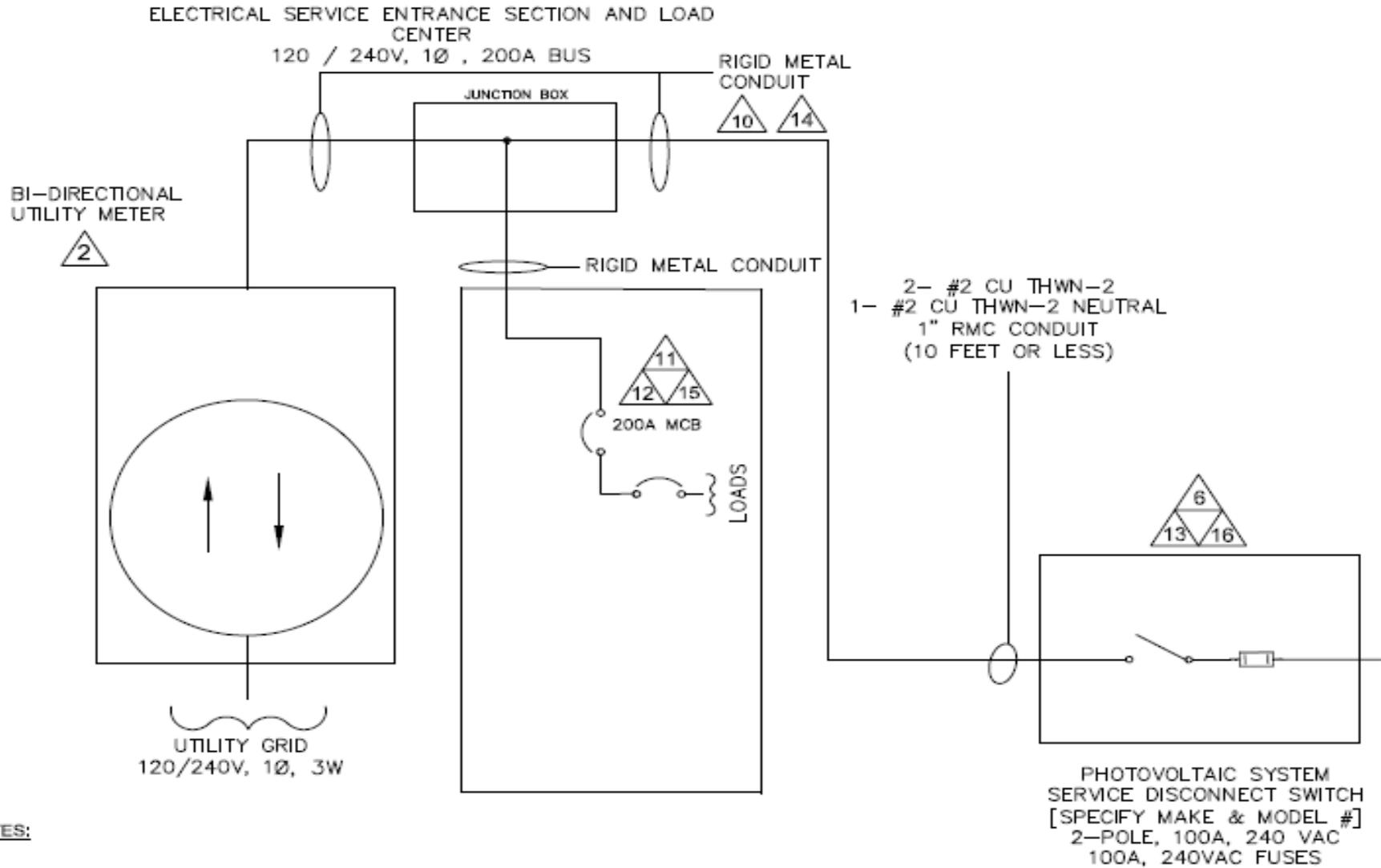
Supply Side Connection (cont.)

- 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:



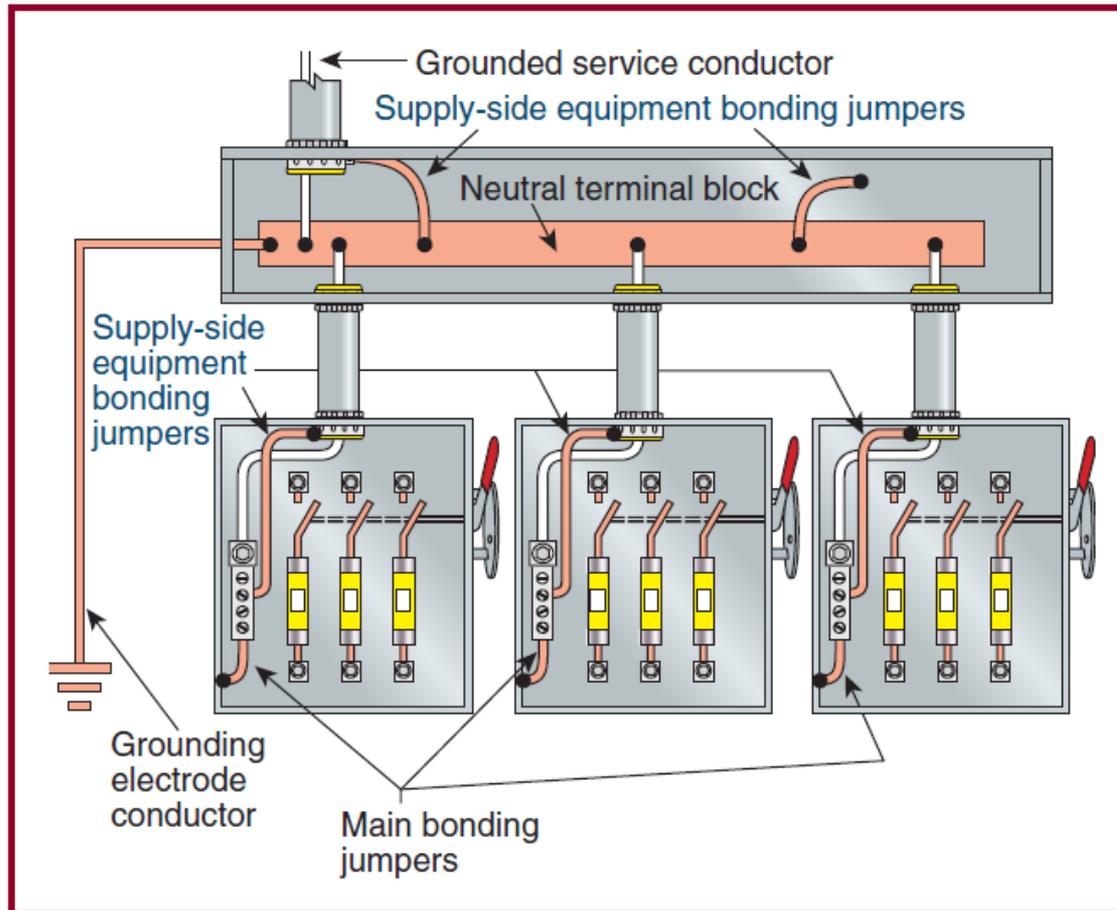
- APS will only operate the Photovoltaic System Utility Disconnect Switch, as this is our clearance point.
- For most applications, APS will require two disconnect switches (exception to this would be an approved “Solar Ready” panel)

Supply Side Connection (cont.)



NOTES:

Supply Side Connection (cont.)



NEC 250.94

EXHIBIT 250.34 *Grounding and bonding arrangement for a service with three disconnecting means.*

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

PE Stamp Requirements

APS clarified when PE Stamp and AHJ Permit is required

- For Residential Systems, Electrical drawings stamped by a Professional Engineer (Electrical) registered in the State of Arizona OR may provide a copy of the building permit issued by the AHJ **when specifically required by Utility in writing**
- For Commercial Systems, Electrical drawings stamped by a Professional Engineer (Electrical) registered in the State of Arizona

NOTE: APS may require a copy of the building permit issued by the AHJ when specifically required by Utility in writing

What to do if an AHJ doesn't issue a permit for PV/Energy Storage System:

- Once APS approval is granted, in accordance with SB1417, install GF following APS and NEC applicable requirements
- Sign and provide the “Letter In-Lieu of Electrical Clearance” form to APS

NOTE: Per Section 17 of the APS Interconnection Requirements manual, APS reserves the right to require diagrams submitted to be stamped by Professional Engineer (Electrical) registered in the State of Arizona

IEEE 1547 & Advanced Inverter Standards

On February 15th, 2018, the IEEE-SA Standards board approved the revised IEEE 1547 Standard. The IEEE Standard outlines the various Advanced Inverter grid support capabilities.

What does an Advanced Inverter offer?

- Voltage support at the point of interconnection
- Rides through grid level voltage and/or frequency events
- Remote control and monitoring

How Does this Fit within the APS Interconnection Requirements manual?

- Section 8.7(A)(11) Outlines the various capabilities documented within IEEE 1547
- Most/all inverter manufacturers should have Advanced Inverter capabilities
- No changes to settings unless APS requires based on feeder level need

As is the case with the various utilities in the State of California; APS will require “Advanced Inverters” for all installations when Rev 8.3 of the APS IRM becomes effective

Battery Back-Up Systems Background

- 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
- Inverters listed to UL1741/UL1741SA.

Peak Shaving

- PV Panels and Critical load panel is not required.
- Normally will have either one or two inverters
- In the event of an outage, the system will shut down
- Multiple configurations available for metering and isolation
- Battery system (via a DC to AC inverter) is programmed to provide a portion of the load draw to the customer's electric service via CTs and communication circuitry



AC Coupled Systems

- Normally installed in conjunction with a separate PV System.
- Battery System will draw power from the utility to keep batteries charged
- Essential loads placed in-between PV System and main electric service
- In the event of an outage: (1) PV system ceases to operate, (2) Isolation Relay opens up, and (3) Battery System will power the essential load panel
- The Battery System metering will be required
- APS will require a Utility Disconnect Switch at each system (PV and Battery Back-up), and a Production Meter at the PV system

DC Coupled Systems

- Installations normally by Outback Power Systems
- This is a one (or two) inverter system with both batteries and panels connected to the inverter (separate inputs)
- Essential load panel is installed as an output to the inverter
- Inverter DC Disconnect and Bypass switch required to disconnect power to the Essential Load panel
- In the event of an outage: (1) back-feed controller to the grid is disabled, (2) essential loads are powered by the batteries with the PV panels (or optional generator input) charging batteries
- APS will require Utility Disconnect Switches & Production Meters
- Meters required would be 2S, but older design could be 12S electro-mechanical
- **NOTE: Batteries must be fully charged prior to APS Meter-Set**

Battery Back-Up Systems (cont.)

This is an example of two 2S production meters installed for a 120/240V battery backup system (Outback DC Coupled Type)

- For testing purposes, Customers may provide **electro-mechanical** meters. Meter-sockets shall be labeled per APS requirements
- Each Meter is comprised of a utility energy component and an output circuit component
- APS will change out meters to AMI type metering for remote reads (could occur prior to PTO)
- 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.

Standby Battery Systems

- Installed for backup power only, will not backfeed the APS System
- Only systems utilizing a transfer switch tested, listed and marked UL 1008 will be considered as a separate system
- Off-grid and/or other systems not utilizing a UL 1008 listed transfer switch will be required to sign a connection agreement with APS, demonstrate to APS that the system does not backfeed the utility, and will be required to install a visual open disconnect switch in accordance with Section 4.1 and 8.2 of the APS Interconnection Requirements Manual
- APS is in development of short process document to aid with the installation of standby systems (battery and generators)

NFPA 855 ES Location Requirements

- ES are permitted to be located inside equipment rooms.
- Directories and signage is required for disconnects and facilities with multiple power production sources
- ES shall not be permitted to be located in areas subject to damage from impact by a motor vehicle unless properly guarded
- Dedicated use buildings are allowed granted they are not intended for occupancy, built to local building codes, and limited access to ES equipment to only ops personnel
- ES located on floors that can be accessed via external Fire Department laddering
- Remote locations permitted with limitations (more than 100 ft from buildings, lot lines, public ways, stored combustible materials, hazardous materials, etc.)
- Mobile ES shall not be installed indoors

Do Batteries need to be UL Listed?

Background: Normally, integrator/installer purchases batteries, racking, wiring, terminations, etc. and assembles individual strings

What does NEC Say?

- NEC Art 110.2 Requires that equipment is reviewed and approved
- NEC Art 110.3 Equipment shall be examined, listed and labeled
 - AHJ Approval may require evidence
 - Most common evidence is listing/labeling by 3rd Party
- Annex A of the NEC lists all applicable/appropriate UL Listings for electrical equipment (i.e. UL 1973, UL 1642 and UL 9540)

What Does APS Recommend?

- Installation complies with the NEC
- Suggest a 3rd party/NRTL perform a field inspection for any/all field integrations (i.e. battery racks/strings)
- Integrator should hire an Electrical P.E. to evaluate and provide engineering analysis/review in order to ensure installation meets all applicable safety standards

Breaker & Wire Sizing

Breaker Sizing: NEC (2011) 690.8(A)(3), 690.8(B)(1)(a), 240.6(A)

Inverter AC Output Current Rating X 1.25

1 \emptyset : Inverter AC Output Current Rating = Inverter Watts \div Voltage

3 \emptyset : Inverter AC Output Current Rating = $\frac{\text{Inverter Watts}}{\text{Voltage} \times \sqrt{3}}$

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

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

OCPD = 45A (combiner box)

In Parallel

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

OCPD = 90A (back-fed breaker)

Breaker & Wire Sizing (cont.)

Wire Sizing NEC (2011) 690.8(B)(2)

Table 310.15(B)(16) - 90°C Column X Temp Correction [Table 310.15(B)(2)(A)]

Table 310.15(B)(16):

Size AWG or kcmil	Temperature Rating of Conductor		
	60°C (140°F)	75°C (167°F)	90°C (194°F)
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
	COPPER		
18	—	—	14
16	—	—	18
14**	15	20	25
12**	20	25	30
10**	30	35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145

Assume an ambient temp of 105-113°F

Temp Correction = 0.87

41.6A (circuit to combiner previous slide)

55A X 0.87 = 47.85A → Use 1-#8 Cu THWN-2 per phase

In Parallel

83.3A (parallel circuit previous slide),

95A X 0.87 = 82.7A < 83.3A

115A X 0.87 = 100A → Use 1-#3 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.

Voltage Drop/Rise Calculation

Voltage Drop/Rise Equation

- $V_D = 2 \times \frac{\Omega}{1k \cdot ft} \times L \times A$
 - L = length of circuit (one-way)
 - A = load amps (inverter output)
 - $\frac{\Omega}{1k \cdot ft}$ = based on conductor from NEC Table 9

- Example:

- 85 feet conductor run
- 7.68kW inverter
 - Single phase – 240V
 - 7.68kW/240V=32A
 - Unity power factor
- #8 CU conductor
 - $0.78 \frac{\Omega}{1k \cdot ft}$ from Table 9

- $V_D = 2 \times 0.78 \frac{\Omega}{1k \cdot ft} \times 85ft \times 32A$
- $V_D = 4.2V$
- $V_{D\%} = \frac{4.2V}{240V} = 1.8\%$

Voltage Rise Calculation (Cont.)

Estimated Voltage Drop Calculator

Input

Load Voltage	240V 1Ø
Conductor Size	8
Conductor Type	Cu <input checked="" type="radio"/> Al <input type="radio"/>
Number of Sets	1
Distance (one way)	85 Feet
Load (A)	32 A

Output

	Unity Power Factor	85% PF
Voltage Drop (V)	4.3 V	3.8 V
Voltage Drop (%)	1.8 %	1.6 %
Voltage at Load	235.7 V	236.2 V
Minimum Conductor Size for 3% VD	10	
Minimum Conductor Size for 5% VD	12	

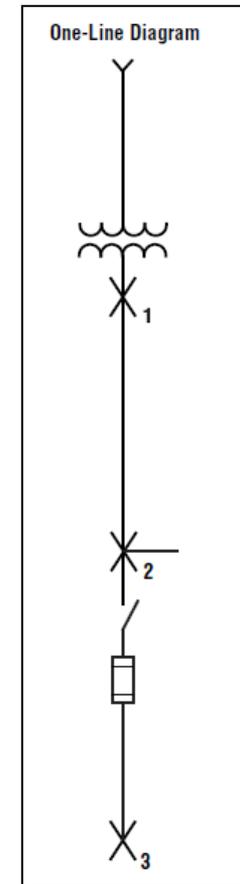
SIEMENS

[This voltage drop calculator can be found online. Search for 'Siemens voltage drop calculator' on the web.](#)

Fault Current Calculations

- Table 800.2-1 of the APS ESRM provides the worst case fault current values from the utility utilizing the infinite bus method. (<https://www.aps.com/library/esp%20services/800.pdf>)
 - Fault tables assume 80% loading and 25' of conductor length including Ins and Outs (sweeps)
 - Based on lowest impedance values (APS publishes ranges for your use if needed on the APS ESRM website (www.aps.com/esrm))
- A customer is determining fault current value at their DG System Disconnect Switch, the following information is needed:
 - DG System Size (for breaker and conductor validation)
 - Distance from the main service to the disconnect switch
 - Conductor type (wire properties are available via the NEC and also Short Circuit Calculation Section out of the Bussman-Eaton manual)
- Add inverter contribution (1.5 times is industry standard, but some modeling programs assume 2 times).

A useful fault current calculation program that APS uses is available via www.mikeholt.com



Fault Current Calculations (Cont.)

- Example 1: 200A Service @ 120/240 V, 1Φ, 50 foot of #8 Cu, breaker size is 40A, 7500W single phase 120/240 V inverter.
 - what is the fault current at the disconnect?

Available Fault Current Calculation			
Utility Fault Current	14,318 amperes	kVA =	
		E =	240
$I = \frac{kVA \times 1000}{E} = \text{trans. FLA}$		trans. FLA =	0
Isca = $\frac{\text{trans. FLA} \times 100 \times PF}{\text{transformer Z}}$	=	PF =	100%
Isca = ampere short-circuit current RMS symmetrical.		Z =	
		Isca =	0 amperes
Point to Point Method			Single Phase 240/120
'f' factor = $\frac{2 \times L \times I}{N \times C \times E \text{ L-N}}$	Length (distance) FEET (ASC)	L =	50
	# conductors per phase	N =	1
	Phase conductor constant	C =	1,559
	Volt Line to Line	E L-L =	240 Volt
		f =	3.827
	Neutral conductor constant	C =	1,559
	Volt Line to Neutral	E L-N =	120 Volt
		f =	11.482
Multiplier		M =	0.207
$M = \frac{1}{1 + f}$	Line to Line	M =	0.080
	Line to Neutral	M =	
Fault Current at Service Equipment			
Isca x M = fault current at terminals of main disconnect L- L =			2,966 amperes
Isca x M = fault current at terminals of main disconnect L- N =			1,721 amperes

Fault Current Calculations (Cont.)

- Example 2: 800A Service @ 277/480 V, 3Φ, 100 foot of #4 Cu, breaker size is 90A, 8-7500W three phase inverters (60 kW).
 - what is the fault current at the disconnect?

Available Fault Current Calculation			
Utility Fault Current	<input type="text" value="25,773"/> amperes	kVA = <input type="text" value=""/>	by: John Sakalik Ver. 2014 imp1jds@comcast.net
$I = \frac{kVA \times 1000}{E \times 1.732} = \text{trans. FLA}$		E = <input type="text" value="480"/>	
		trans. FLA = <input type="text" value="0"/>	
$I_{sca} = \frac{\text{trans. FLA} \times 100 \times PF}{\text{transformer Z}}$	=	PF = <input type="text" value="100%"/>	
<small>I_{sca} = ampere short-circuit current RMS symmetrical.</small>		Z = <input type="text" value=""/>	
		I _{sca} = <input type="text" value="0"/> amperes	
Point to Point Method		<input type="text" value="Three Phase 480/277"/>	
'f' factor = $\frac{1.732 \times L \times I}{N \times C \times E_{L-N}}$	Length (distance) <input type="text" value="100"/> FEET (ASC)	L = <input type="text" value="100"/>	<input type="text" value="Copper in Metal Raceway"/>
	# conductors per phase	I _{sca} = <input type="text" value="25,773"/>	
	Phase conductor constant	N = <input type="text" value="1"/>	
	Volt Line to Line	C = <input type="text" value="3,806"/> Phase Conductor	<input type="text" value="4"/>
		E L-L = <input type="text" value="480"/> Volt	
		f = <input type="text" value="2.443"/>	
Multiplier	Neutral conductor constant	C = <input type="text" value="3,806"/> Neutral Conductor	<input type="text" value="4"/>
	Volt Line to Neutral	E L-N = <input type="text" value="277"/> Volt	
		f = <input type="text" value="6.351"/>	
	Line to Line	M = <input type="text" value="0.290"/>	
	Line to Neutral	M = <input type="text" value="0.136"/>	
Fault Current at Service Equipment			
$I_{sca} \times M$	= fault current at terminals of main disconnect L- L =	<input type="text" value="7,485"/> amperes	
$I_{sca} \times M$	= fault current at terminals of main disconnect L- N =	<input type="text" value="3,506"/> amperes	

Common Errors and Violations

1. **Drawings were not per APS Samples:** i.e. block drawings vs. schematic drawings, 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:** APS Engineering will reject applications missing this information Keyed Notes.
7. **Access/Workspace Notes:** Provide 24-hr access, workspace clearance and meter separation between water and gas notes.

Common Errors and Violations (cont.)

8. **Production Meter orientation:** APS requires the Utility Disconnect switch to be located on the line/utility side of the APS production meter.

If a leasing company production meter is installed, it shall be located on the load/inverter side of the APS required production metering.

9. **Installation prior to approval:** SB 1417 mandates that a distributed energy generation system cannot be *installed, energized, or interconnected* until the utility has approved the application.

10. **Other common issues:**

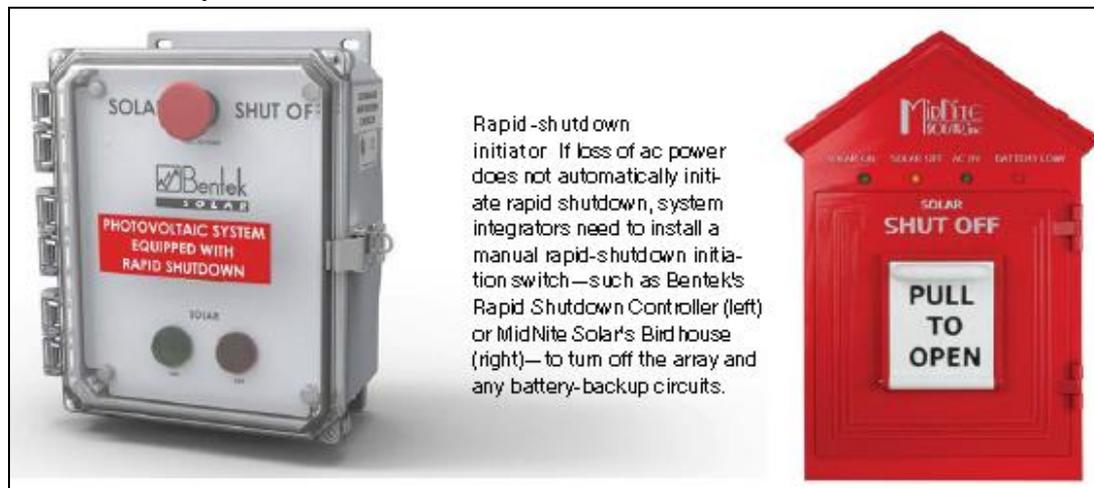
- a. Wrong size tap kit for supply side connection
- b. Blades for disconnect switches facing the wrong direction
- c. Lack of details and ambiguity on drawings
- d. Missing one line diagram on applications
- e. Terminals on meters not properly shown, line and load side for bi-directional meters missing, missing information on form type, ring type
- f. Combiner panels being labelled as load center
- g. Colored drawings not allowed

Questions?

Appendix - Rapid Shutdown of PV Systems

For the 2011 version of the NEC NFPA 70, 690.11 “DC Arc-Fault Circuit Protection” was added to mitigate fire initiation hazards associated with arcing faults, but does nothing to eliminate shock hazards associated with PV power circuits.

- For the 2014 version of the NEC NFPA 70, 690.12 “Rapid Shutdown of PV Systems on Buildings” was added.
- A listed device that controls specific PV System conductors (5’ in length inside a building or 10’ distance from a PV array).
- No specifics as to the location of the rapid shutdown initiating device to allow AHJs, System Integrators and First Responders the flexibility to locate devices and warning labels at location most appropriate for the specific installation.
- Limit of 30 volts and 240 volt-amperes with 10 seconds of initiation.
- **Solar optimizers (DC-DC Contactors)** can be used for rapid shut down (i.e. Tigo Energy retrofit solution or SolarEdge whole system solution).
- Microinverters or ac modules inherently comply with 690.12 as loss of AC power immediately de-energizes all PV system circuits outside the array areas.
- Warning label in accordance with 2014 NEC 690.56(C).



Appendix - 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 2011_ 705.12(D)(2)], customer may de-rate the main in order to accommodate the installation of a PV system. Load calculations 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.
- ***2014/2017 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.***

Step Up Xfmr Fault Current Calculations

Example 3: 800A Service @ 120/208 V, 3Φ, 50 foot to utility disconnect switch and production meter, then 50' to step up xfmr 75 kVA (~128 A of backfeed)

Useful Formulas: $f_{3\phi} = \frac{\sqrt{3} \times L \times I_{3\phi}}{C \times n \times ELL}$; $M = \frac{1}{1+f}$; $I_{scRMS} = I_{SC} \times M$;
C = conductor constant; n = number of conductors per phase; I = available short circuit current (in amps); E = voltage; L = length of conductor

Step 1: Starting Isc from APS for above configuration is 49,505A

Step 2: install ~ 50' of 3-1/0 Cu in metallic conduit (C = 8925; n = 1)

$f = 2.3607$; $M = 0.30242$, $I_{sc} = 14,971 A + I_{SCDER}$

Step 3: install ~ 50' of 3-1/0 Cu in non-metallic conduit (C = 9317; n = 1)

$f = 0.6876$ $M = 0.5925$, $I_{sc} = 9130.61 A + I_{SCDER}$

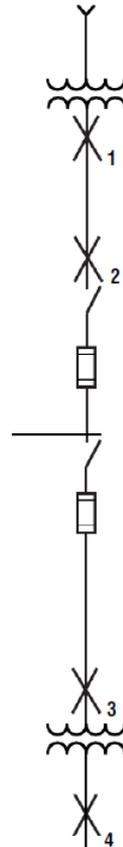
Step 4: Step voltage from 120/208V, 3Φ to 277/480V 3Φ; %Z (75 kVA) is 4.5%

$$f = \frac{I_{sc} \times V_{LLstart} \times \sqrt{3} \times \%Z}{100,000 \times kVA_{xfmr}} = \frac{9130.61 A \times 208 V \times 1.732 \times (4.5)}{100,000 \times 75} = 1.974; M = \frac{1}{1+f} = \frac{1}{1+1.974} = 0.3363$$

$$I_{sc} = \frac{V_{LLstart} \times M \times I_{sc}(\text{step 3})}{V_{LLend}} = \frac{208 V \times 0.3363 \times 9130.61 A}{480 V} = 1330.6 A + I_{SCDER}$$

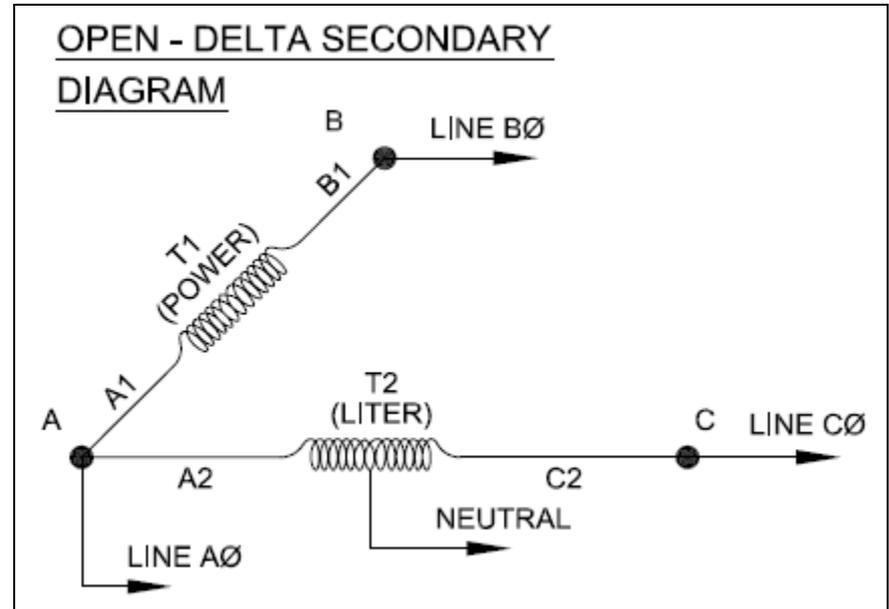
NOTE: Don't forget to add the potential DG contribution to all steps (~ 128 A X 2 = 256 A @ 208 V, and 55.5 A X 2 = 111 A @ 480 V)

One-Line Diagram



Appendix - 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.**

Appendix - 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: National Electrical Code, Section 690 “Solar Photovoltaic Systems”

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

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

IEEE Std 1547-2018: IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems Interfaces

IAEA: A Closer Look at Batteries, John Wiles – 09/16/2013

Eaton/Bussman Short Circuit Analysis – 2014 Application Guide

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