Distributed Resources Engineering (DRE) Interconnection Updates

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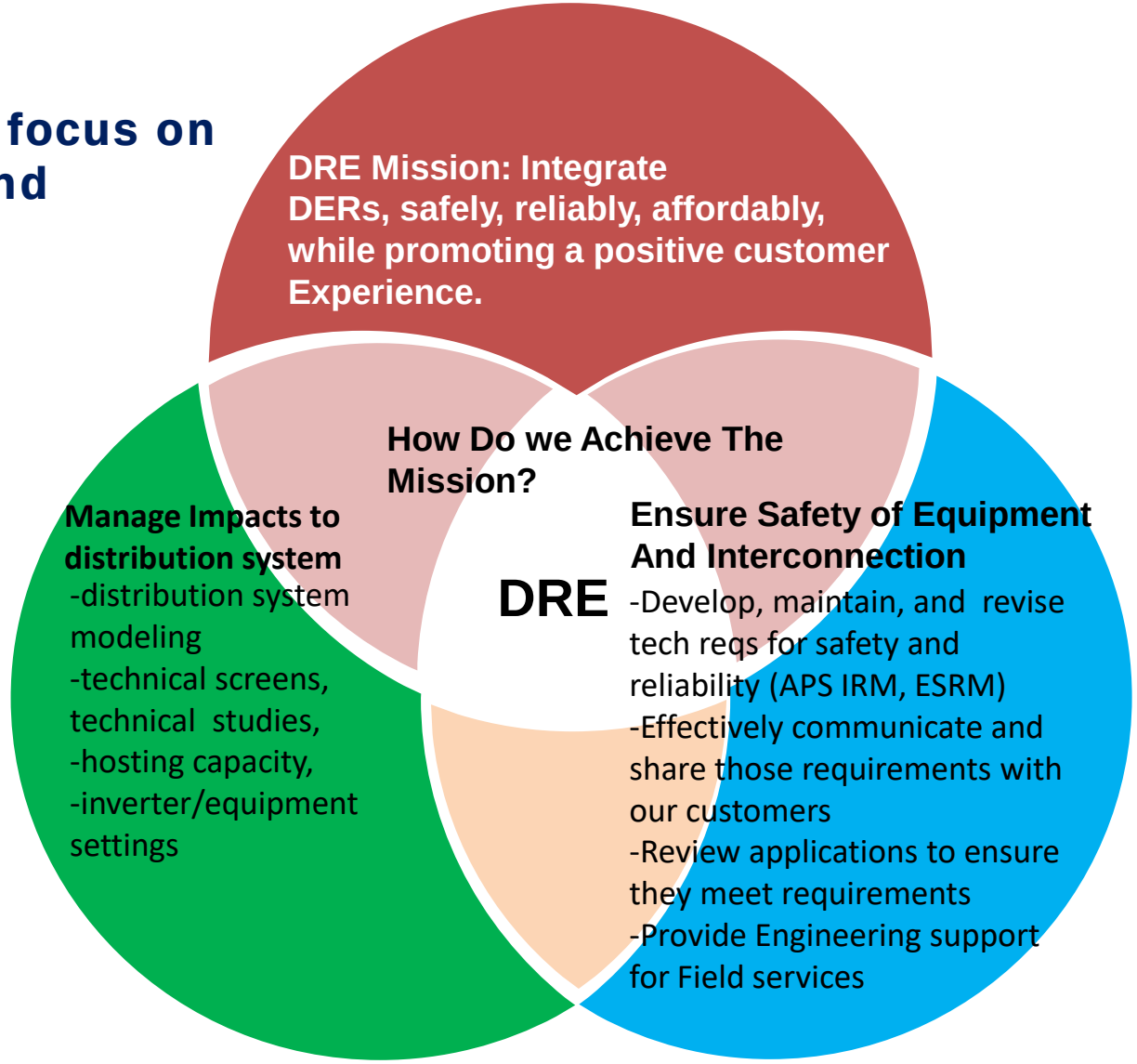
2021

Agenda Topics

- DRE Mission
- Interconnection Process
  - ACC Interconnection Rules
  - APS Interconnection Requirements
- Inverter Settings
- Where to find Interconnection Information
  - Templates, checklists, & diagrams

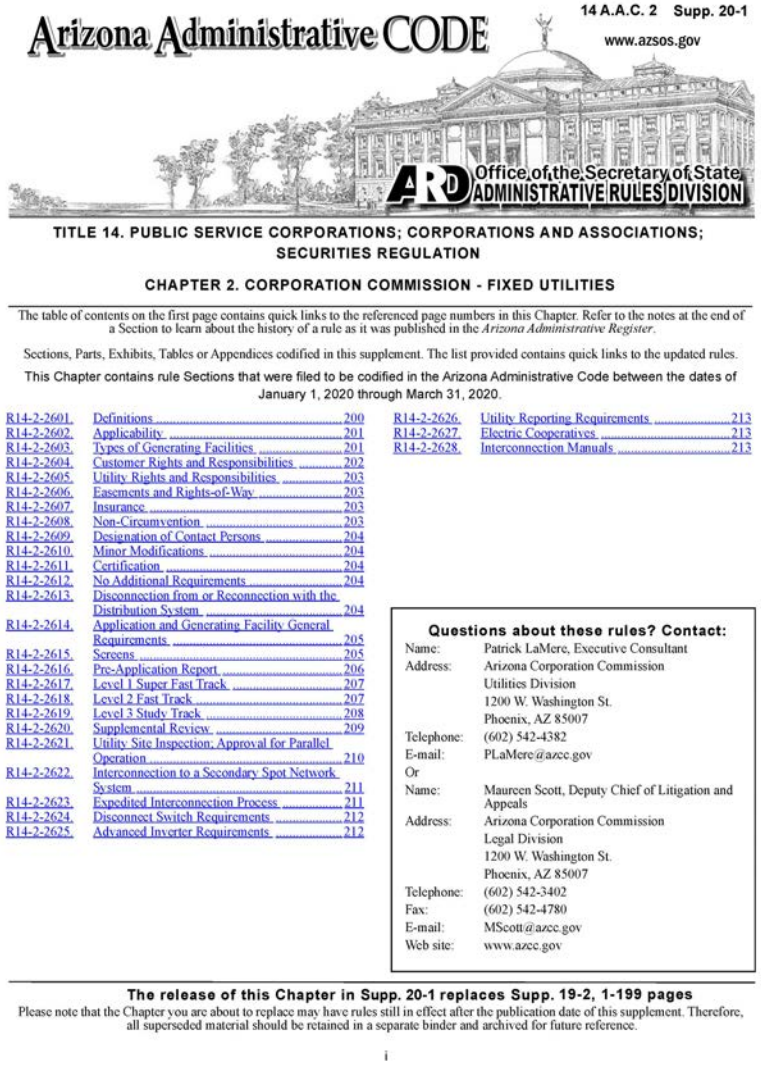
DRE's Mission:

To partner with our customers to sustainably integrate DERs to the distribution grid with a focus on safety, reliability, flexibility, power quality, and customer affordability.



State Level Interconnection Rules & APS Interconnection Requirements Manual Updates/Alignment

- Formal Rules Adopted in February 2020
  - https://apps.azsos.gov/public_services/Title_14/14-02.pdf
- APS filed Rev 8.5 of the APS interconnection Manual in July 2020 to Comply with ACC Rule Adoption
  - Updates in Rev 8.5 bring requirements in alignment with State Level Rules
  - https://www.aps.com/dg#Interconnection
    - Under Common Requirements



Arizona Administrative CODE

14 A.A.C. 2 Supp. 20-1

www.azsos.gov

Office of the Secretary of State
ADMINISTRATIVE RULES DIVISION

TITLE 14. PUBLIC SERVICE CORPORATIONS; CORPORATIONS AND ASSOCIATIONS; SECURITIES REGULATION

CHAPTER 2. CORPORATION COMMISSION - FIXED UTILITIES

The table of contents on the first page contains quick links to the referenced page numbers in this Chapter. Refer to the notes at the end of a Section to learn about the history of a rule as it was published in the *Arizona Administrative Register*.

Sections, Parts, Exhibits, Tables or Appendices codified in this supplement. The list provided contains quick links to the updated rules.

This Chapter contains rule Sections that were filed to be codified in the Arizona Administrative Code between the dates of January 1, 2020 through March 31, 2020.

Questions about these rules? Contact:

Name: Patrick LaMere, Executive Consultant
Address: Arizona Corporation Commission
Utilities Division
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Phoenix, AZ 85007
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Name: Maureen Scott, Deputy Chief of Litigation and Appeals
Address: Arizona Corporation Commission
Legal Division
1200 W. Washington St.
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Fax: (602) 542-4780
E-mail: MScott@azcc.gov
Web site: www.azcc.gov

The release of this Chapter in Supp. 20-1 replaces Supp. 19-2, 1-199 pages

Please note that the Chapter you are about to replace may have rules still in effect after the publication date of this supplement. Therefore, all superseded material should be retained in a separate binder and archived for future reference.

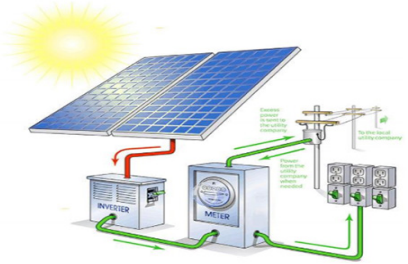
i

ACC / APS Interconnection Requirements

- Apply to all systems that interconnect to the grid
- System Categories
  - Exporting Systems
    - PV, Battery, anything that regularly exports to the grid
  - Inadvertent Export Systems
    - Programmed Not to Export, (PV + Inverters/Battery)
  - Non-Exporting Systems
    - Separate Systems, Back Up Only
- Screens for each track to determine if further study is needed
  - 4 Review Tracks based on system size/category
    - Expedited (Inadvertent Export System under 20 kW)
    - Super Fast (Exporting Systems under 20 kW)
    - Fast (Systems between 20 kW and 2 MW)
    - Study Track (Systems over 2 MW)
- APS interconnection requirements
  - Align with Rules
  - Provide more detailed technical and safety requirements

Screens for Systems under 20 kW

- Screen A
  - Limits the aggregate generation that can be interconnected to a distribution line without additional study.
    - Under 15% of annual peak load, or
    - Under hosting capacity calculated for that distribution line (whichever is greater)
- Screen E
  - Limits the aggregate generation capacity on a single-phase shared secondary to under 75% of the transformer rating without additional study
- Screen F
  - Limits the current imbalance of a system connected to a single phase system that is connected to a transformer providing 120/240V secondary service to under 20% of the rating of the transformer between the two sites of the 240 V service.



HOW SOLAR POWER SYSTEM WORKS!

Navigating the Interconnection Process

DRE Preliminary Project Support

- Recommended for systems over 100 kW
- Pre-Application Report
  - Review of existing information regarding available feeder capacity
- Pre-Application Meeting
  - Discussion of technology/location, project scope, project development support
- Preliminary Engineering Support
- Reach out to your local APS Customer Project Rep or Commercial-Renewables to initiate

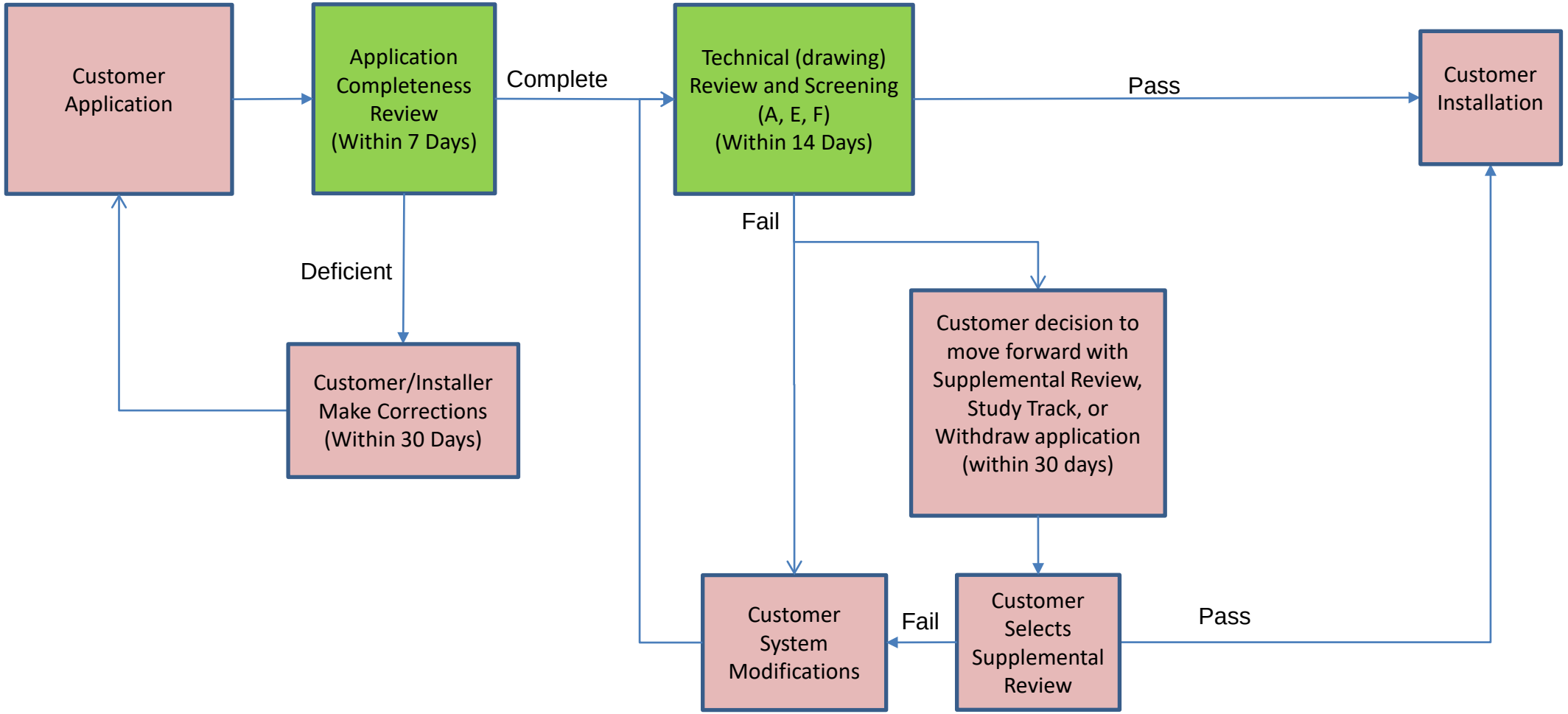
Customer Submit Complete Application

- Load Meter or Temp Meter Installed
- Drawings
  - City or AHJ approved drawings

DRE Formal Application Review and Studies

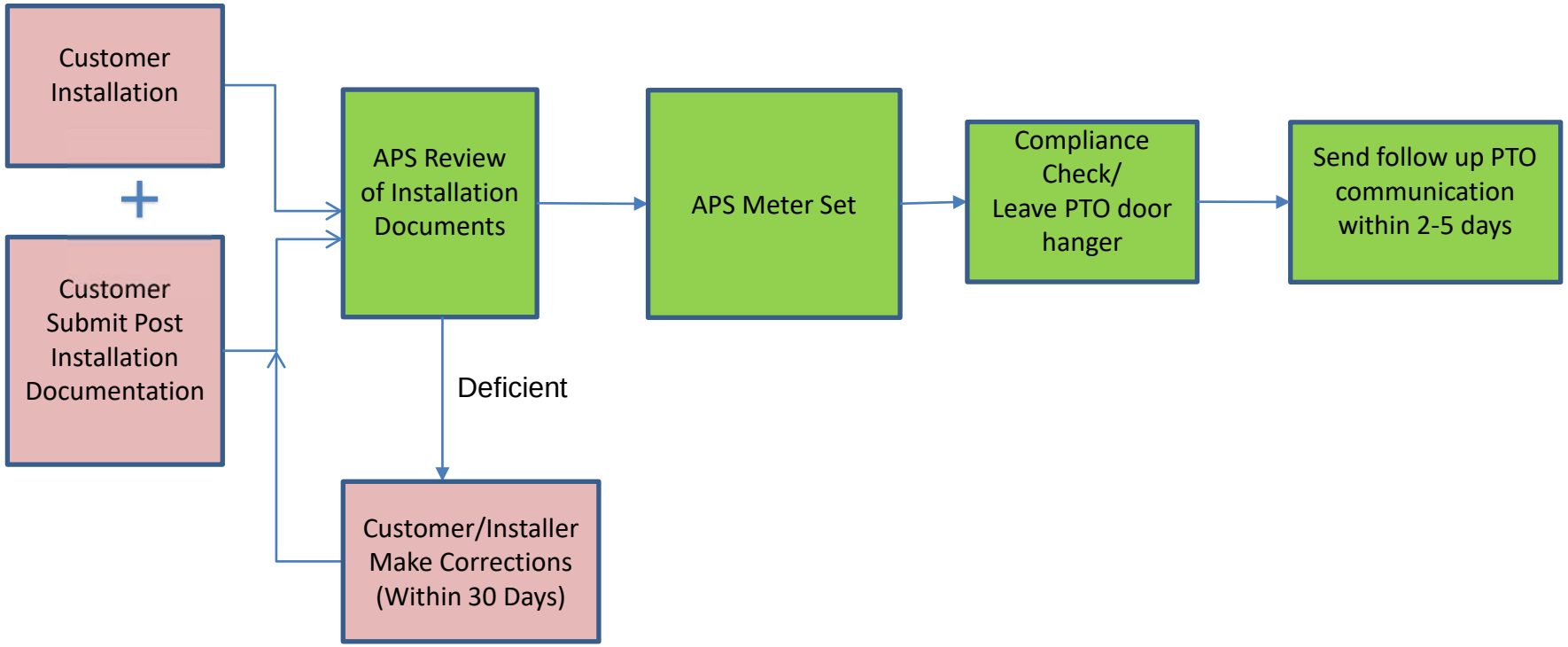
- Application Review
- Drawing Review
- Technical Studies

General Application Review Process for Systems under 20 kW



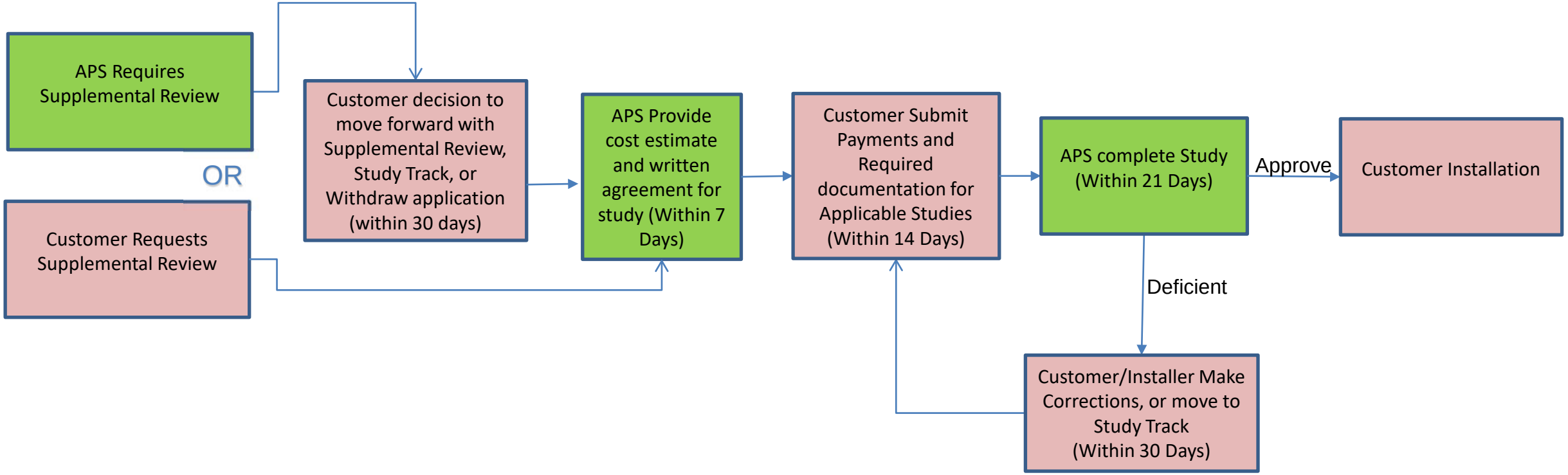
General Installation Process for Systems under 20 kW

- Customer has 180 days from application approval to PTO



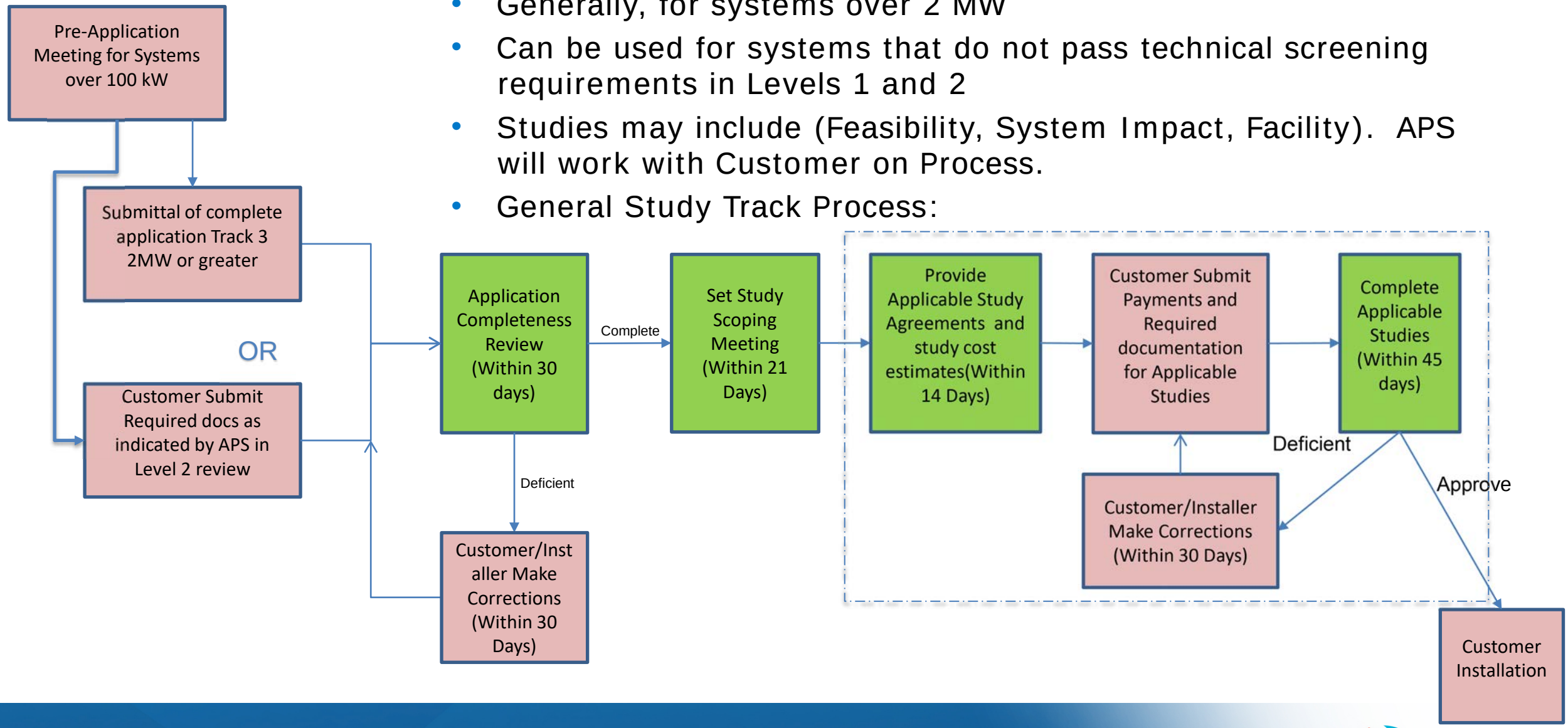
Supplemental Review

- Generally, for systems that fail 1 or more of the technical screens
- General Supplemental Review Process:



Study Track

- Generally, for systems over 2 MW
- Can be used for systems that do not pass technical screening requirements in Levels 1 and 2
- Studies may include (Feasibility, System Impact, Facility). APS will work with Customer on Process.
- General Study Track Process:



IEEE 1547 Advanced Inverter Standards & Settings

All inverters interconnecting to the APS system should have advanced inverter capability as of publication of Rev 8.3 of the APS Interconnection Requirements.

APS to Determine Settings

- Initial settings will not negatively impact customer performance
- APS advanced inverter policy document
- APS advanced inverter setting sheet
- APS will be implementing IEEE 1547-2018 standard effective Jan. 1, 2022

How Does this Fit within the APS Interconnection Requirements manual?

- Section 8.7(A)(11) Outlines the various capabilities documented within IEEE 1547-2018
- Most/all inverter manufacturers should have Advanced Inverter capabilities – IEEE 1547 compliant inverters

Summary of Resources Available at www.aps.com/dg

- Interconnection Process Guide (What submit/design type)
- Applicant User Guide (PowerClerk)
- Plan Review and Installer Guidelines Checklist
- APS Interconnection Requirements Manual, Rev 8.5
- Supply Side Connection Requirements
- PV & ESS Concept Drawings
- Sample Diagrams

https://www.aps.com/dg or https://www.aps.com/dg#Interconnection

aps.com/dg

Residential Business Contact us Help Español

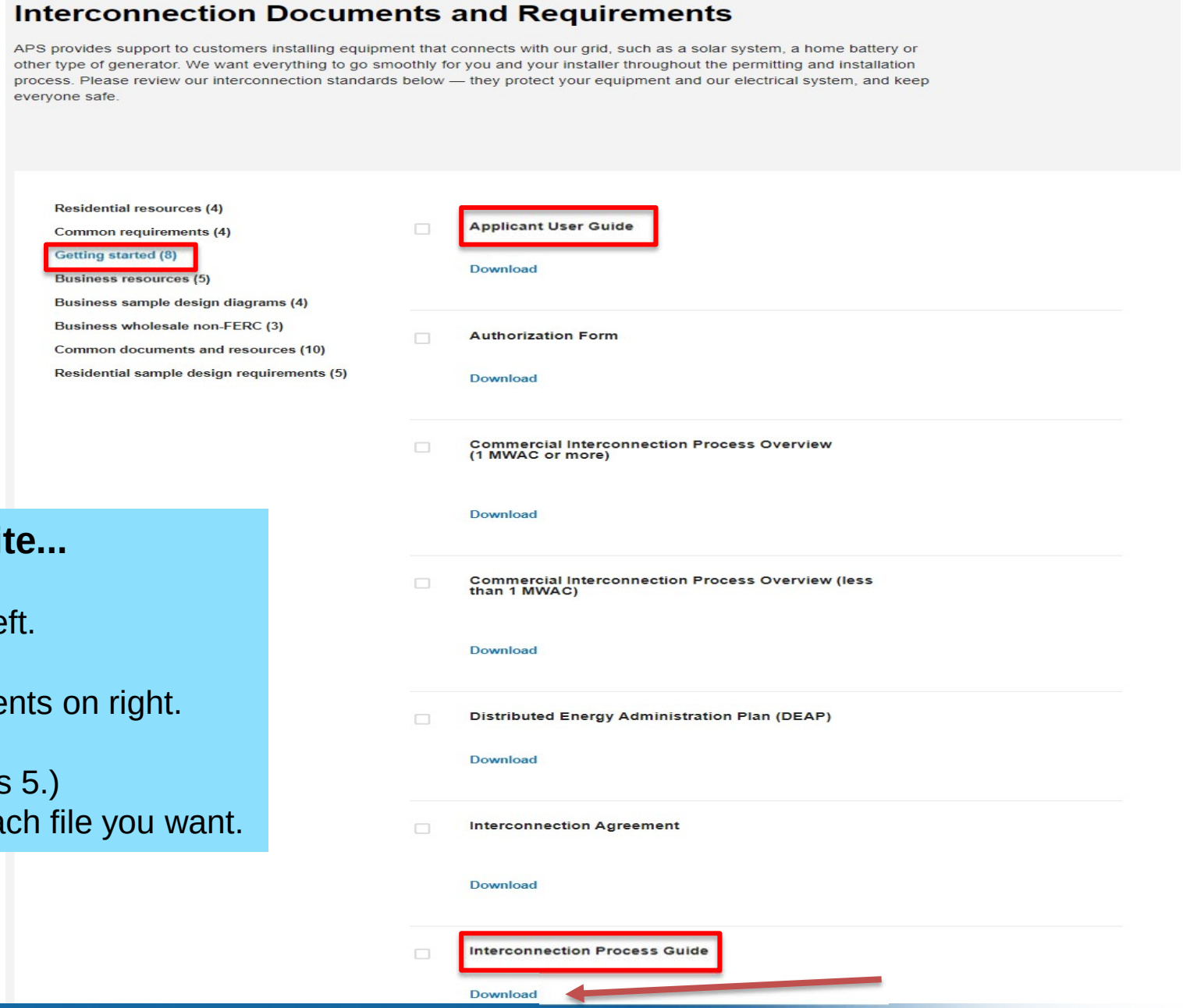
aps COVID-19 resources Account Billing and payment Service plans Save money and energy Outages Log in

How to navigate the dg site...

1. Go to aps.com/dg.
2. Ignore top menus. They take you away from dg.
3. Click on Interconnection.

Understanding Solar

Renewables FAQs Interconnection



How to navigate the dg site...

5. Scroll down to list at lower left.
6. Select topic(# documents).
7. Scroll through list of documents on right. (Hint: may be more pages of documents. Default only shows 5.)
8. Click on Download below each file you want.

Interconnection Documents and Requirements

APS provides support to customers installing equipment that connects with our grid, such as a solar system, a home battery or other type of generator. We want everything to go smoothly for you and your installer throughout the permitting and installation process. Please review our interconnection standards below — they protect your equipment and our electrical system, and keep everyone safe.

- Residential resources (4)
- Common requirements (4)
- Getting started (8)
- Business resources (5)
- Business sample design diagrams (4)
- Business wholesale non-FERC (3)
- Common documents and resources (10)
- Residential sample design requirements (5)

APS Interconnection Requirements

Download

Load Side Connection Requirements

Download

Supply Side Connection Requirements

Download

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- Residential sample design requirements (5)

Plan Review & Installer Guidelines Checklist

Download

Single Phase 120-240V Fault Current AC Disco Guide

Download

Typical Wind Diagram

Download

Utility Disconnect Checklist

Download

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- Residential sample design requirements (5)

APS ESS Metering and Isolation Concept Drawings

Download

APS PV Solar Metering and Isolation Concept Drawings

Download

Consumer Acknowledgement

Download

Diagram Checklist

Download

- Residential resources (4)
- Common requirements (4)
- Getting started (8)
- Business resources (5)
- Business sample design diagrams (4)
- Business wholesale non-FERC (3)
- Common documents and resources (10)
- Residential sample design requirements (5)

200A Typical Residential Diagram for Load Side Connection

Download

400A Typical Residential Diagram for Load Side Connection

Download

240V Battery System Diagram

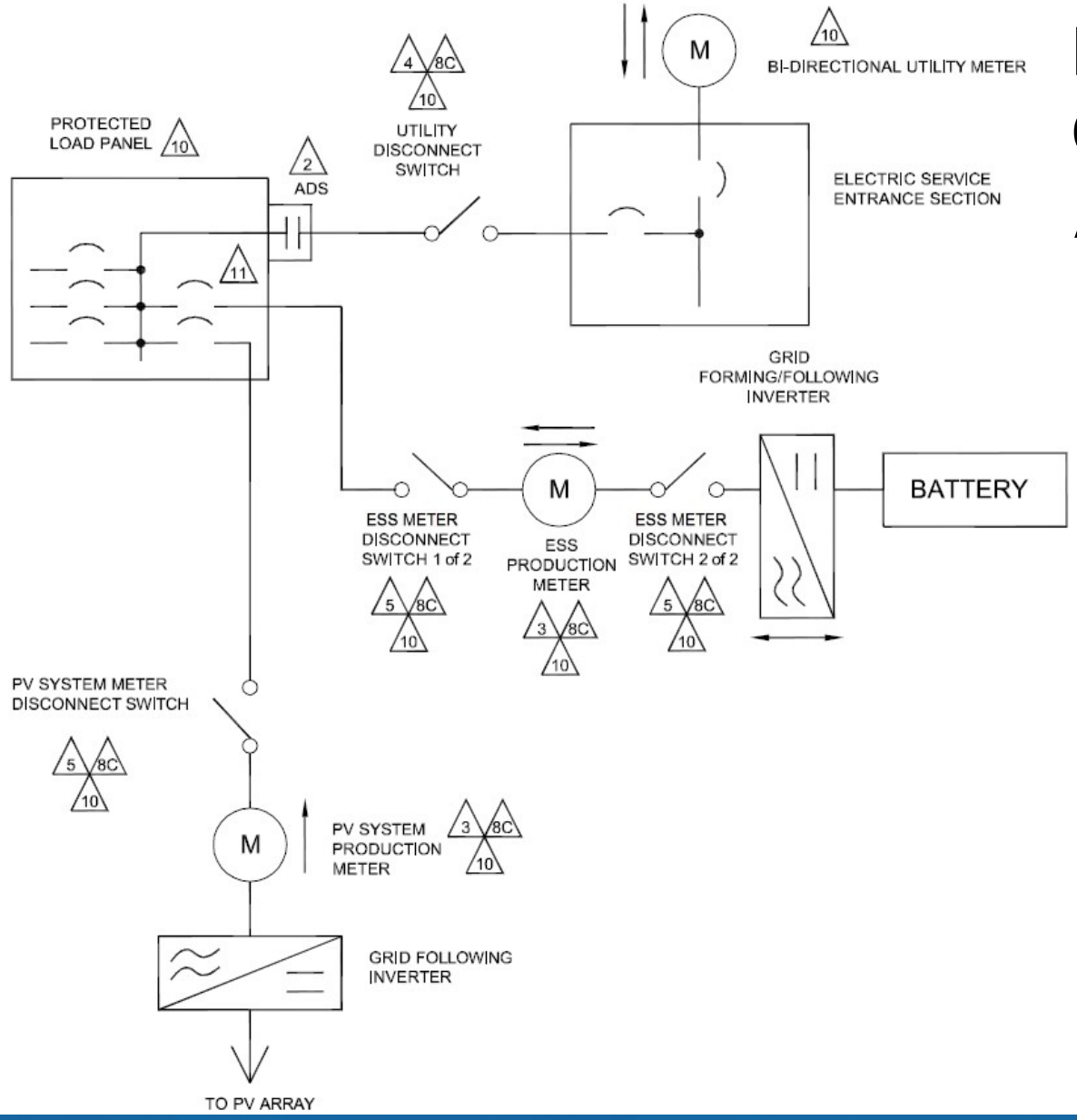
Download

400A Typical Residential Diagram for Load Side Tap

Download

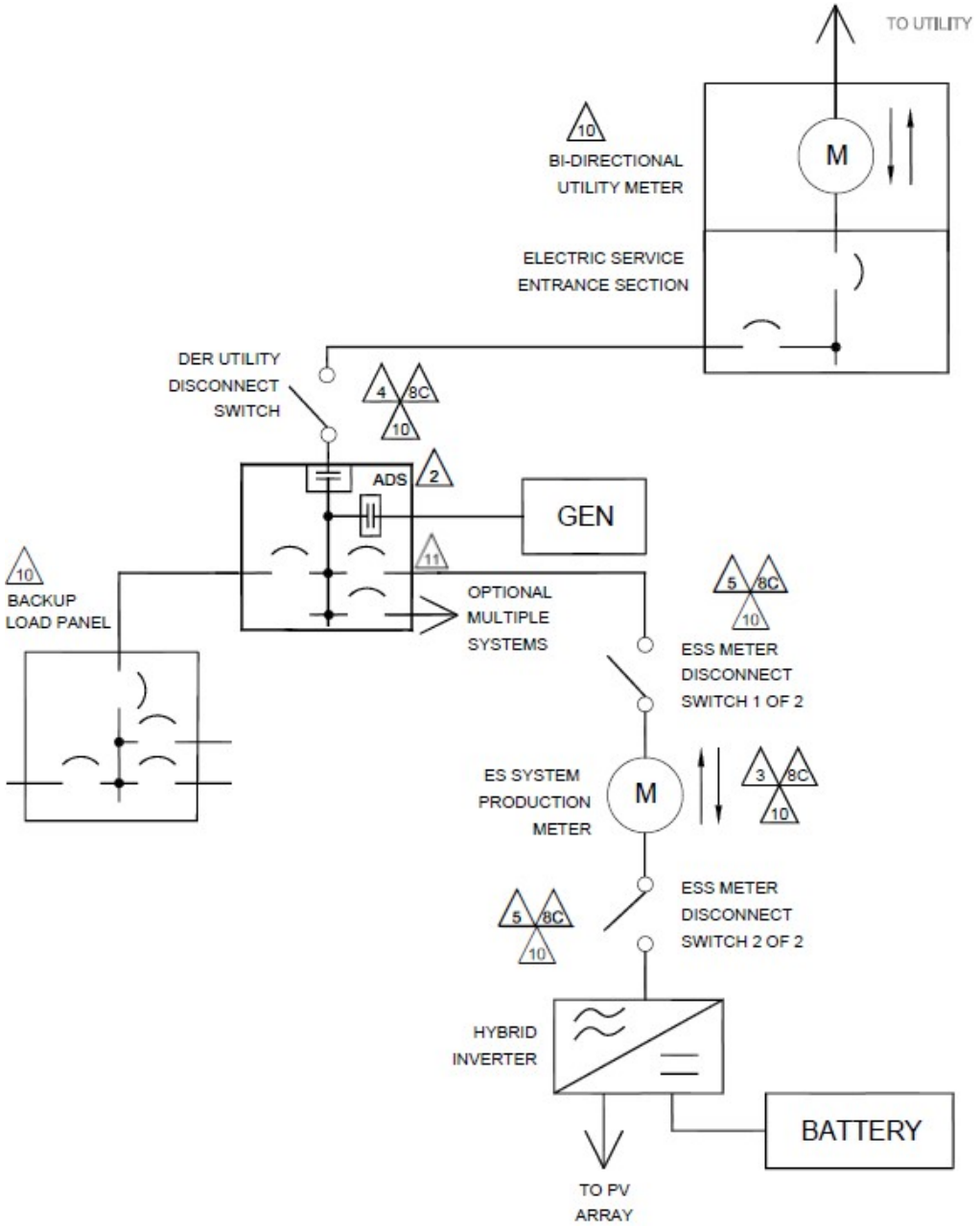
Typical Residential Diagram for Supply Side Tap

ESS Metering Isolation Concept Drawing AC Coupled Config. B-3



For multiple Battery Meters, identify System 1, System 2, etc.

ESS Metering Isolation Concept Drawing DC Coupled Config. C-2 draft



For multiple Battery Meters, identify System 1, System 2, etc.

Questions?

Required Diagrams for PV Systems
(Residential and Small Commercial Larger than 1kW, < 1MW)

- **Residential**
  - Electrical One-Line Diagram*
  - Electrical Three-Line Diagram
  - Site Plan

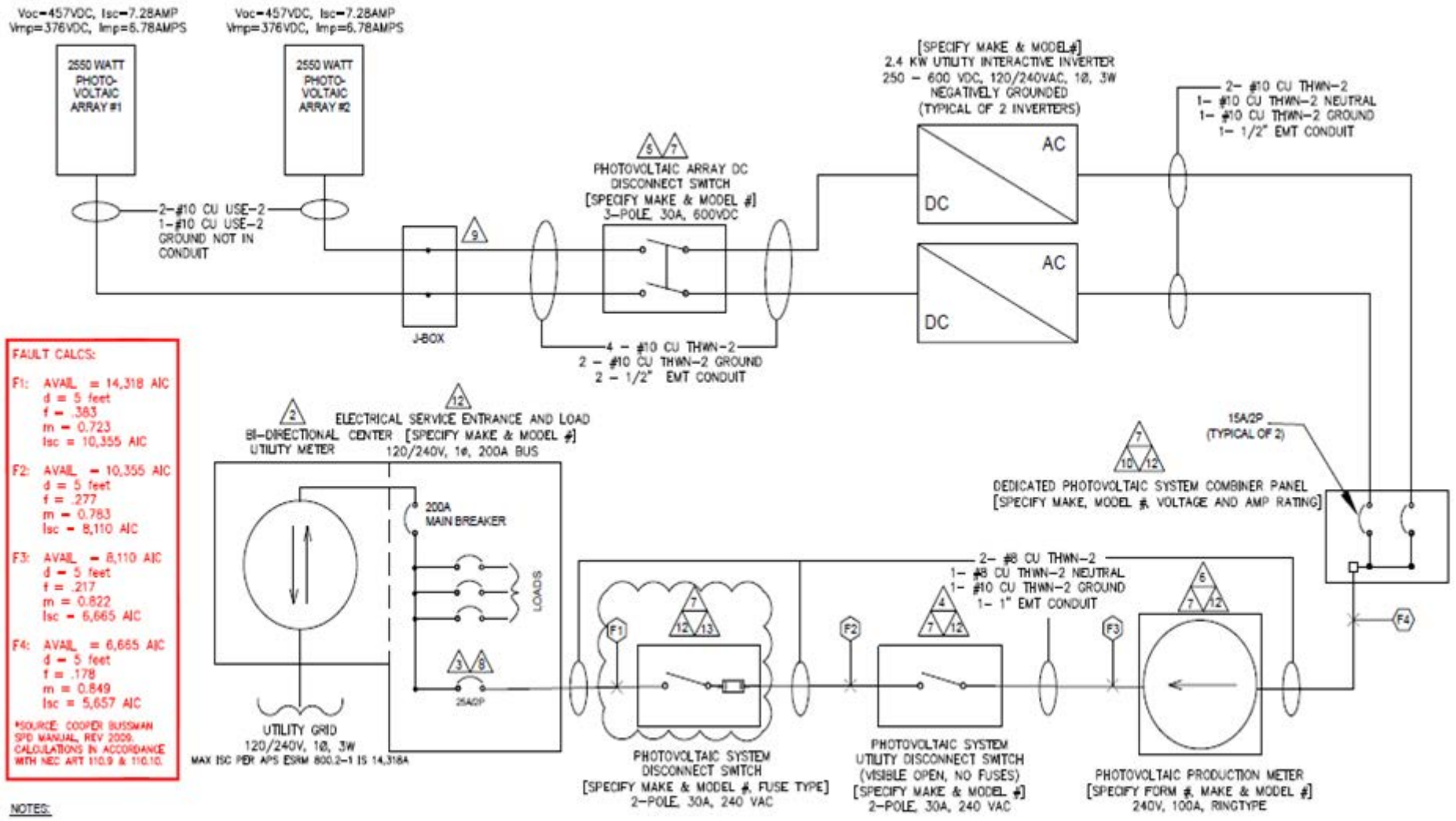
- **Commercial**
  - Electrical One-Line Diagram
  - Electrical Three-Line Diagram & Three-Line Array
  - Plant Location
  - Site Plan

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.***

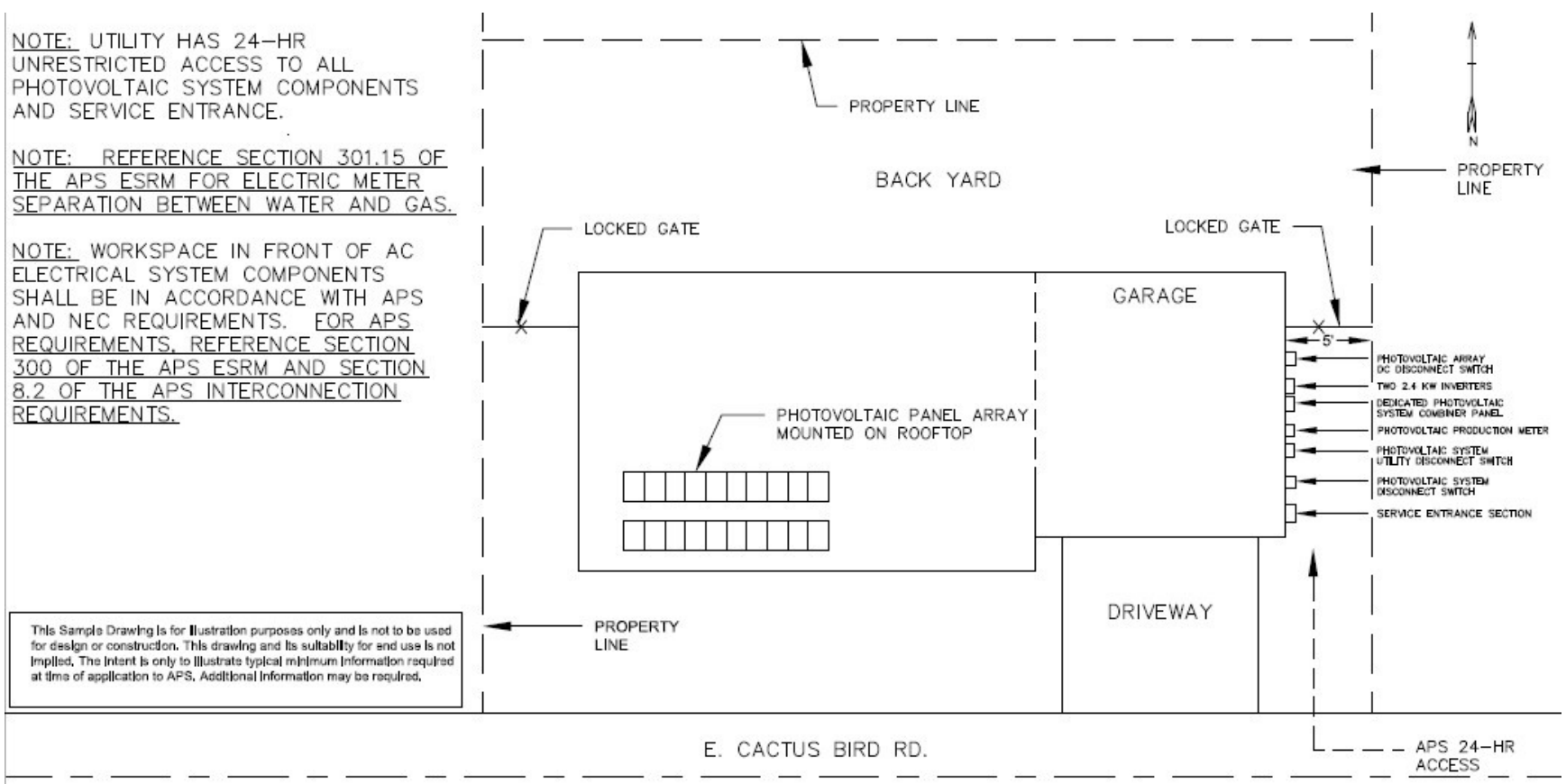
Sample 1-Line Diagram



NOTE: UTILITY HAS 24–HR UNRESTRICTED ACCESS TO ALL PHOTOVOLTAIC SYSTEM COMPONENTS AND SERVICE ENTRANCE.

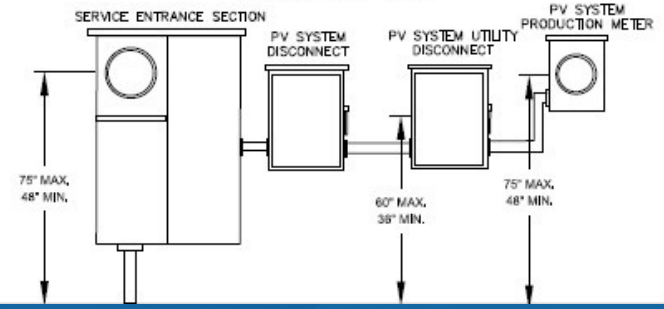
NOTE: REFERENCE SECTION 301.15 OF THE APS ESRM FOR ELECTRIC METER SEPARATION BETWEEN WATER AND GAS.

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.

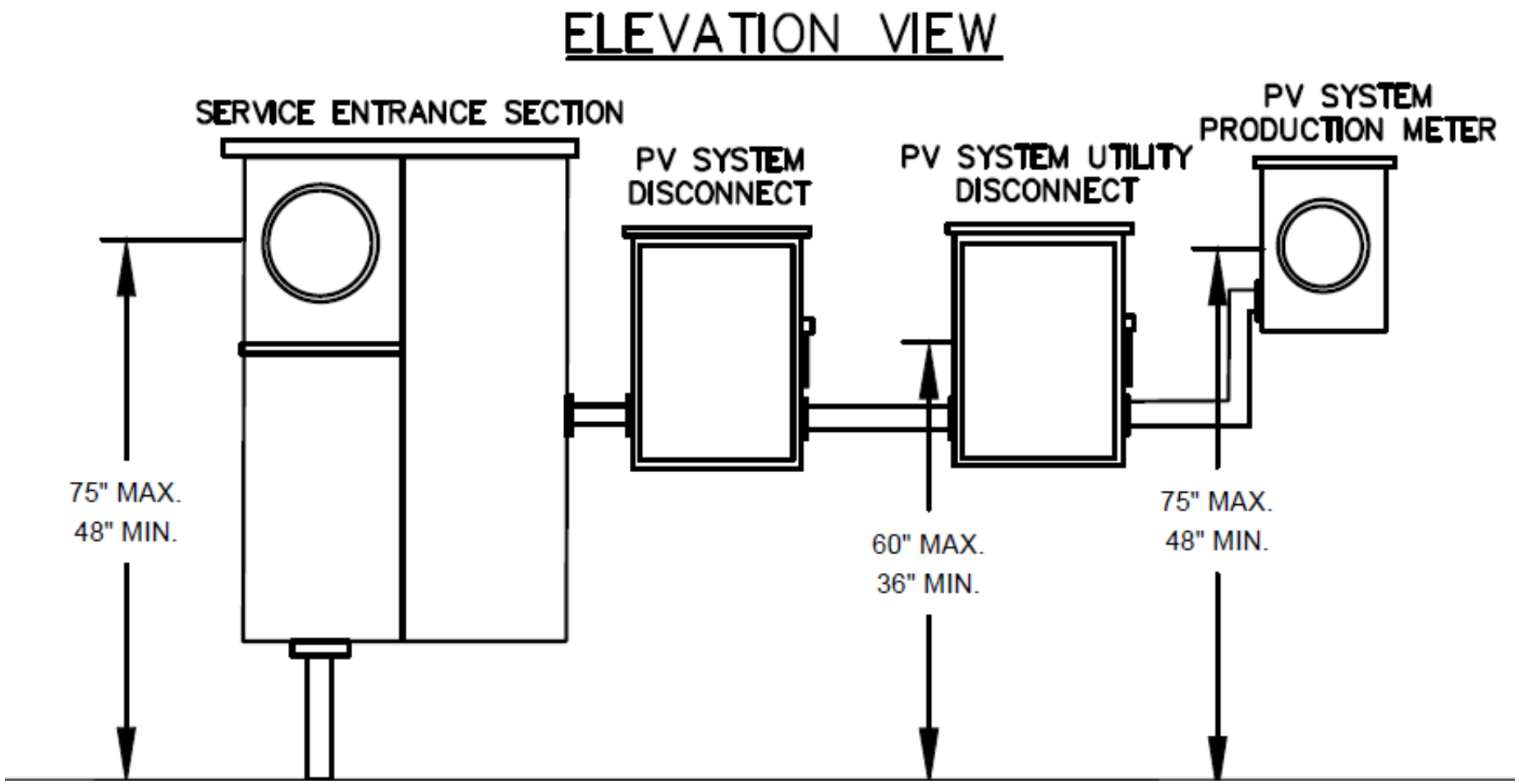


This Sample Drawing is for illustration purposes only and is not to be used for design or construction. This drawing and its suitability for end use is not implied. The intent is only to illustrate typical minimum information required at time of application to APS. Additional information may be required.

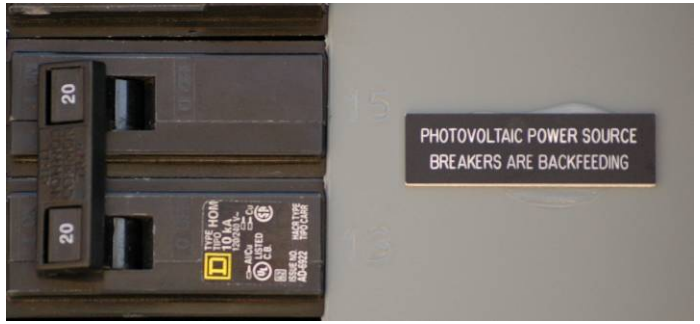
ELEVATION VIEW

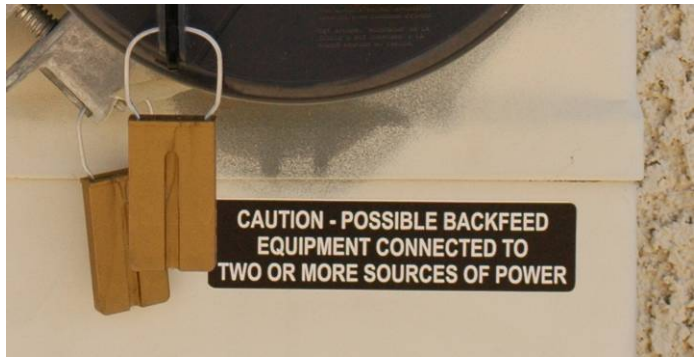


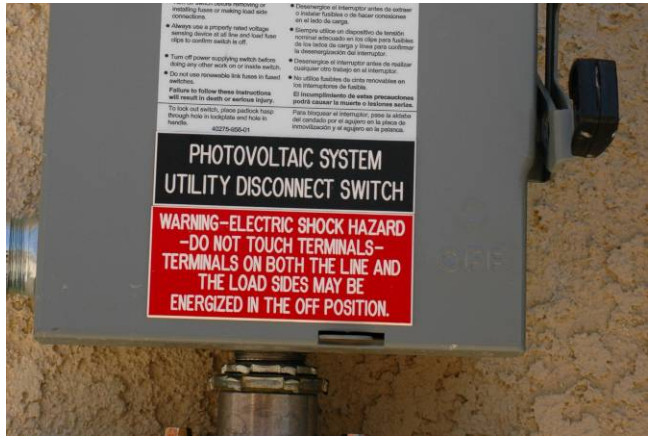
Example - Residential PV System



Example of PV System Warning Labels







NOTE: Typical APS Equipment Labels Handout is located at www.aps.com/dg. ANSI color standards may be used, but is not 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 PREFORMING 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

Standard APS 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 24/7.
- 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 adjacent to the SES, APS requires a placard at the SES and a placard at the Disconnect with explicit written directions to the location of the other:

Standard APS Interconnection Requirements:

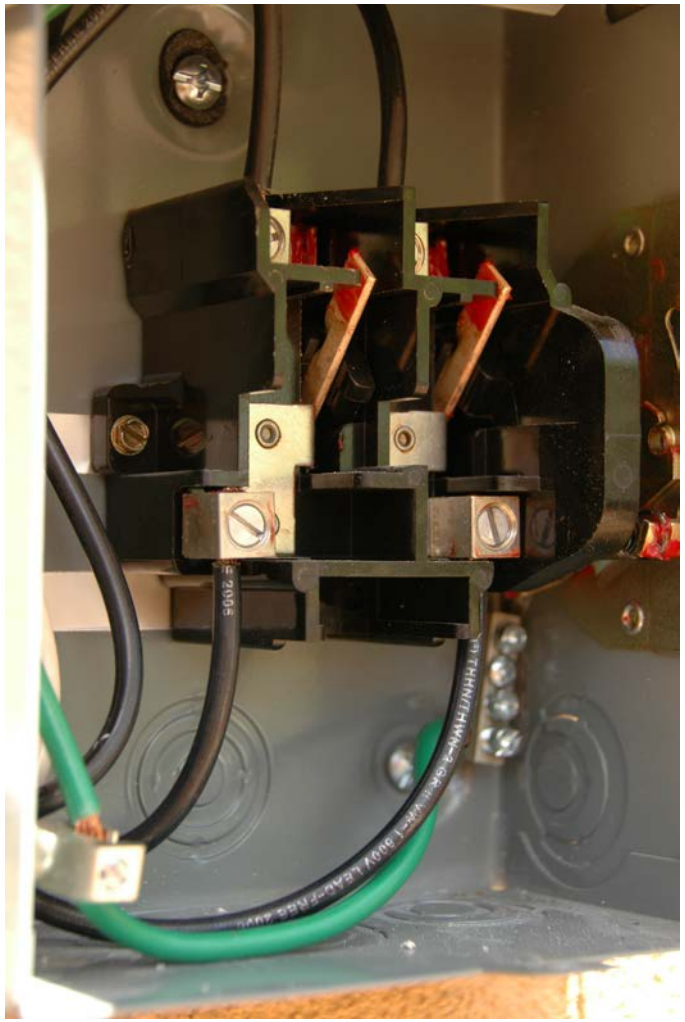
Disconnect Switch (cont.)

Blades

- Shall be de-energized in the open position in accordance with NEC 404.6(C) and OSHA 1926.405(C) (hinged on Inverter Side).

Arc Shields

- Acceptable only if do not impede true visual open. **NOTE: Arc shields may not be removed in order to verify the visual open.**



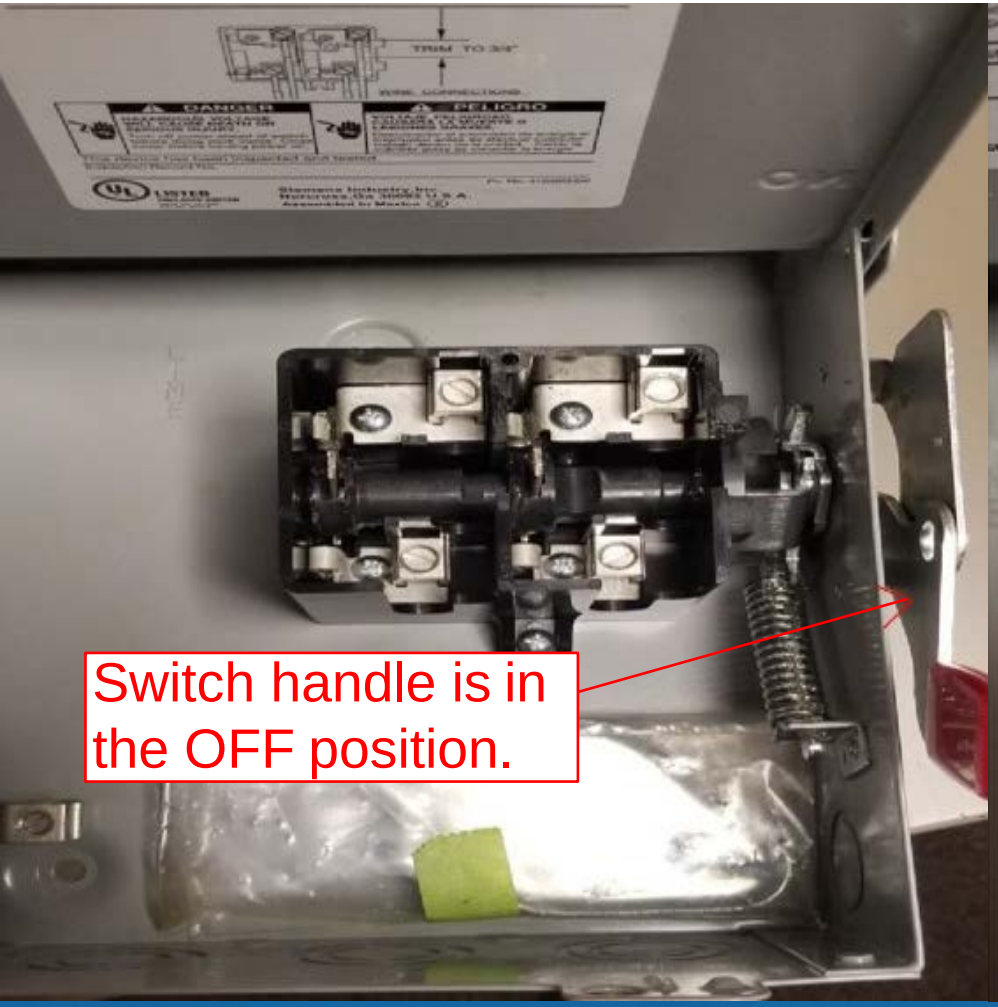
TRUE VISUAL OPEN

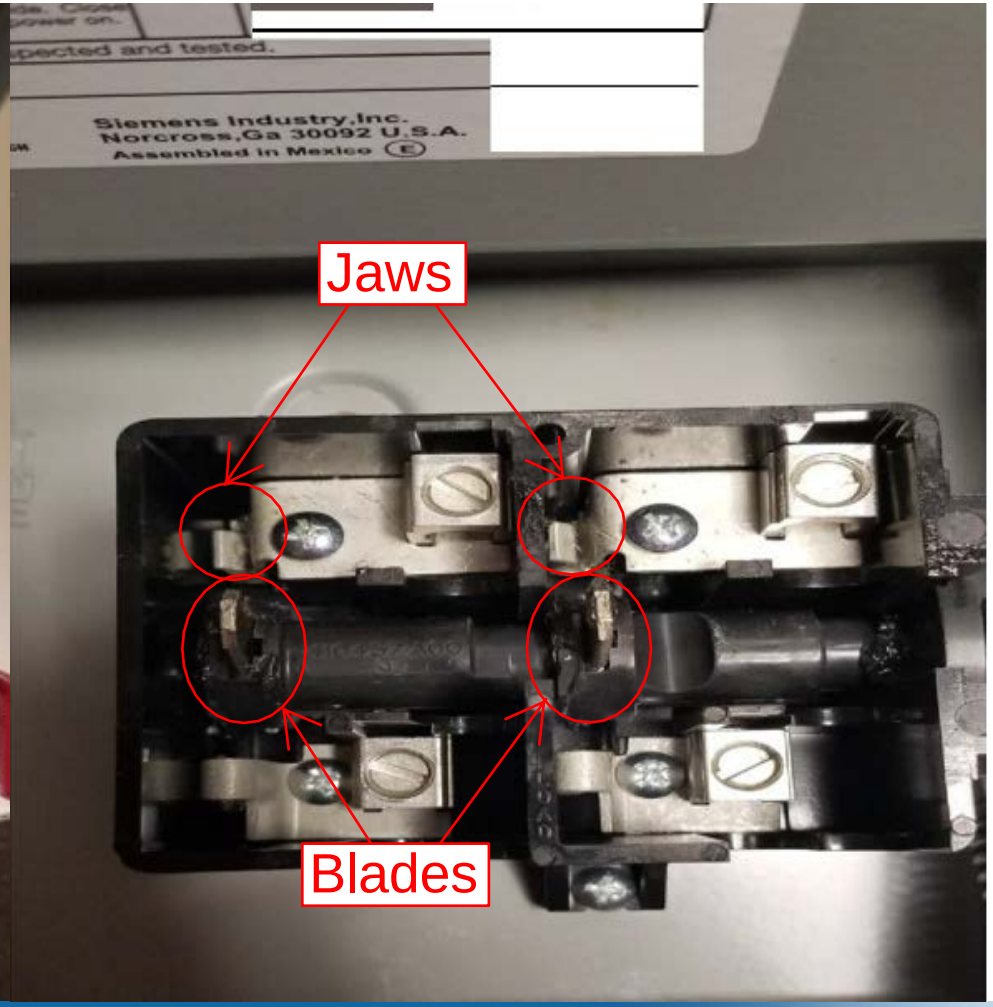
The “Utility Disconnect Switch” shall be a true visual open disconnect. The blades, jaws and air gap between them shall be clearly visible when the switch is in the open position.

TRUE VISUAL OPEN

The photograph depicts the switch in the ON (closed) position. The blades and the jaws are in contact with each other and current can flow through.

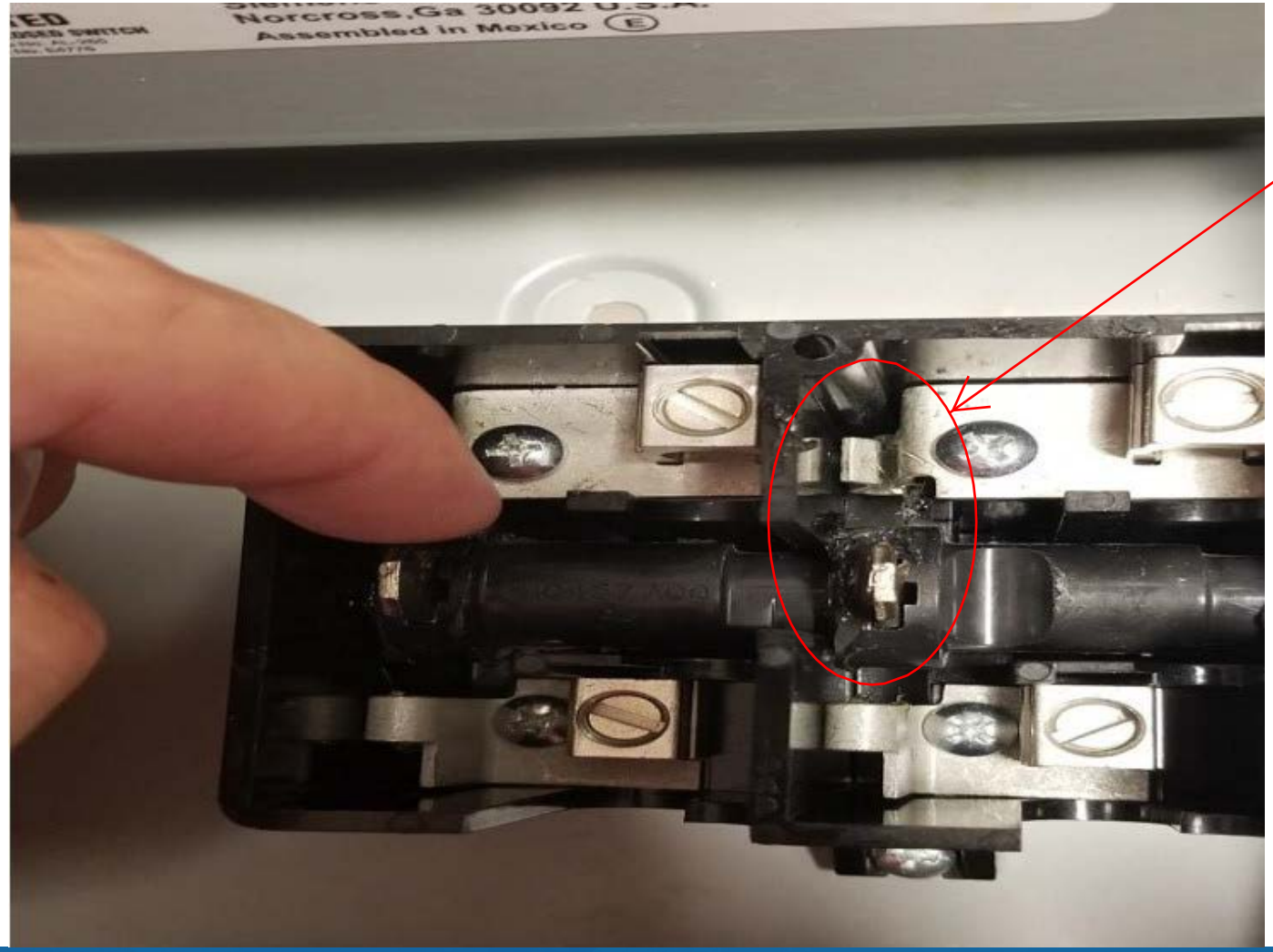
TRUE VISUAL OPEN





The photographs above depict the switch in the OFF (open) position. The blades and the jaws are not in contact with each other and are separated by an air gap prohibiting the flow of current through the switch.

TRUE VISUAL OPEN



"True Visual Open"

"True Visual Open" means having the ability to clearly see the blades, the jaws, and the physical separation (air gap) between them.

Standard APS Interconnection Requirements:

Disconnect Switch (cont.)

Multiple Utility Disconnects

- Multiple systems connected to the service.
- System expansions.
- Properly labeled and contain switch numbers (i.e., 1 of 2, 2 of 2).

Fused Disconnect

- APS requires a fused disconnect ahead of the APS required unfused disconnect to meet fault current requirements (Refer to APS ESRM 800.2).
- Shall be locked by the customer/installer and is not required to meet APS visual open criteria.

Standard APS Interconnection Requirements:

Production Metering

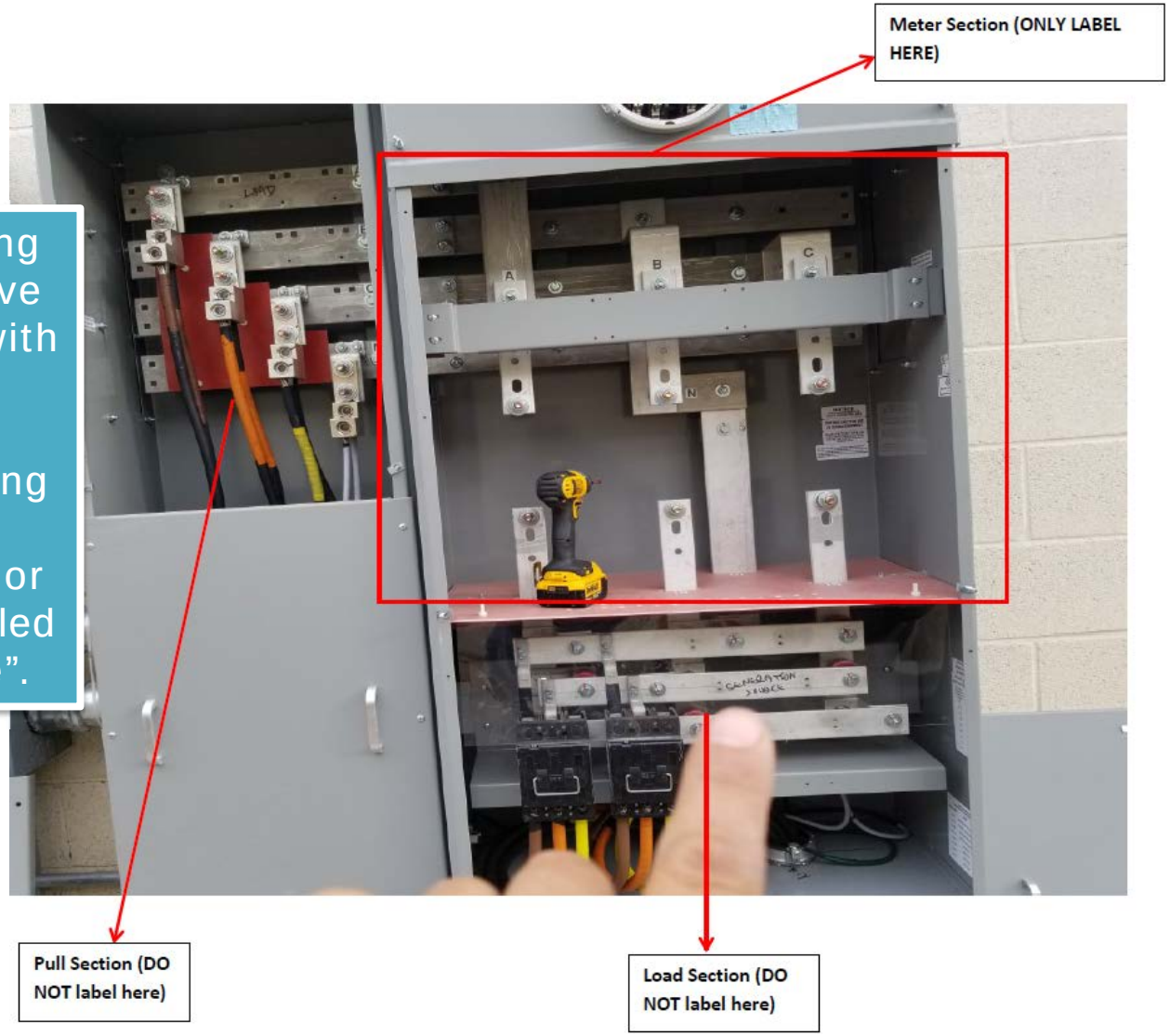
Customer must provide and install, at Customer's expense, meter sockets and metering cabinets in accordance with APS service standards, in locations acceptable to APS.

- 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 approved visual open disconnecting means for isolation.

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 permanent marker or temporary tag labeled “Generation Source”.



Standard APS Interconnection Requirements:

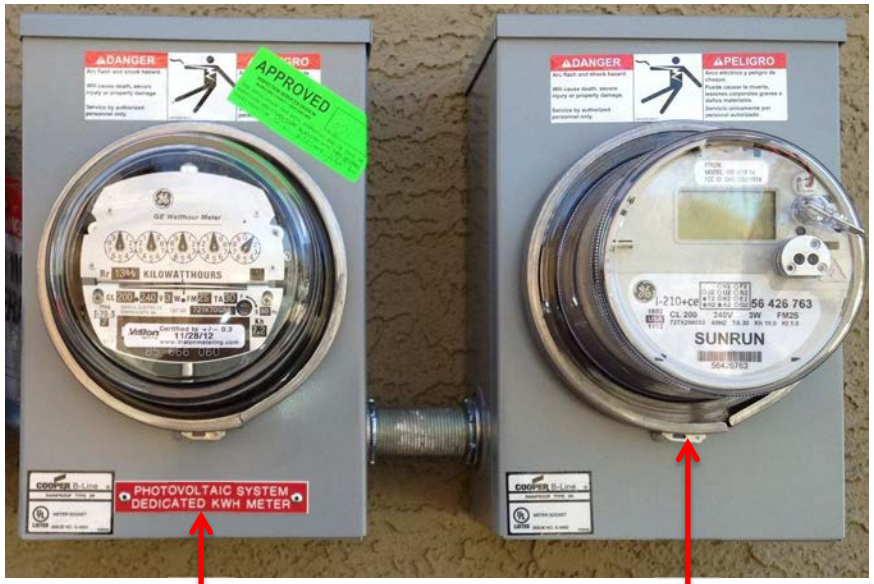
Production Metering (cont.)

3rd Party Production Metering

- Customer may install 3rd party production meter, if correctly labeled and located on the inverter side of the APS Production Meter.

Multiple Production Metering

- Production Meters shall be properly labeled with meter identification per system (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.

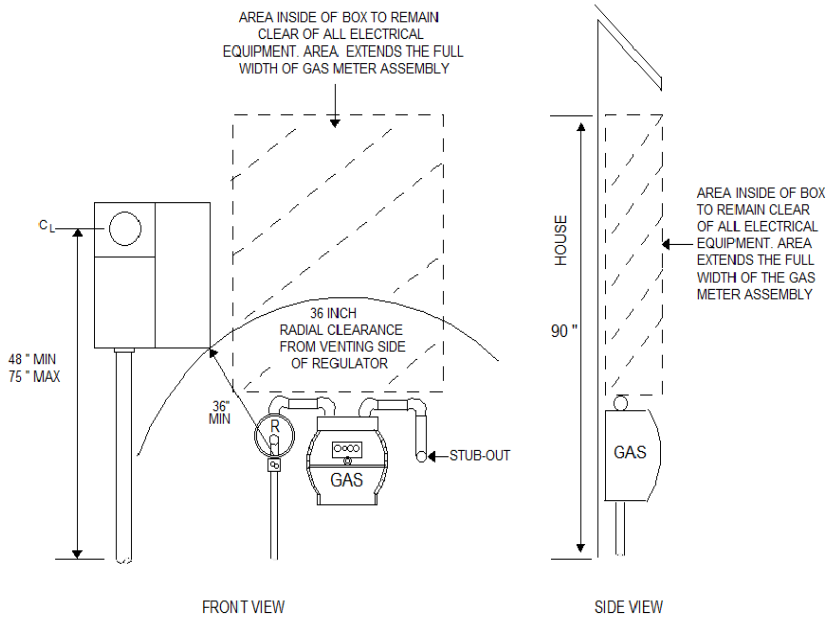
NOTE:
Cardboard is not an acceptable cover material.
Cover material shall be fiberglass, plastic, glass or Plexiglas.

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

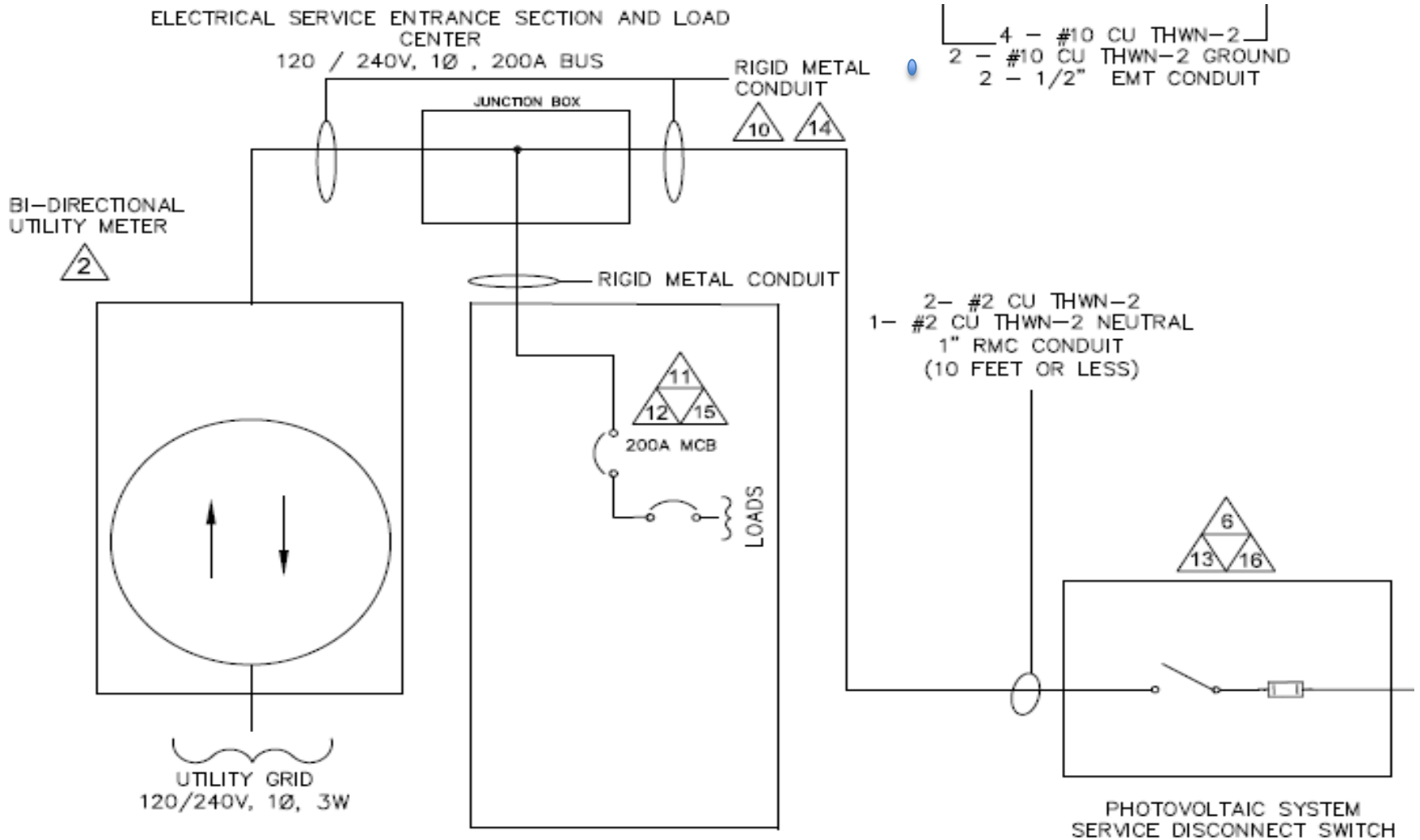
- Most serious design type because working with unprotected service conductors.
- Allowed per 2011/2014/2017 NEC 705.12 (A):
  - “The output of a utility-interactive inverter shall be permitted to be connected to the supply side of the service disconnecting means as permitted in 230.82(6)” (basically installing a second service per APS ESRM 104.11.2).
- RMC (Rigid Metal Conduit) required 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. Minimum is 60A.
- Neutral to ground bond must be established in the fused service 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)

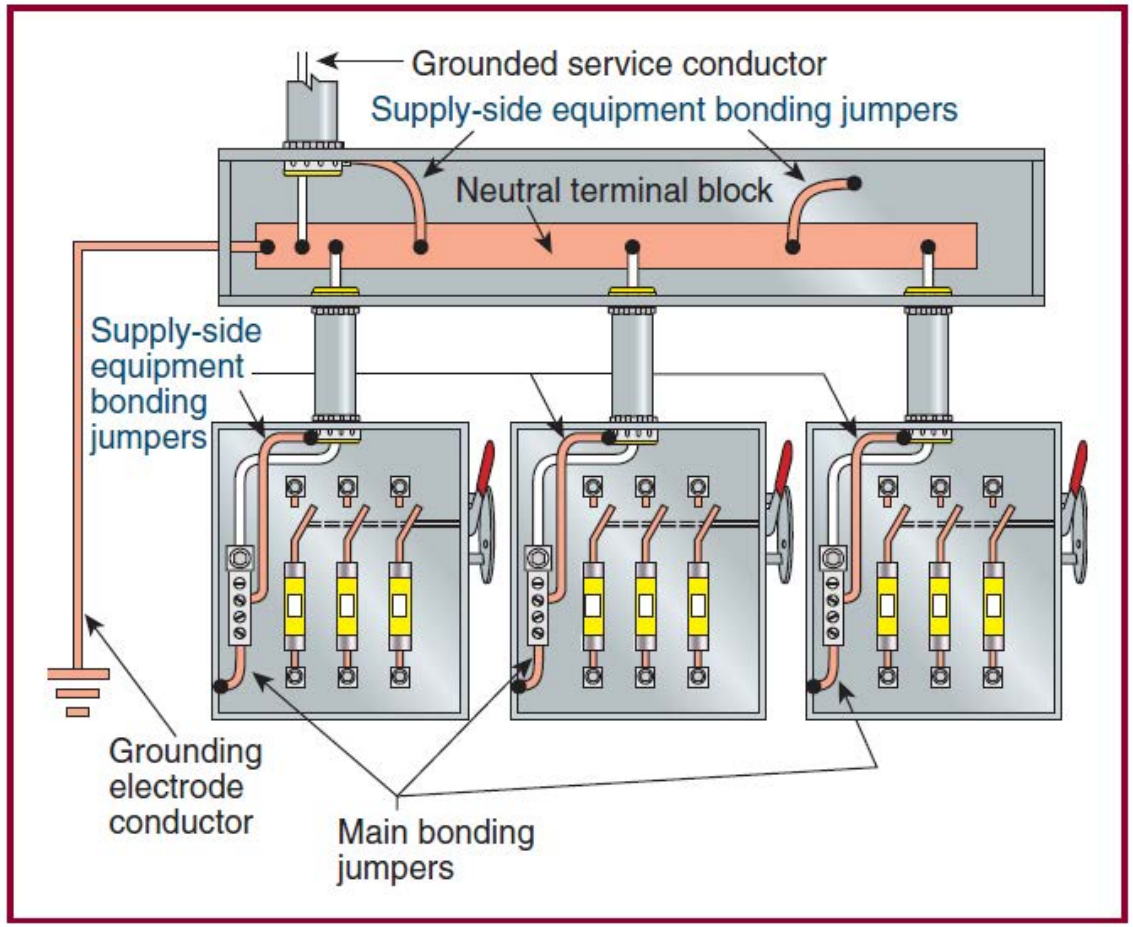
Supply Side Connection (cont.)



NOTES:

⚠ EQUIPMENT SHALL BE INSTALLED IN ACCORDANCE WITH THE NEC AND

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

Do not 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:

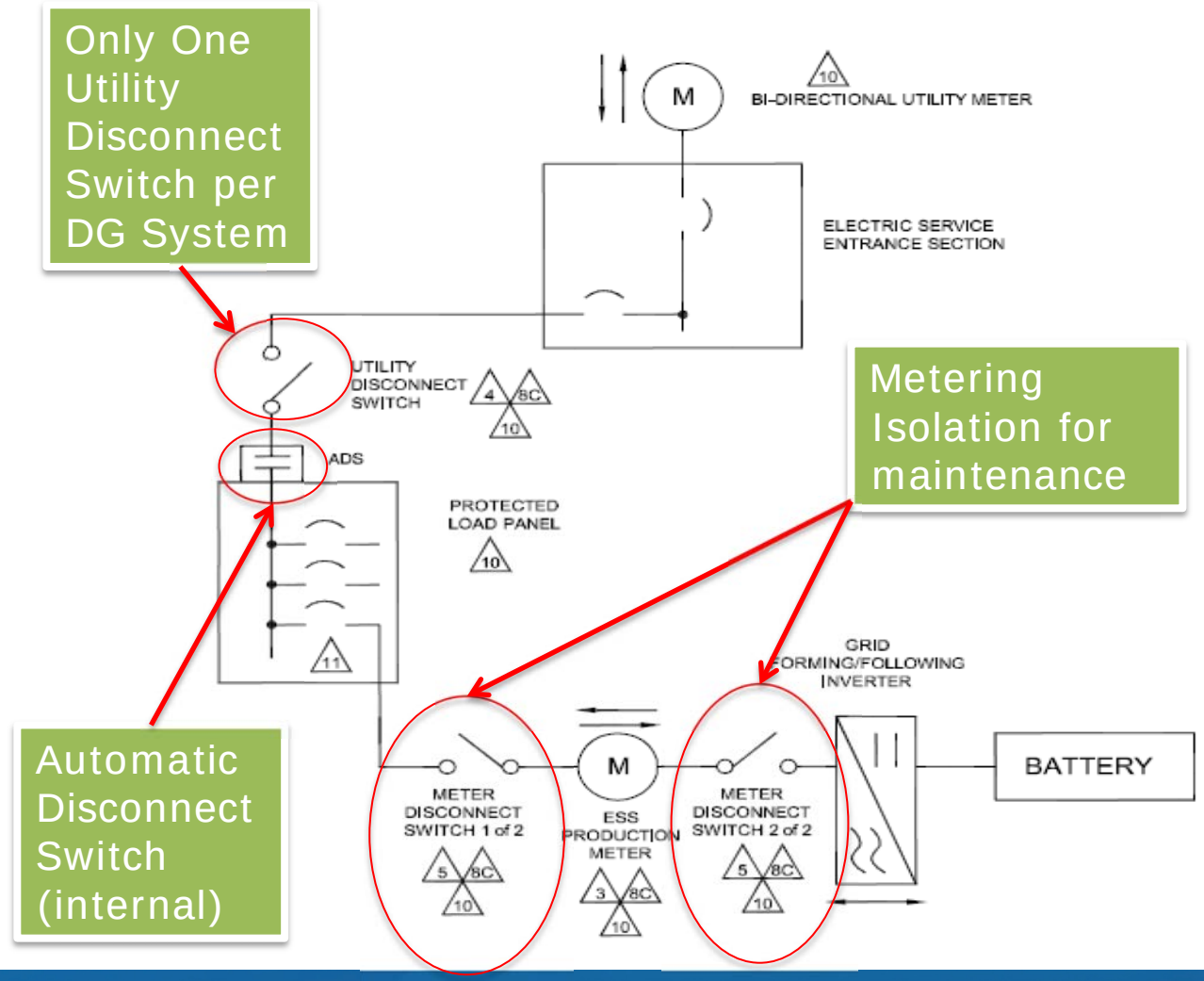
- Once APS approval is granted, in accordance with SB1417, install GF following APS and NEC applicable requirements
- Sign and provide the "Letter In-Lieu of Electrical Clearance" form to APS

NOTE: Additional information available per Section 16 of the APS Interconnection Requirements manual

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.***
- Customers 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 only if proper warning signs and written procedures/instructions are provided.
- 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 homeowner, First Responders and maintenance personnel that may work on the system from time to time.
- Inverters listed to UL1741/UL1741SA.

Battery One Line Example



- Isolation required on both sides of ESS Production meter
- ADS Opens upon Grid Outage
- Protected Load Panel not normally 24-7 accessible

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 programed 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, and (3) Battery System will power the essential load panel.
- The Battery System metering will be required.
- APS will require a meter and meter disconnects at each system (PV and Battery Back-up).

DC Coupled Systems

- Installations traditionally by Outback Power Systems with UL1008 transfer inherent in the inverter did not require meter disconnect on inverter side.
- This is a one (or two) inverter system with both batteries and panels connected to the inverter (separate DC inputs).
- Backup load panel was traditionally installed as an output to the inverter. Today, other systems connect Backup load panel to an interface device separate from the inverter.
- Inverter DC Disconnect and internal Bypass switch was required to disconnect power to the Backup Load panel.
- In the event of an outage: (1) controller opens automatic disconnect to isolate from the grid, (2) backup loads are powered by the batteries with the PV panels (or optional generator input) charging batteries.
- APS will require Utility Disconnect Switch & Production Meters with Meter Disconnect Switches.
- Meters required would be 2S.
- **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)

- Customers 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 Utility Disconnect switch in accordance with Section 4.1 and 8.2 of the APS Interconnection Requirements Manual.

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

1Ø : Inverter AC Output Current Rating = Inverter Watts÷Voltage

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

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

8kW/240V = 33.3A X 1.25 = 41.6A
OCPD = 45A (combiner box)

In Parallel
16kW/240V = 66.6A X 1.25 = 83.3A
OCPD = 90A (back-fed breaker)

Breaker & Wire Sizing (cont.)

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

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

Table 310.15(B)(16):

Size AWG or kcmil	Temperature Rating of Condu		
	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 105-113ºF

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

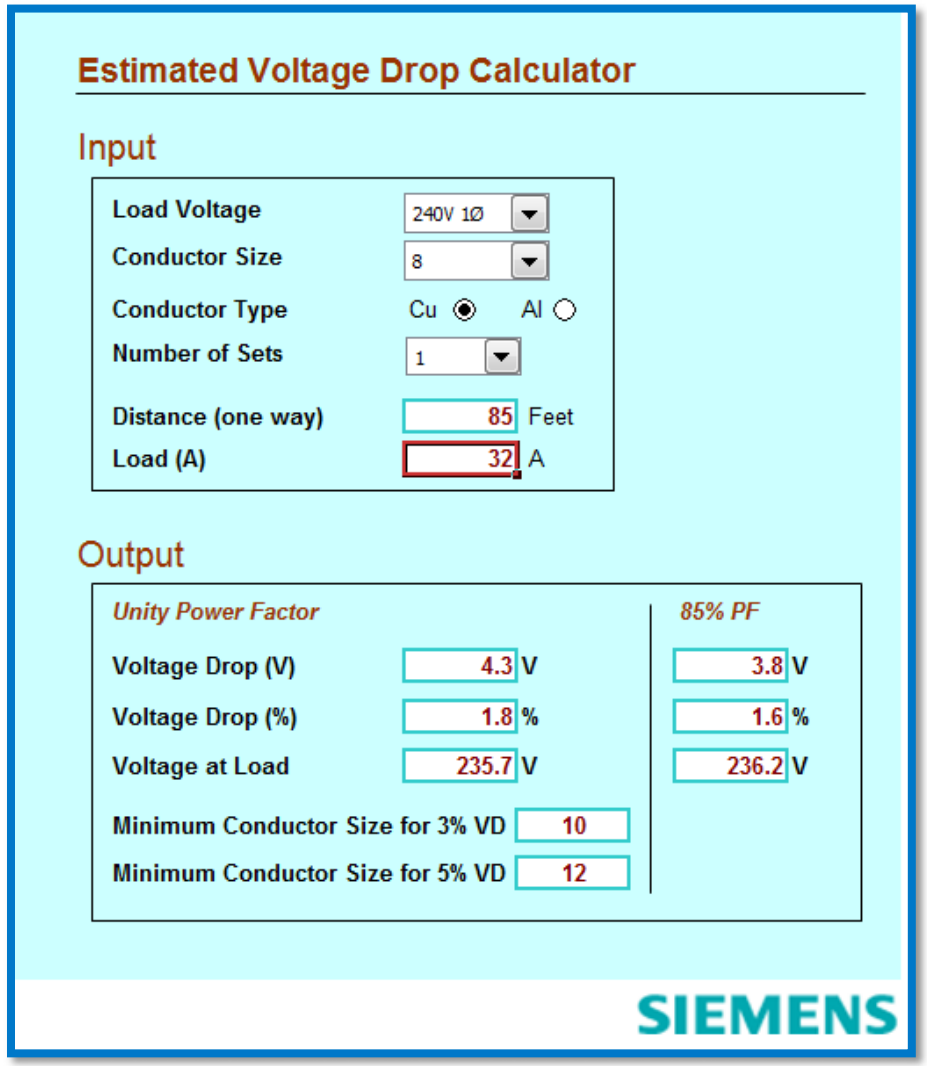
Voltage Drop/Rise Equation

- $V_D = 2 \times \frac{\Omega}{1k \cdot ft} \times L \times A$
  - 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

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

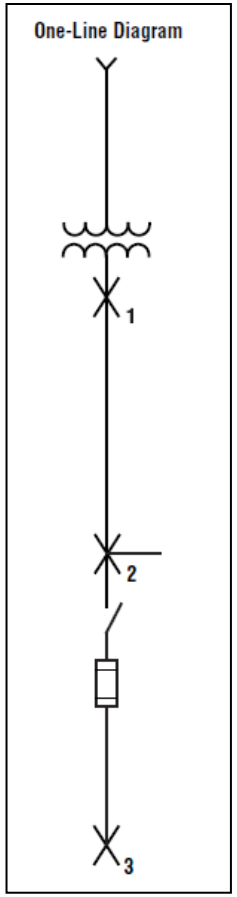
Voltage Rise Calculation (Cont.)



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 or 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

by:John Sakalik Ver. 2014
jmp1jds@comcast.net

Utility Fault Current 14,318 amperes

kVA =
E = 240
trans. FLA = 0

I = kVA x 1000 = trans. FLA
E

Isca = trans. FLA x 100 x PF / transformer Z =

PF = 100%
Z =

Isca = ampere short-circuit current RMS symmetrical.
Isca = 0 amperes

Single Phase 240/120

Point to Point Method

Length (distance) FEET — L = 50 — Copper in Metal Raceway
(ASC) — Isca = 14,318

'f ' factor = 2 x L x I / N x C x E L-N

conductors per phase — N = 1
Phase conductor constant — C = 1,559 — **Phase Conductor** 8
Volt Line to Line — E L-L = **240** Volt
f = 3.827

Neutral conductor constant — C = 1,559 — **Neutral Conductor** 8
Multiplier — Volt Line to Neutral — E L-N = **120** Volt
f = 11.482

M = 1 / 1 + f

Line to Line — M = 0.207
Line to Neutral — M = 0.080

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

by:John Sakalik Ver. 2014
jmp1jds@comcast.net

Utility Fault Current 25,773 amperes

kVA =
E = 480
trans. FLA = 0

I = kVA x 1000 = trans. FLA
E x 1.732

Isca = trans. FLA x 100 x PF / transformer Z =

PF = 100%
Z =

Isca = ampere short-circuit current RMS symmetrical.

Isca = 0 amperes

Point to Point Method

Three Phase 480/277

Length (distance) FEET — L = 100 — Copper in Metal Raceway

'f ' factor = 1.732 x L x I / N x C x E L-N

(ASC) Isca = 25,773

conductors per phase N = 1

Phase conductor constant C = 3,806 **Phase Conductor** 4

Volt Line to Line E L - L = **480** Volt

f = 2.443

Neutral conductor constant C = 3,806 **Neutral Conductor** 4

Multiplier Volt Line to Neutral E L - N = **277** Volt

f = 6.351

M = 1 / 1 + f

Line to Line M = 0.290

Line to Neutral M = 0.136

Fault Current at Service Equipment

Isca x M = fault current at terminals of main disconnect L- L = → **7,485 amperes**

Isca x M = fault current at terminals of main disconnect L- N = → **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

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 retro-fit solution or SolarEdge whole system solution).

Rapid-shutdown initiator. If loss of ac power does not automatically initiate rapid shutdown, system integrators need to install a manual rapid-shutdown initiation switch—such as Bentek's Rapid Shutdown Controller (left) or MidNite Solar's Bird house (right)—to turn off the array and any battery-backup circuits.

- 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).

NEC Code References

- **Six Handle Rule: NEC 230.71(A)**
  - In the event of 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). Battery systems would not be exempt considering battery charging constitutes a load.
  - ***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 and panel schedules to APS and consider PV into the calculations**.
- **Main Breaker De-Rate: NEC 230.79**
  - If customer is in violation of the 120% Rule [NEC 2017_705.12(B)(2)(3)(b)], 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.
- **Non-isolated (Transformerless) Inverters: NEC 690.47**
  - 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.

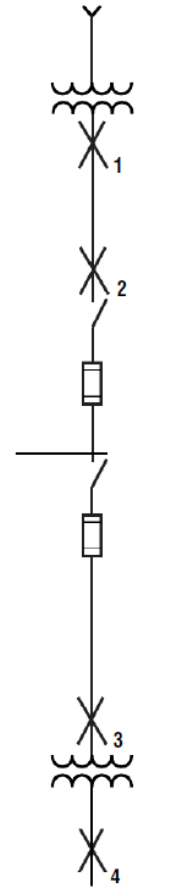
Step Up Xfmr Fault Current Calculations

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: $f_{3\Phi} = \frac{\sqrt{3} \times L \times I_{3\Phi}}{C \times n \times ELL}$; $M = \frac{1}{1+f}$; $I_{sc\ RMS} = I_{SC} \times M$;

C = conductor constant ; n = number of conductors per phase; I = available short circuit current (in amps); E = voltage;
L = length of conductor

One-Line Diagram



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%

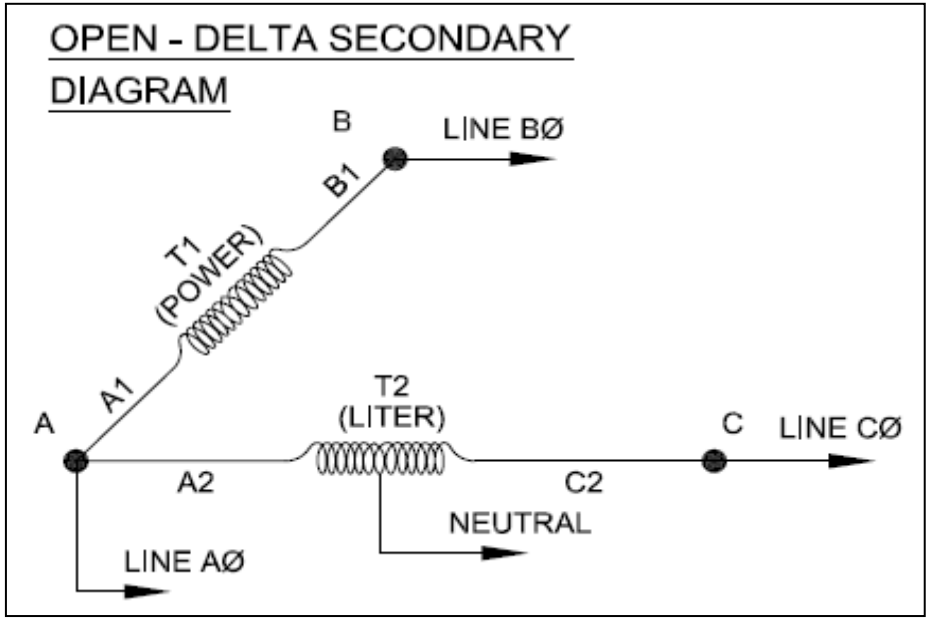
$$f = \frac{I_{sc} \times V_{LLstart} \times \sqrt{3} \times \%Z}{100{,}000 \times kVAxfmr} = \frac{9130.61\ A \times 208\ V \times 1.732 \times (4.5)}{100{,}000 \times 75} = 1.974;\ M = \frac{1}{1+f} = \frac{1}{1+1.974} = 0.3363$$

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

NOTE: Do not 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)

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.**

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”

NEC: National Electrical Code, Section 706 “Energy Storage Systems”

“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 – 2017 Application Guide

APS Requirements:

1. APS “Interconnection Requirements for Distributed Generation” https://www.aps.com/dg
2. APS “Electric Service Requirements Manual” (ESRM) https://www.aps.com/en/About/Construction-and-Power-Line-Siting/Construction-Services