Plug-In Photovoltaic (PIPV) Systems

Residential safety concerns

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- UL Solutions Principal Engineer, Corporate Fellow - PV Modules & Components
- 7 years at UL solutions - standards development, safety research, regulatory engagement, and industry collaboration
- 30 years PV experience – module and mounting system manufacturing, reliability testing, site inspections, failure forensics
- NFPA National Electrical Code Making Panel 4 (PV, interconnections, energy storage)
- Co-convenor of IEC Technical Committee 82 Working Group 2 (PV module standards)
- Co-convener of IEC Committee of Testing Laboratories Expert Task Force 9 (PV module testing)

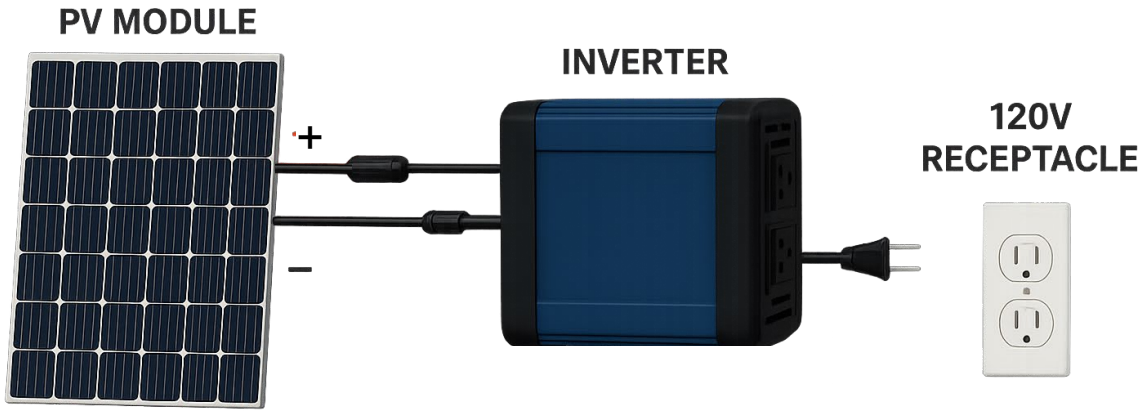
Agenda

- Key differences between traditional PV and plug-in PV (PIPV)
- Evolving state regulations
- Introduction to residential electrical wiring
- PIPV hazards and mitigation strategies
- UL Solutions PIPV white paper
- General safety requirements defined in UL 3700, the Outline of Investigation for Interactive Plug-In PV (PIPV) Equipment and Systems
- Q&A

Key differences between traditional PV and PIPV

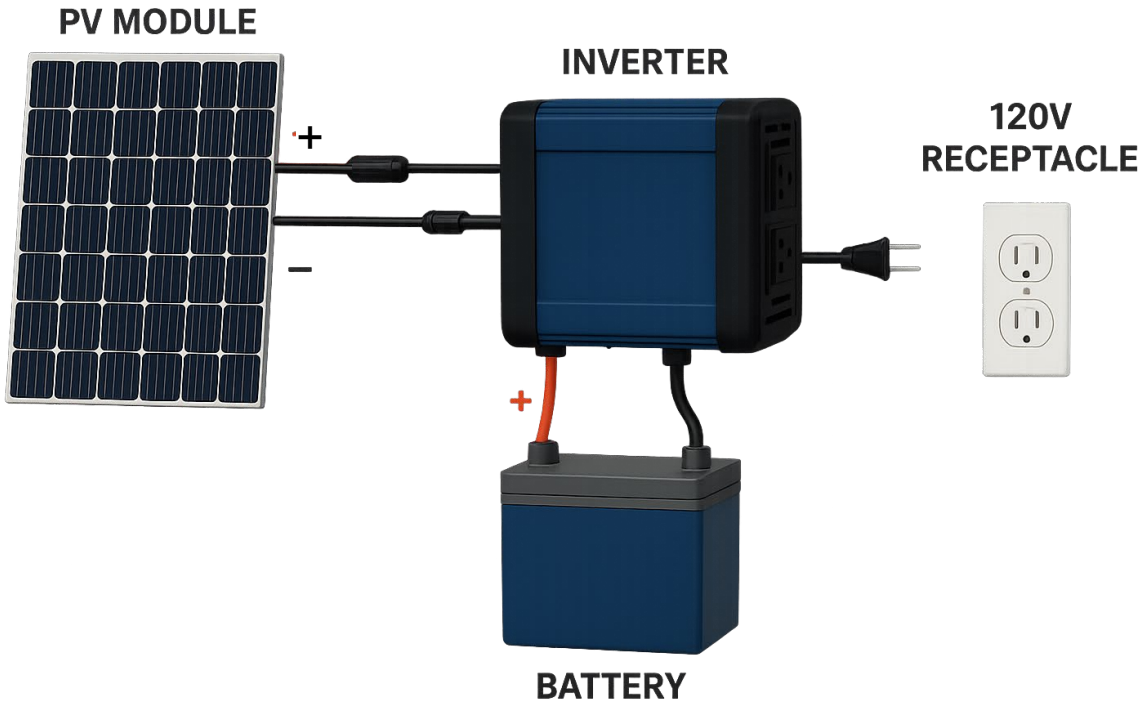
- Installation Method: Traditional PV systems require professional installation and compliance with electrical codes. PIPV systems are designed for consumer installation.
- Electrical Integration: PIPV units backfeed power into existing branch circuits via standard receptacles, creating scenarios not addressed by current codes.
- Safety Oversight: Traditional PV systems undergo rigorous inspection; PIPV systems often do not.

Plug-in PV (PIPV)



- Power-exporting devices
- Connect to premises branch wiring via standard plug and receptacle
- Installed by consumers, often without an interconnection agreement or AHJ oversight.

Plug-in PV (PIPV)



Marketing claims

- No permit required
- Plugs into standard outlets
- Utility approved

★★★★½

$999

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“Some areas don't require permits since the system only powers your home ad doesn't feed excess back to the grid”

“Does not require professional installation”

“You may want to use a dedicated electrical circuit for the outlet”

“as easy as assembling furniture”

“Simply plug into the wall”

“No mounting required”

“Secure to a wall, balcony, or fence with zip ties or anything durable that will keep the panel secured”

“You may use your own mounting from local hardware store”

“All the components are UL, Local, State & Utility approved”

U.S. state regulations

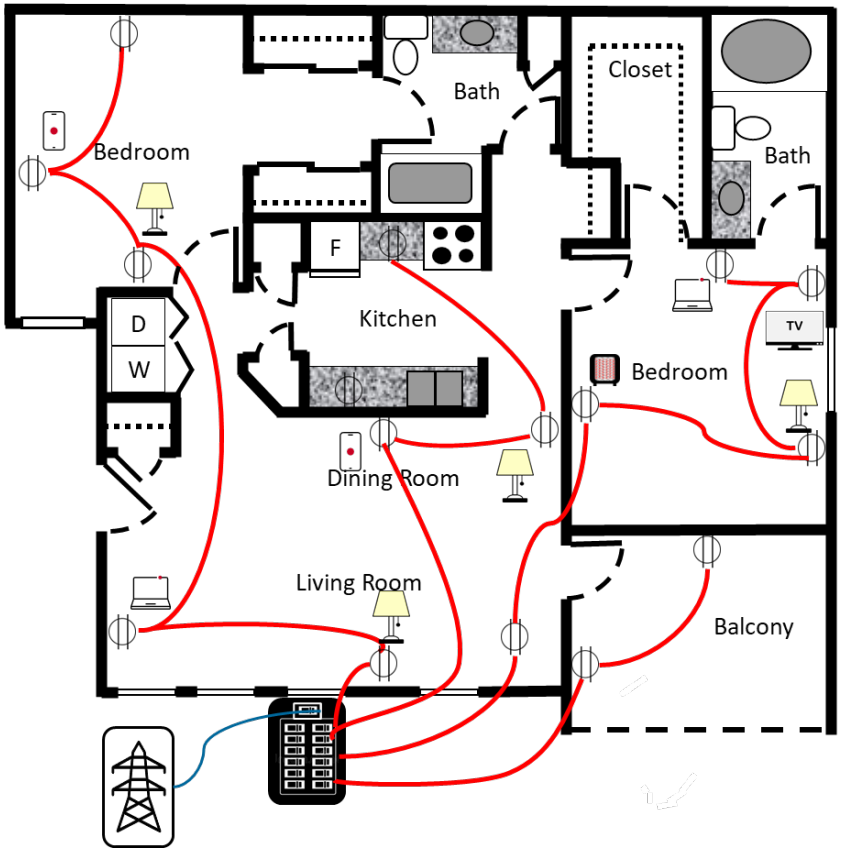
- Utah
  - Passed a law that PIPV could be used and that the utility did not need to be informed (March,, 2025).
  - Product must comply with the NEC and the applicable UL Standards
  - Driver for creation of new PIPV requirements in UL 3700
- Maine, Maryland, Virginia, New York, and Vermont passed similar laws
- 8 States with similar bills advancing

California	Hawaii	New Hampshire
Colorado	Illinois	New Jersey
Connecticut	Massachusetts	

- 16 States with similar bills under discussion

Illinois	Oregon	South Carolina	Michigan
Pennsylvania	Arizona	Iowa	Rhode Island
Hawaii	New Mexico	Alaska	Delaware
Washington	Indiana	Idaho	North Carolina
Michigan	Rhode Island	Delaware	Minnesota

Residential wiring and branch circuits (no PIPV)



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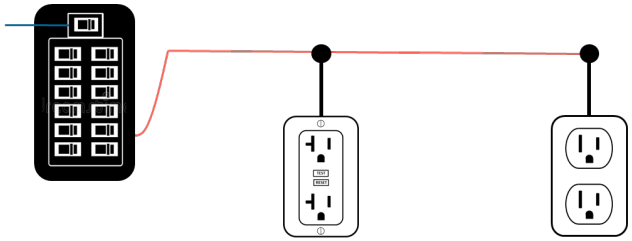

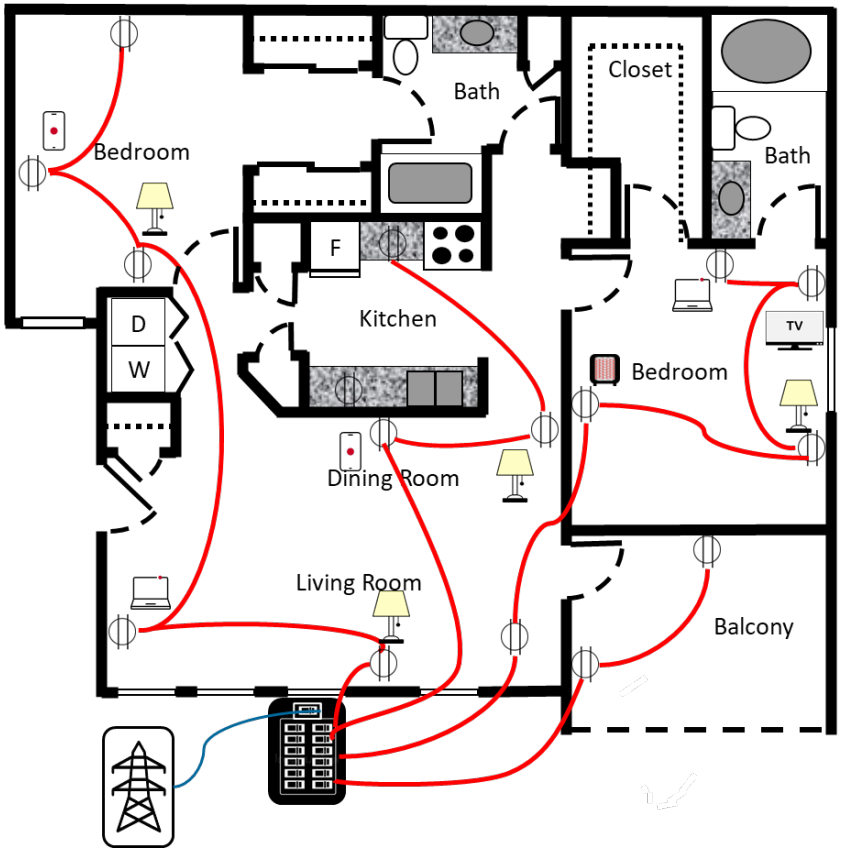

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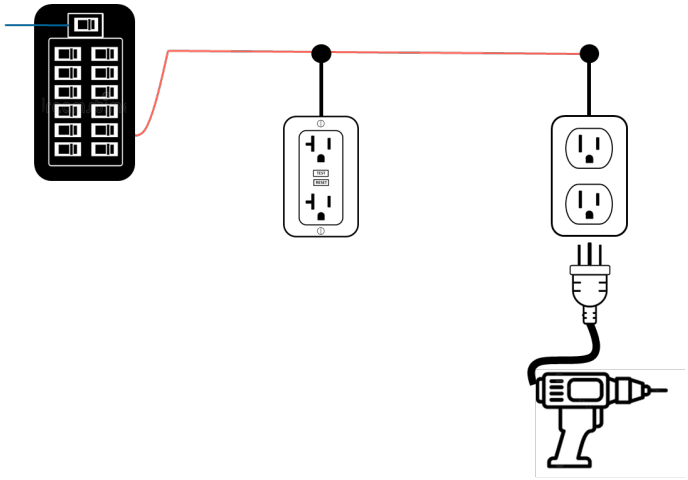
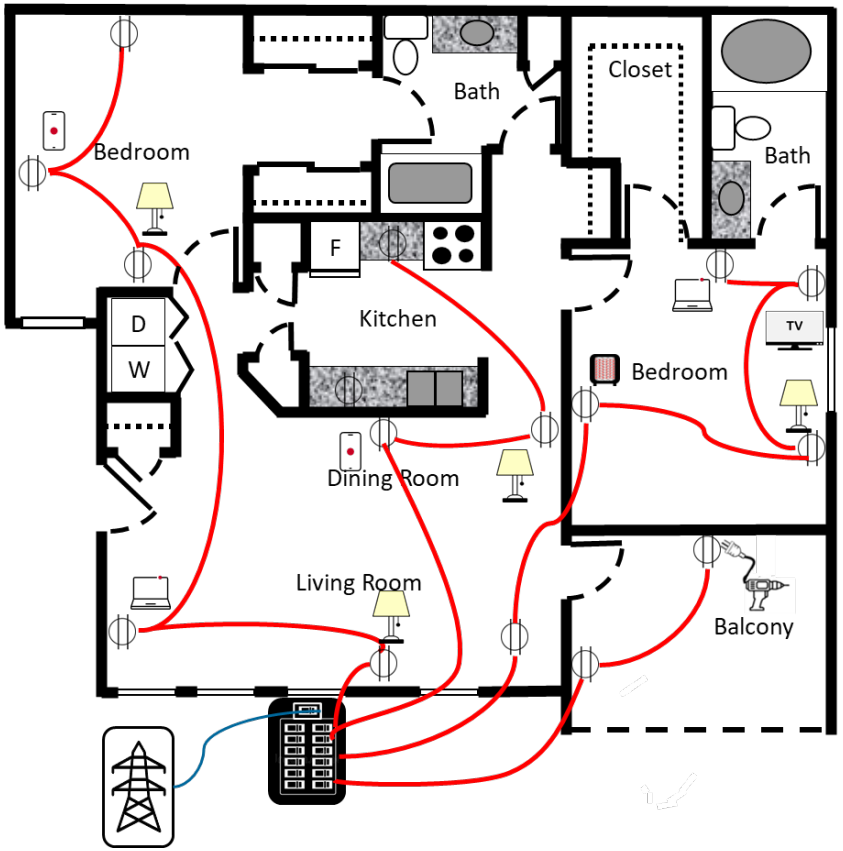
Residential wiring and branch circuits (no PIPV)





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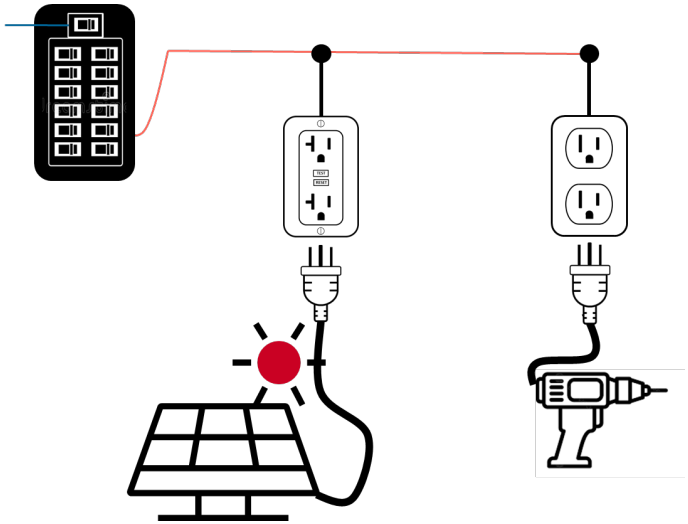
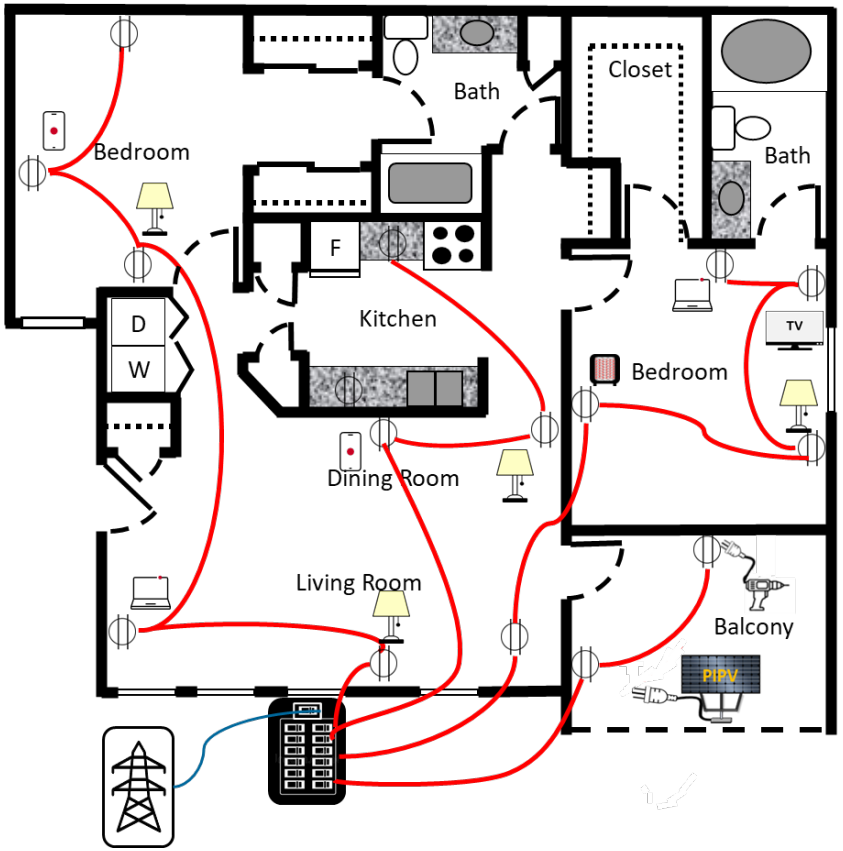
Residential wiring and branch circuits (with PIPV)





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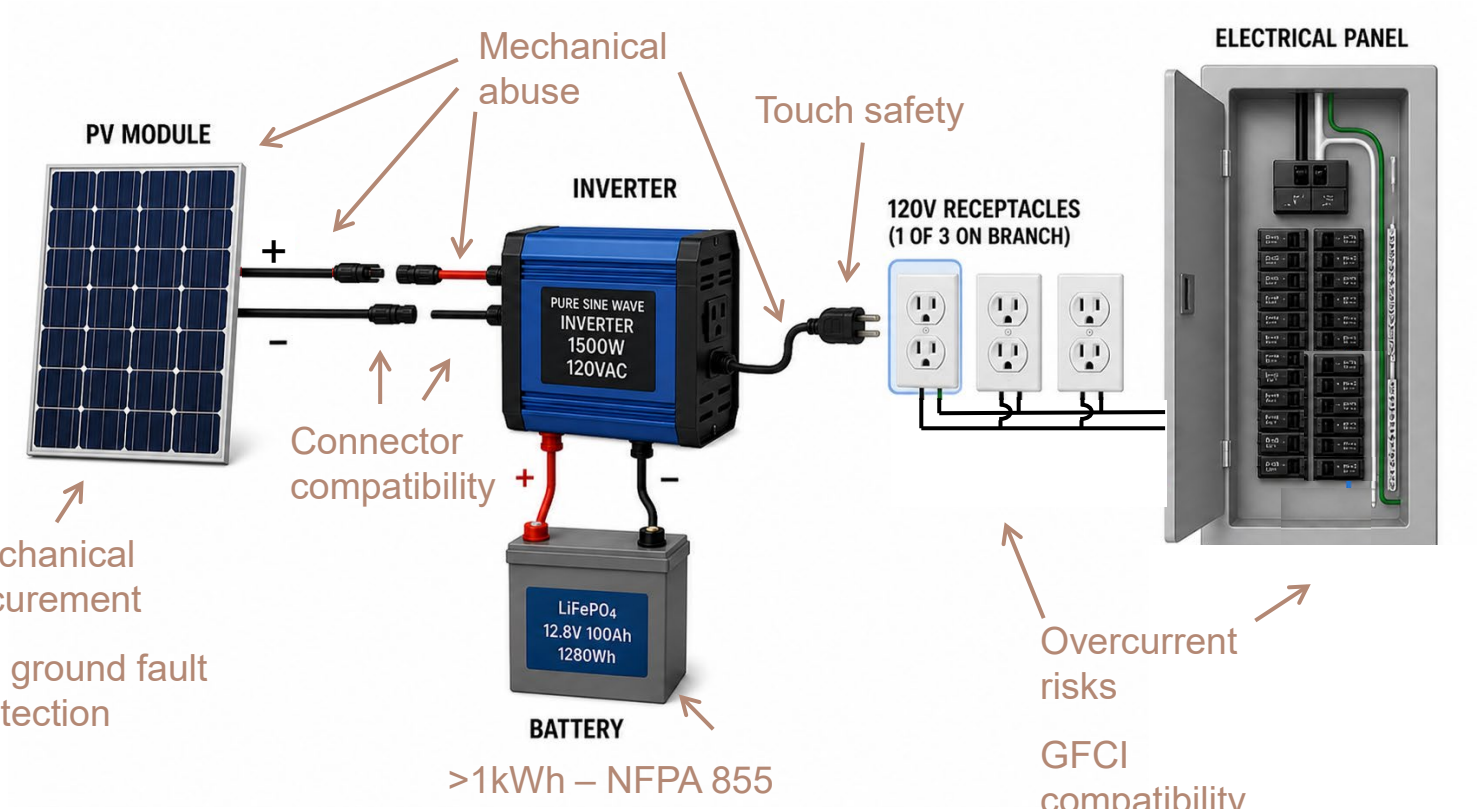
UL Solutions' Whitepaper

3 key risks:

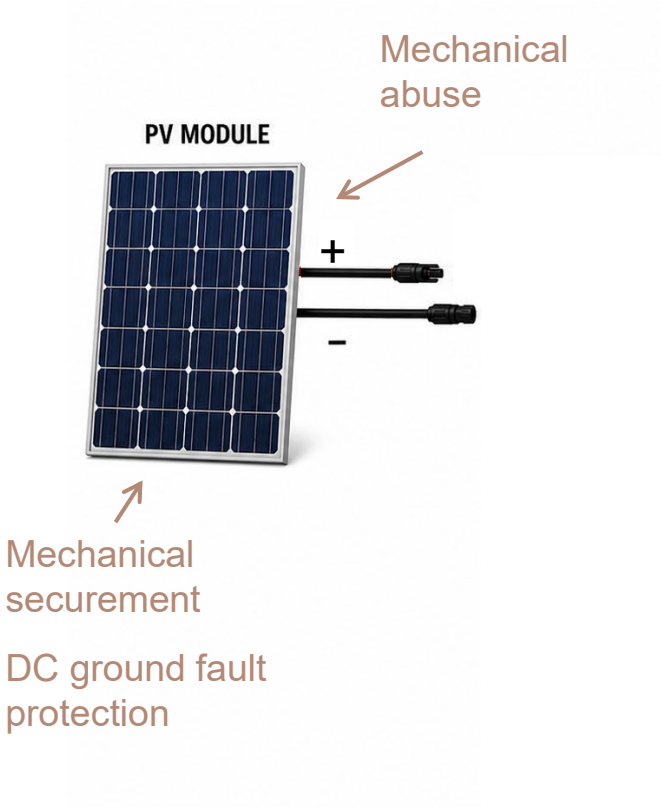
- Touch safety of exposed plug blades
- Ampacity of branch circuit conductors and components
- GFCI compatibility

Access the white paper here

UL 3700 – Safety Requirements for PIPV

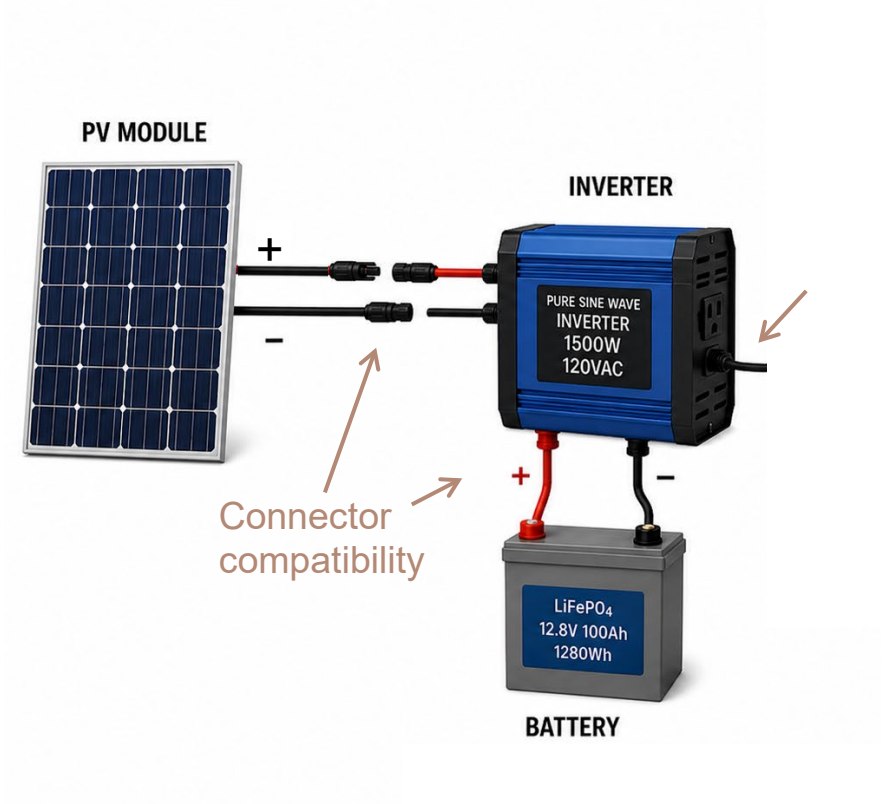


UL 3700: Requirements for PV modules & DC wiring



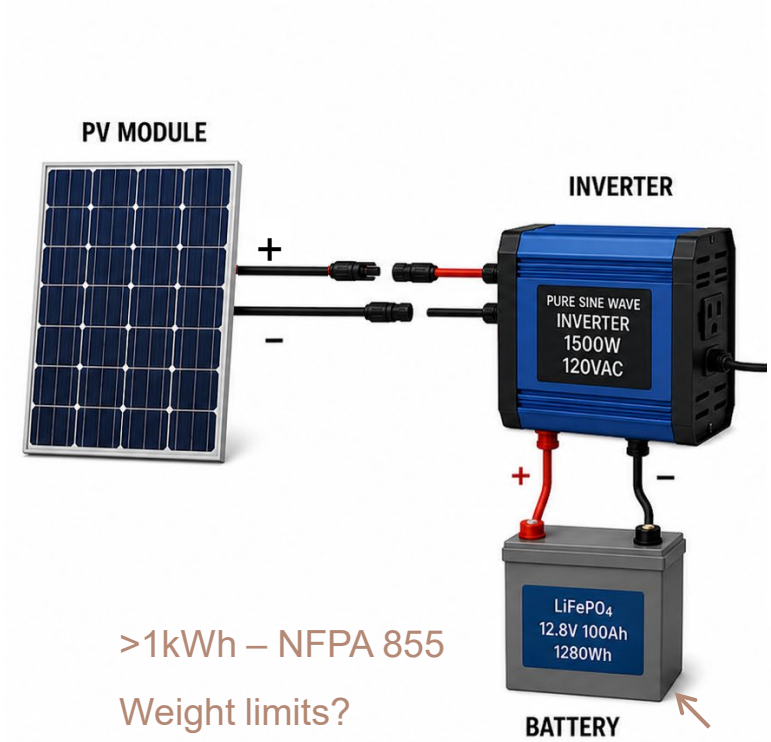
- All UL 61730-1 & 2 requirements
- Additional mechanical abuse tests – consumer use in uncontrolled environment
- 80 V_{DC} maximum
- Enclosed DC wiring >6”
- Detailed manufacturer instructions for securement

UL 3700: Requirements for Connectors



- UL 6703 / 62852
- Connectors intended for mating must be from same manufacturer
- Connectors not intended for mating must not be physically mateable
- No field assembly – connectors must be fully assembled in factory

UL 3700: Requirements for batteries



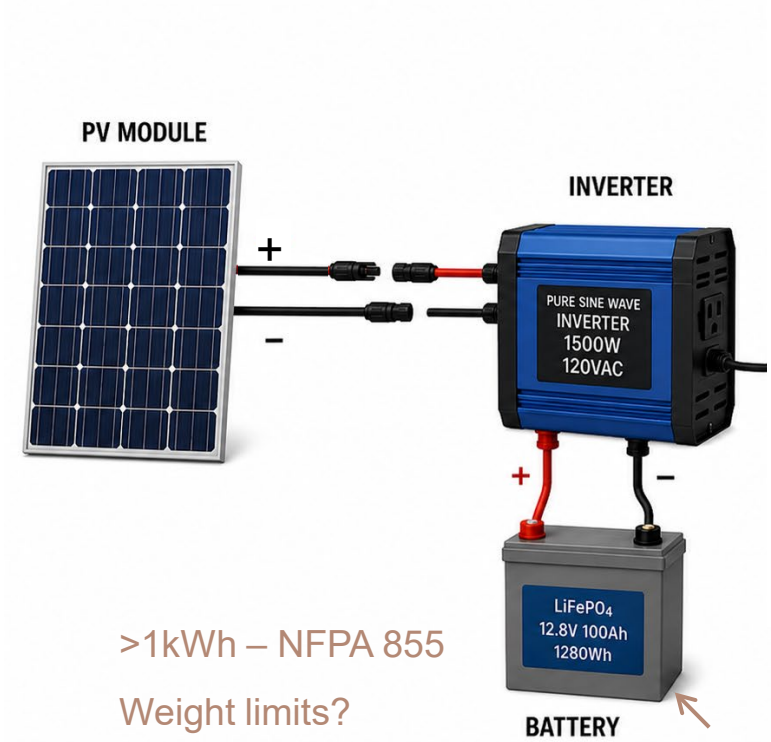
>1kWh – NFPA 855

Weight limits?

Portable vs. stationary

- Maximum capacity 1 kWh
- UL 1973 – stationary

UL 3700: Requirements for batteries



>1kWh – NFPA 855

Weight limits?

Portable vs. stationary

- Maximum capacity 1 kWh
- UL 1973 – stationary
- > 1kWh?
  - NFPA 855 spacing requirements
  - Distance from doors, windows (outdoors)
  - Mechanical securement
  - Installation by qualified person
  - Indoors – restrictions on habitable space
  - UL 9540 / 9540B

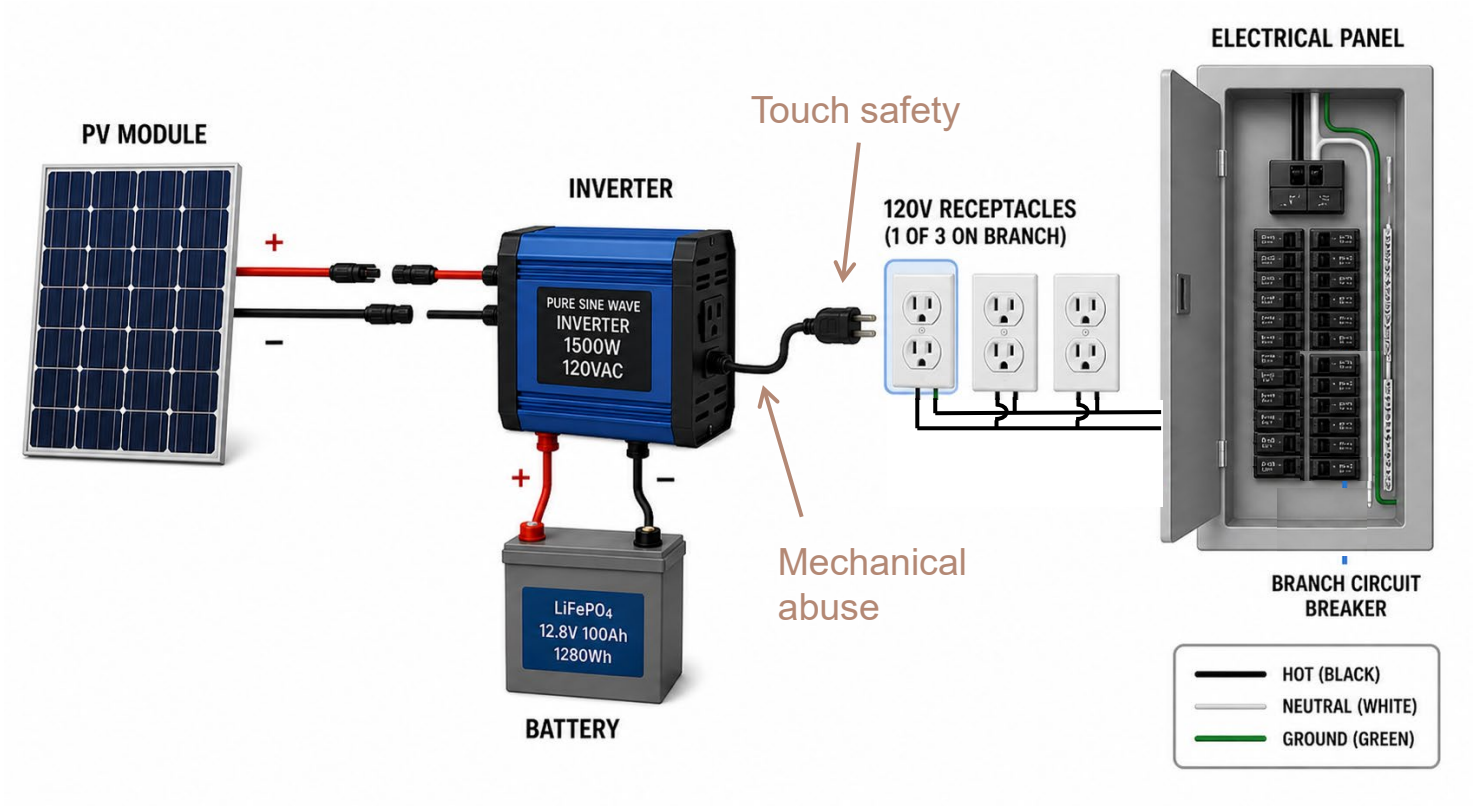
UL 3700: Requirements for batteries

- Maximum capacity 1 kWh
- UL 1973 – stationary
- > 1kWh?
  - NFPA 855 spacing requirements
  - Distance from doors, windows
  - Mechanical securement
  - UL 9540 / 9540B
  - Installation by qualified person
- Additional challenges with large portable battery packs

Large portable power packs in the market

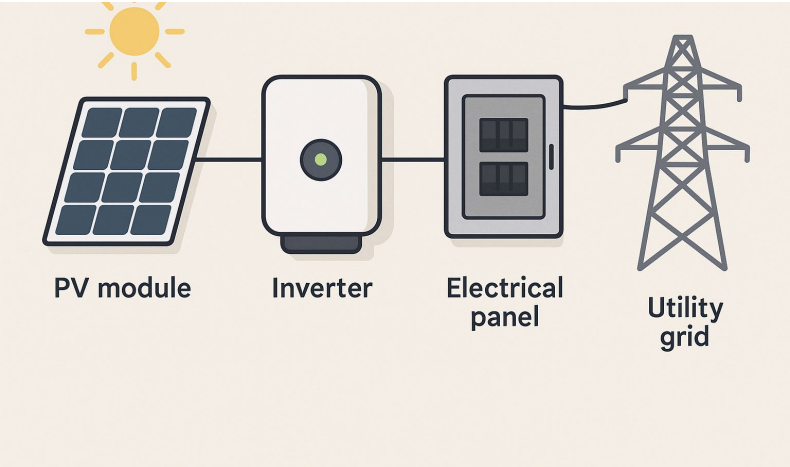
- Exceed weight capacity for UL 2743
- UL 9540, 9540A currently does not have requirements for portable power packs
- Code enforcement for indoor use is unclear (NEC, IRC, IFC, NFPA 855)

UL 3700: Requirements for inverter, PIPV cord & plug



Touch safety hazards
Traditional PV systems

- PV systems produce voltage and current levels that require protection against the risk of shock
- Traditional PV systems address this risk through the use of electrical enclosures to prevent user contact
- Grid interactive inverters are not designed or tested to protect people from shock hazard of accessible circuits



Touch safety hazards

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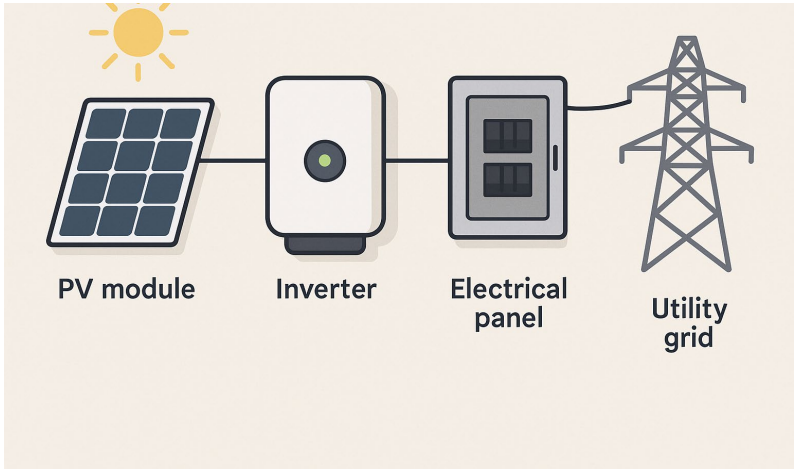
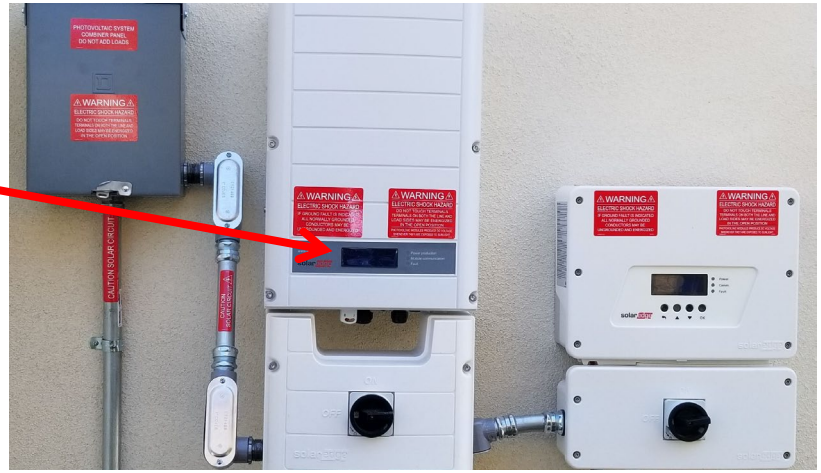
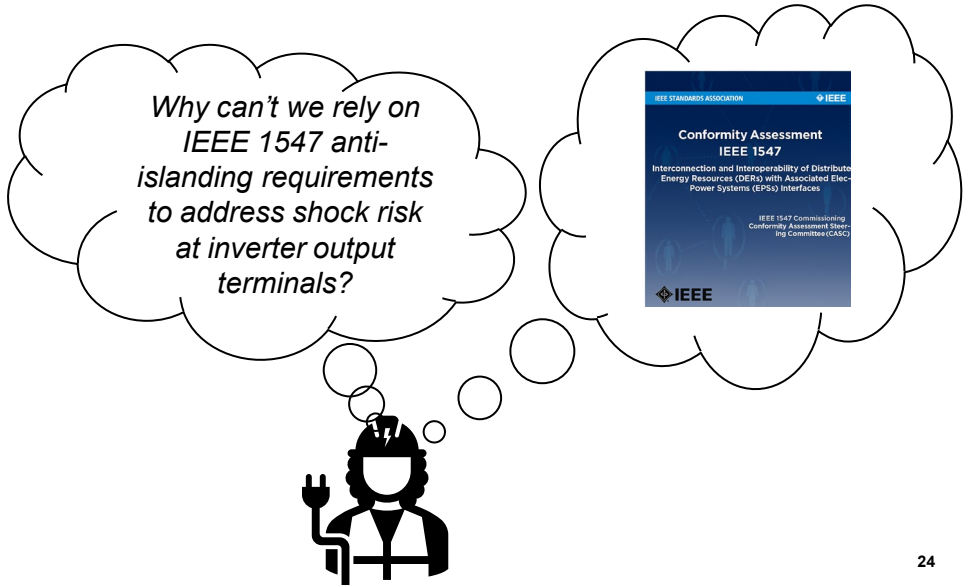


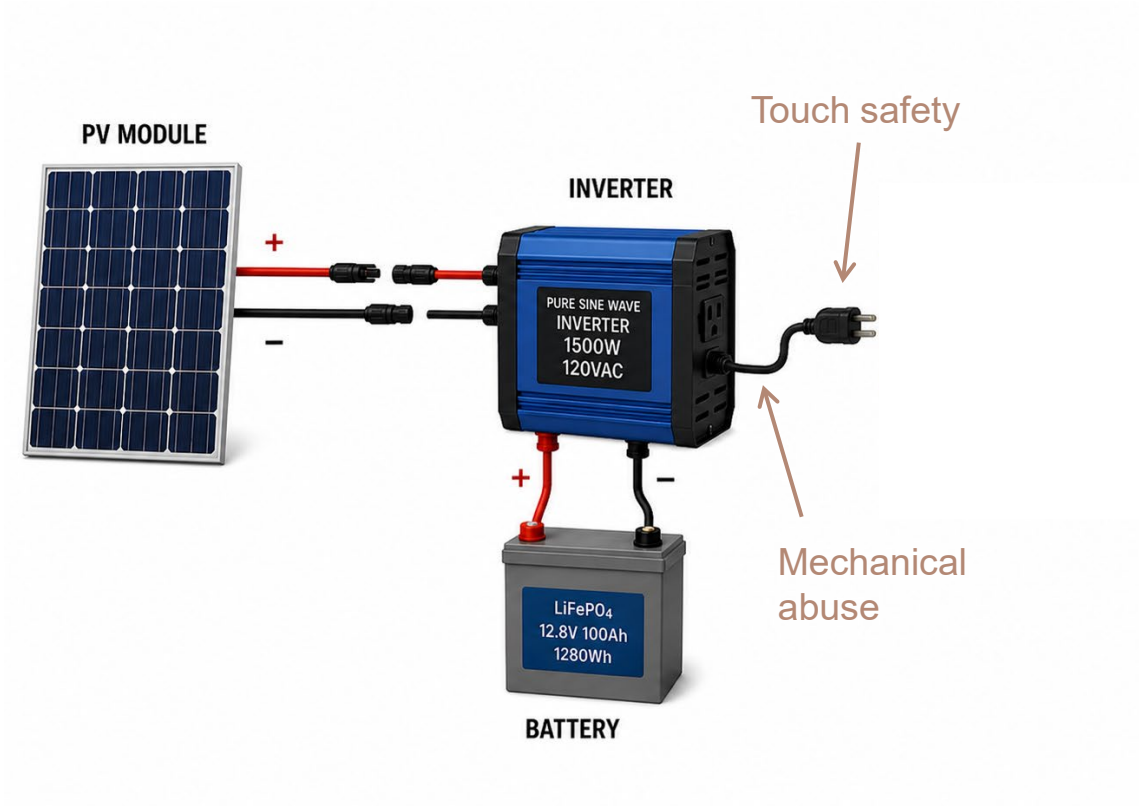


Touch safety hazards
Plug-in PV systems

- Scenario: PIPV backfeeds branch circuit through a wall socket; plug is pulled out of socket.
- IEEE 1547 anti-islanding requirements: cease current generation within 2 seconds
- Exposed plug blades can remain energized
- 2 seconds = 2000 ms = 120 cycles
  - Too long for touch safety
  - Must be faster and incorporate additional safety functions (UL 3700 Annex A), or
  - No exposed blades
- ***Scope of IEEE 1547: grid compatibility – not safety***



UL 3700: Requirements for inverter, PIPV cord & plug



Mechanical damage to PIPV cord
- EV cable UL 2263

Introduction to Ground-Fault Circuit Interrupters (GFCI)

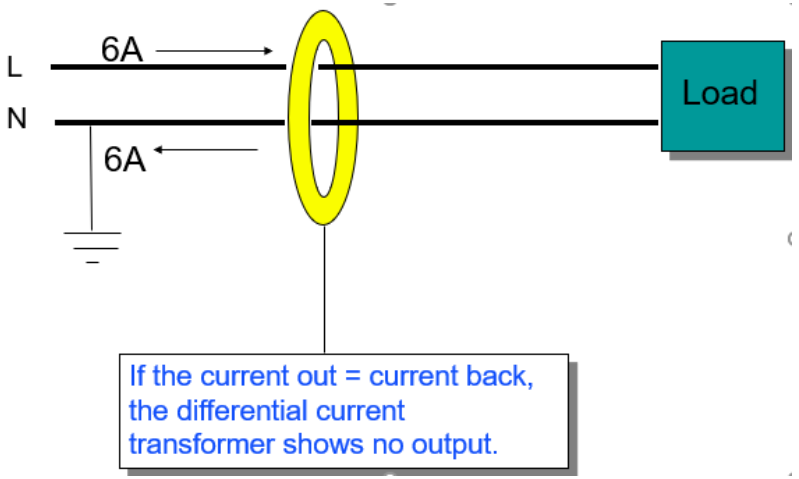
- GFCIs have been required by NEC – Article 210.8 since the seventies for use in environments where the presence of water increases the risk of electric shock. e.g. outdoors, bathrooms, kitchens...
- GFCIs have been credited with reducing residential electrocutions by 81% [1] and workplace electrocutions by 50% [2]
- In practice, this protection is typically provided through one of two common installation methods:
  - **Circuit breaker incorporating GFCI protection**
  - **Receptacle type incorporating GFCI protection**

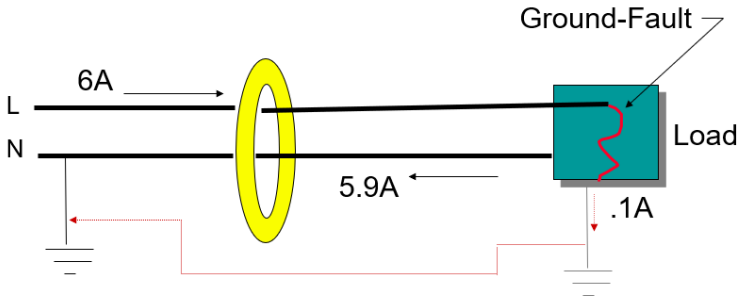
1. Ground Fault Circuit Interrupters: Preventing Electrocution Since 1973 - Electrical Safety Foundation International

2. Worker Deaths by Electrocution: A Summary of NIOSH Surveillance and Investigative Findings

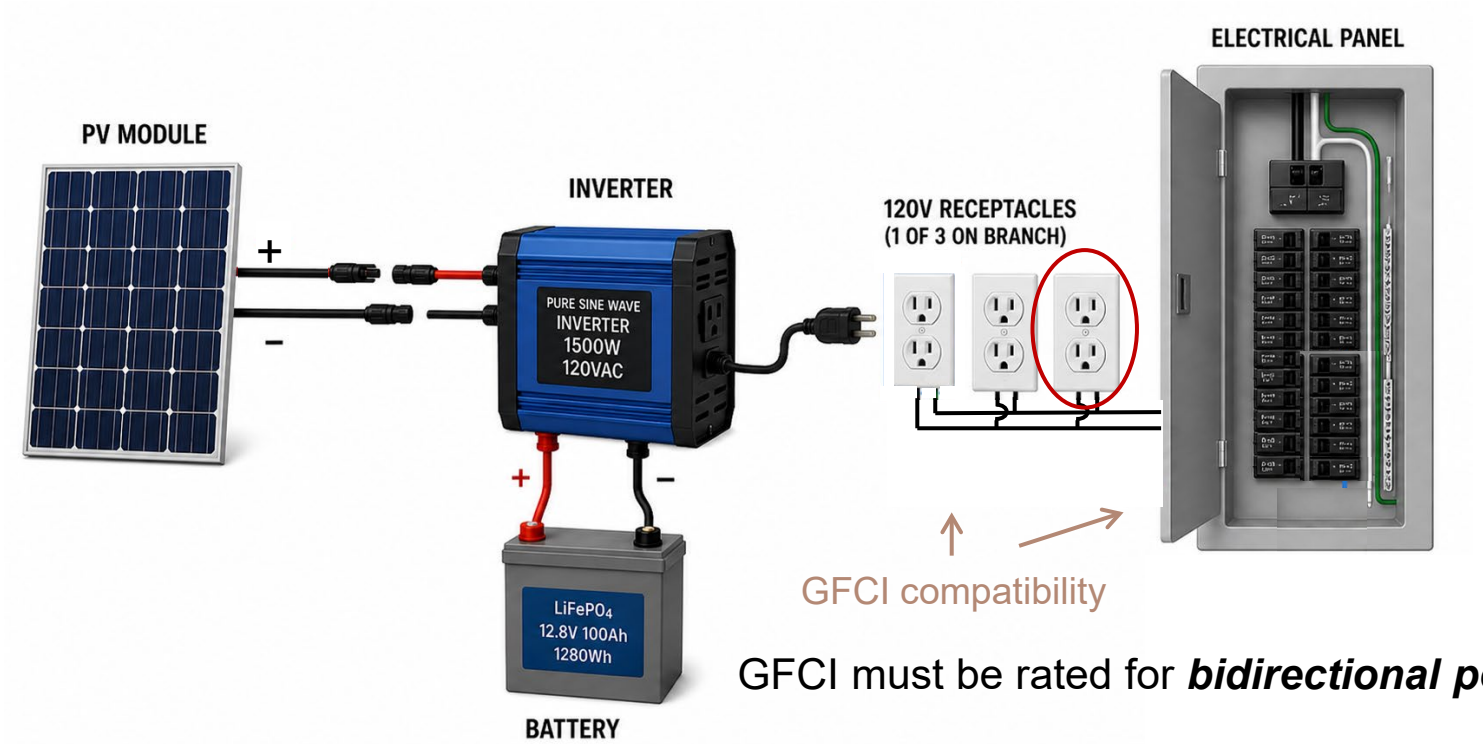
Introduction to GFCIs

- GFCIs are “adding machines”
- Current should flow only through the line conductor (hot) and the grounded neutral conductor.
- The current in the hot conductor should always equal the current in the neutral conductor feeding back from the load.
- A GFCI monitors these two conductors using a toroidal differential current transformer that surrounds both wires.
- If outgoing and returning currents match, the differential current is zero and the transformer output remains zero.
- Any imbalance indicates current is leaking somewhere else (potentially through a person), triggering the GFCI to trip.





UL 3700: Requirements for GFCI Compatibility

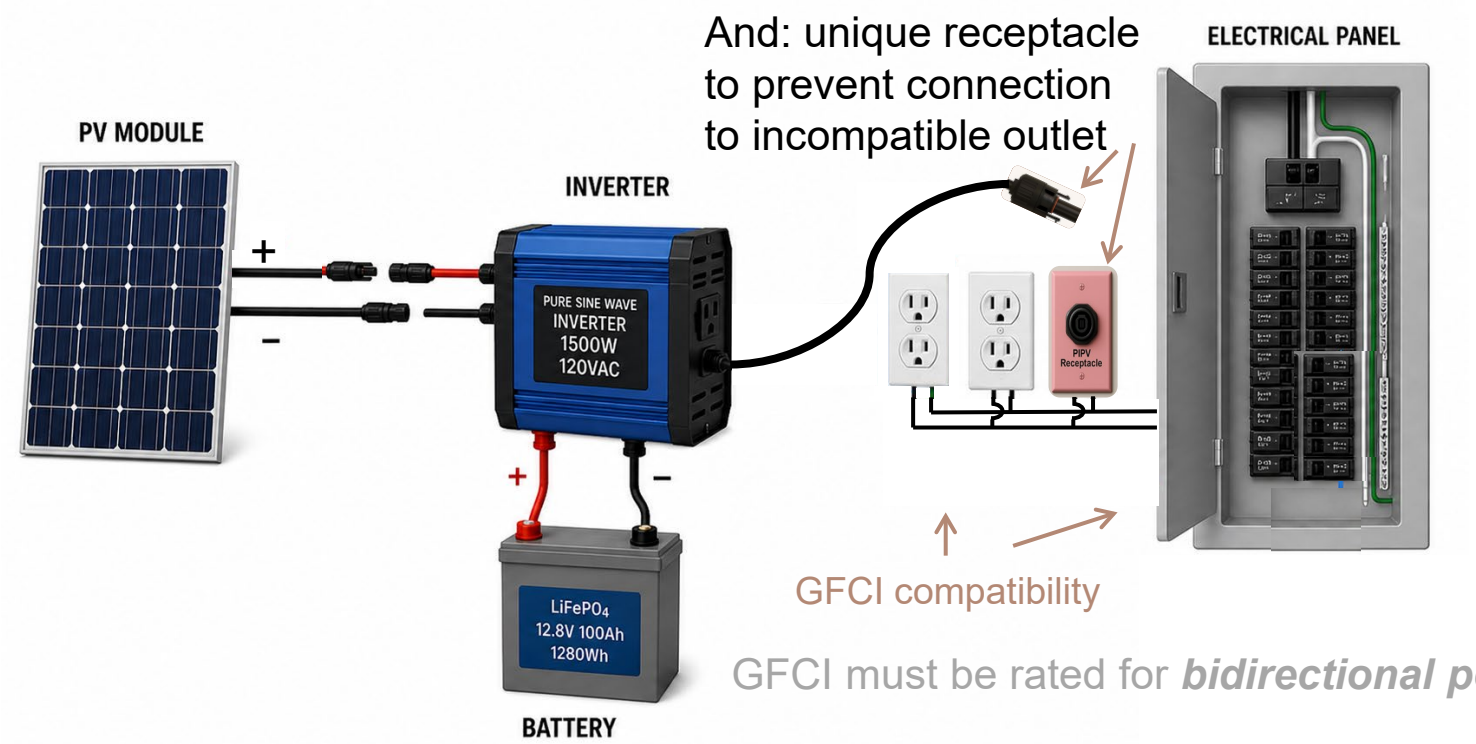


GFCI must be rated for ***bidirectional power flow:***

UL 943 CRD (GFCI receptacle) – ***<u>first in branch,</u>***
or
UL 489 CRD (GFCI circuit breaker).

UL Solutions

UL 3700: Requirements for GFCI Compatibility



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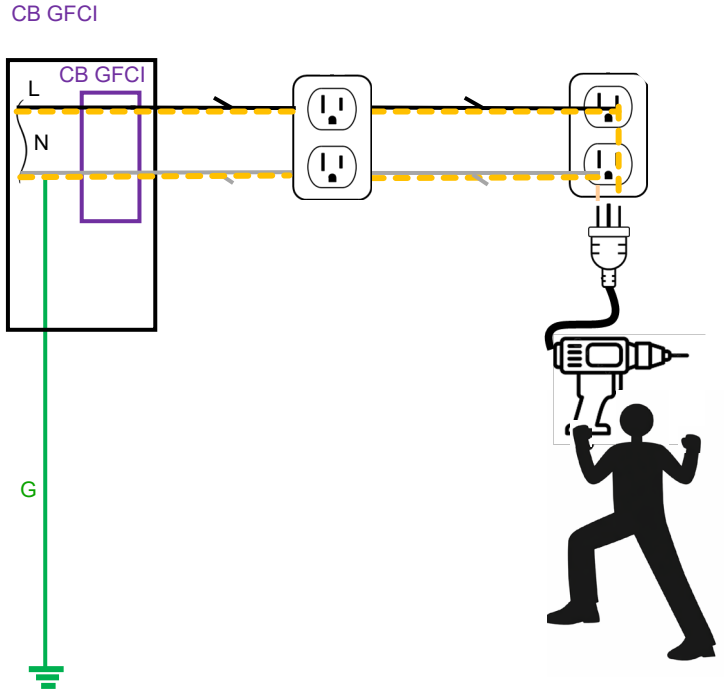
UL 3700: Requirements for GFCI Compatibility

Potential blinding of GFCI

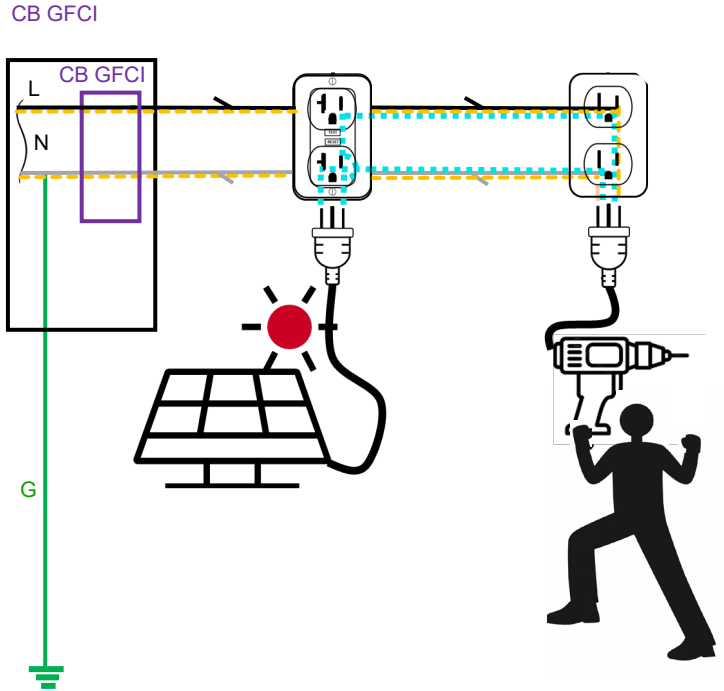
- Outdoor receptacle with legacy GFCI breaker
- A load such plugged into an outdoor outlet.



UL 3700: Requirements for GFCI Compatibility

Potential blinding of GFCI

- Outdoor receptacle with legacy GFCI breaker
- A load such plugged into an outdoor outlet.
- PIPV plugged into same branch



UL 3700: Requirements for GFCI Compatibility

Potential blinding of GFCI

- Outdoor receptacle with legacy GFCI breaker
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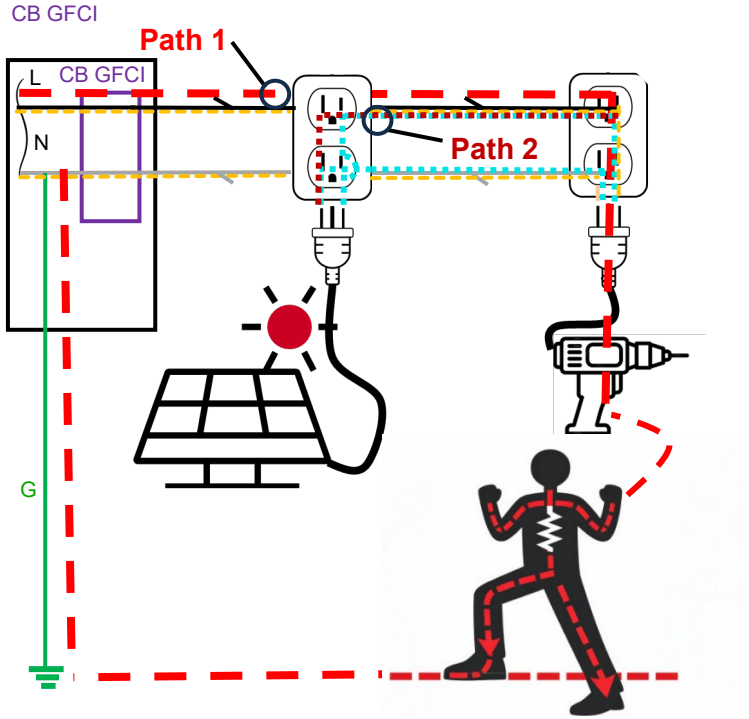
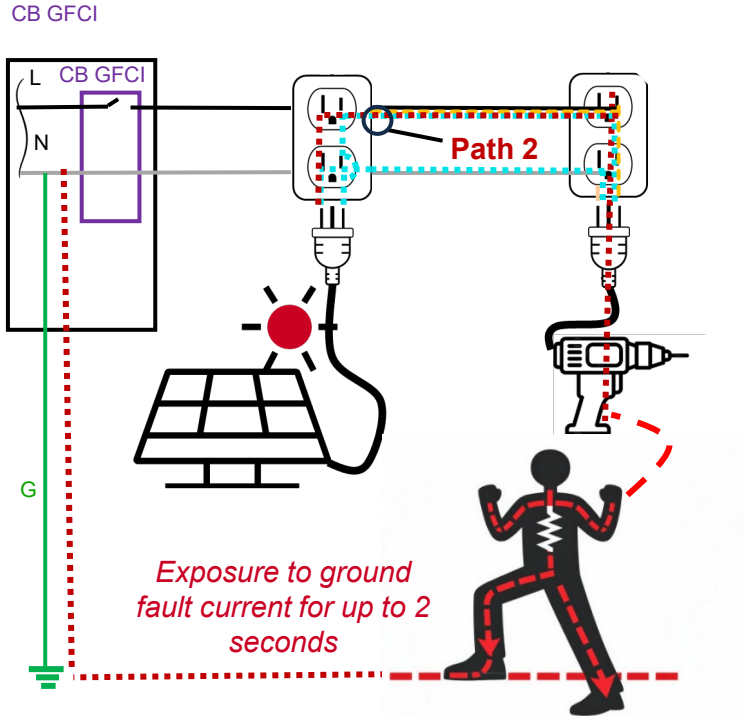
- PIPV plugged into same branch
- In a ground fault scenario, two sources feed the fault: Path 1 (from utility) and Path 2 (from PIPV).



UL 3700: Requirements for GFCI Compatibility

Potential blinding of GFCI

- Outdoor receptacle with legacy GFCI breaker
- A load such plugged into an outdoor outlet.
- PIPV plugged into same branch
- In a ground fault scenario, two sources feed the fault: Path 1 (from utility) and Path 2 (from PIPV).
- GFCI opens hot conductor, PIPV initiates anti-islanding.
- IEEE 1547 allows the PIPV up to 2 seconds (=120 cycles) to cease current
- PIPV may continue supplying Path 2 for up to 2 seconds.

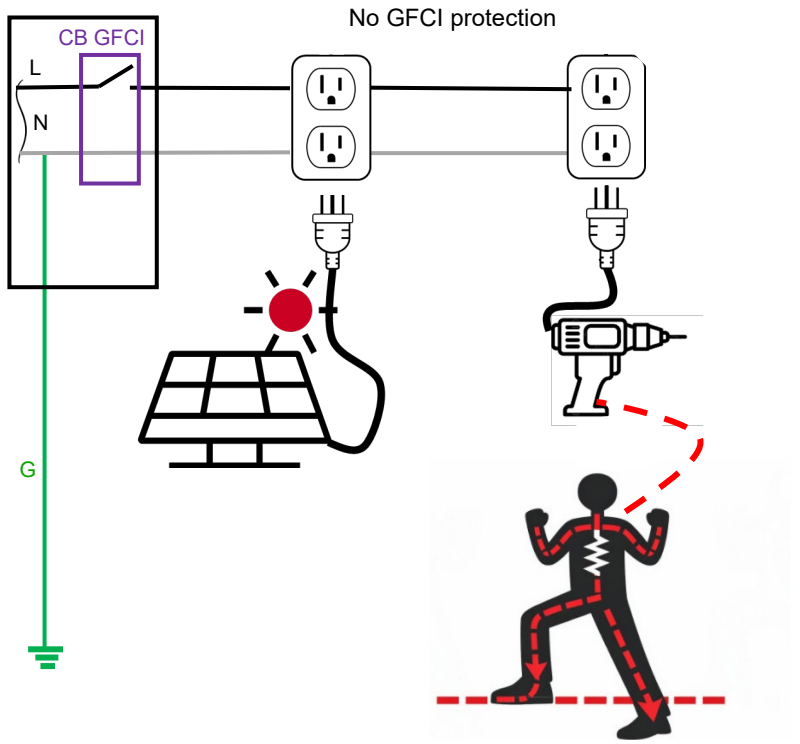


2 seconds >> 28.6 ms allowable trip time for GFCIs. Legacy GFCI circuit breakers are not suitable for PIPV.

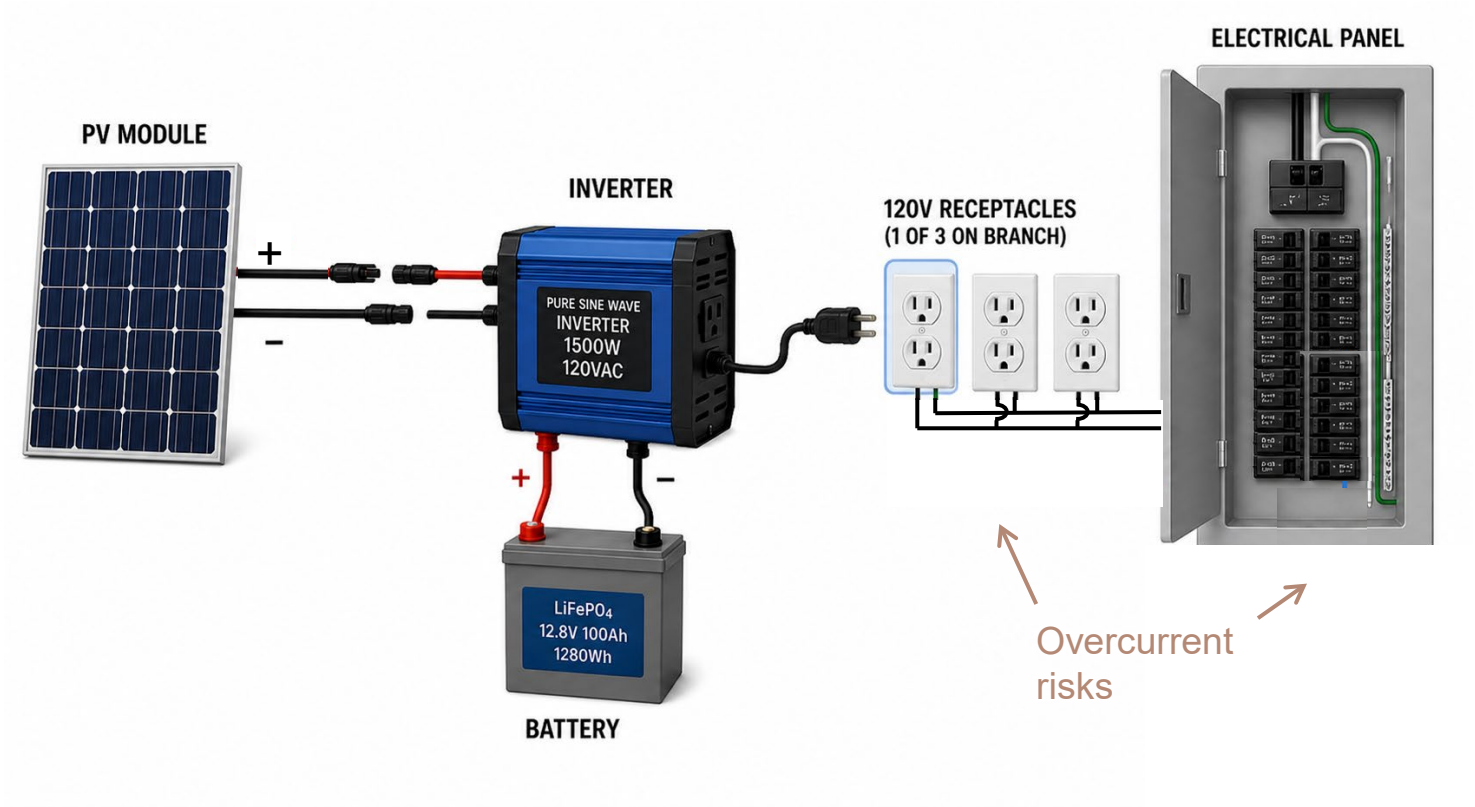
UL 3700: Requirements for GFCI Compatibility

Potential damage to GFCI when backfed

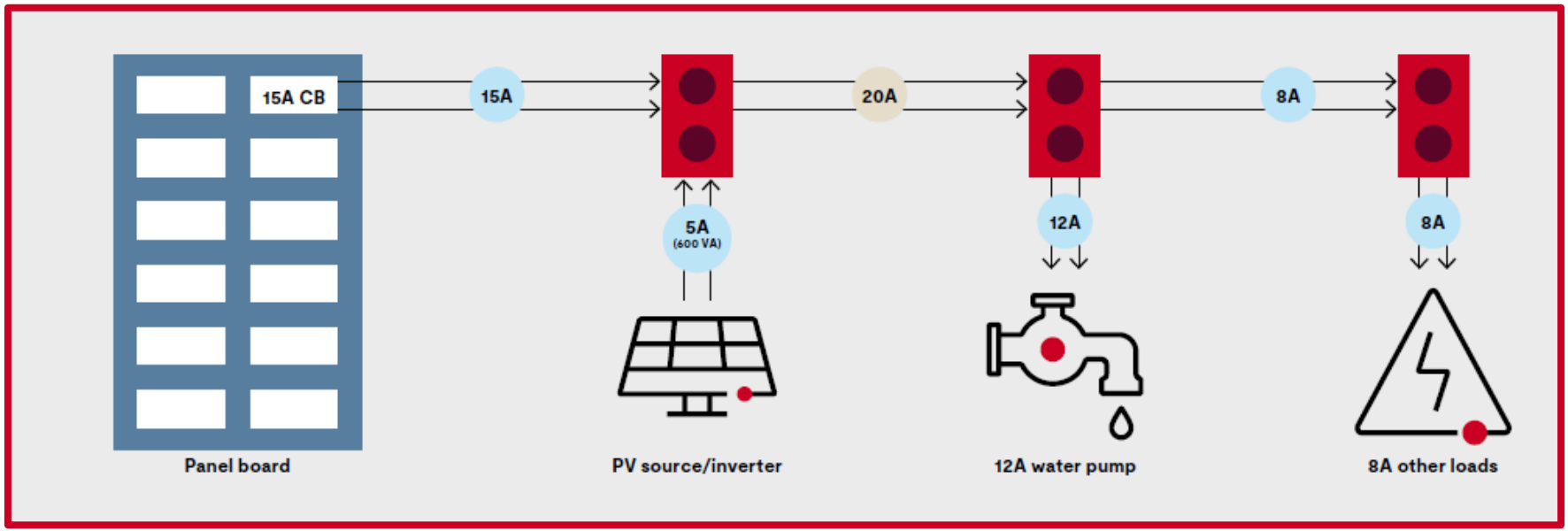
- Legacy GFCIs designed and tested only for unidirectional power flow
- Back-feeding GFCIs damage GFCI solenoid leaving the circuit unprotected.



UL 3700: Requirements for overcurrent protection



UL 3700 overcurrent hazard mitigation options



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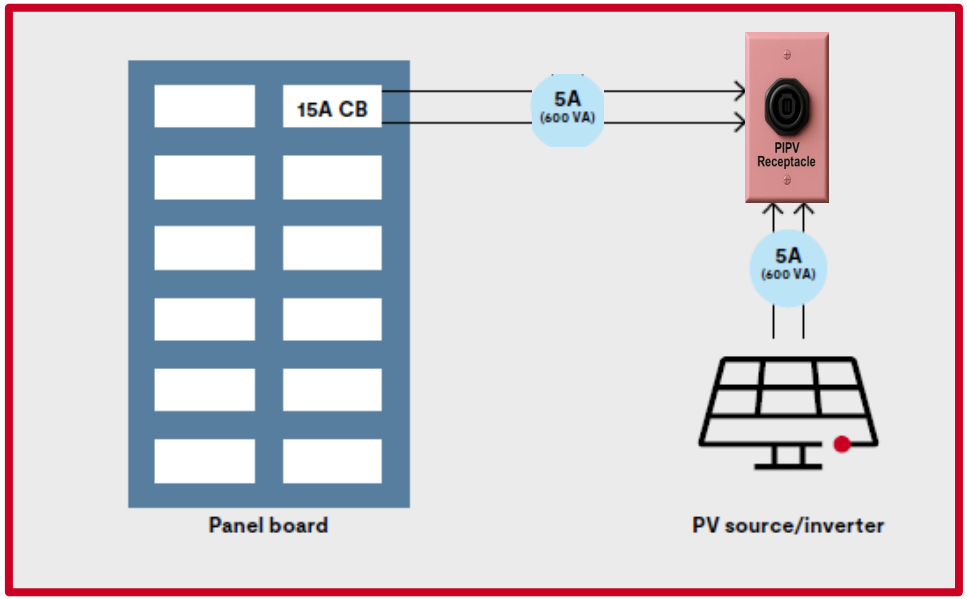
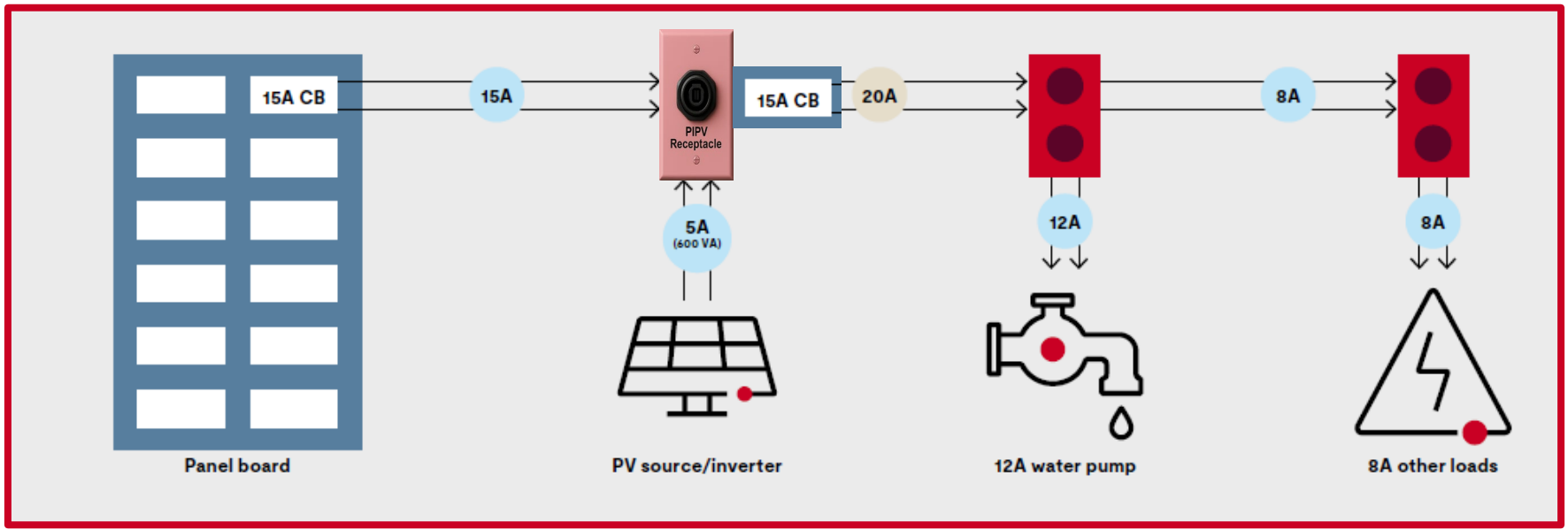


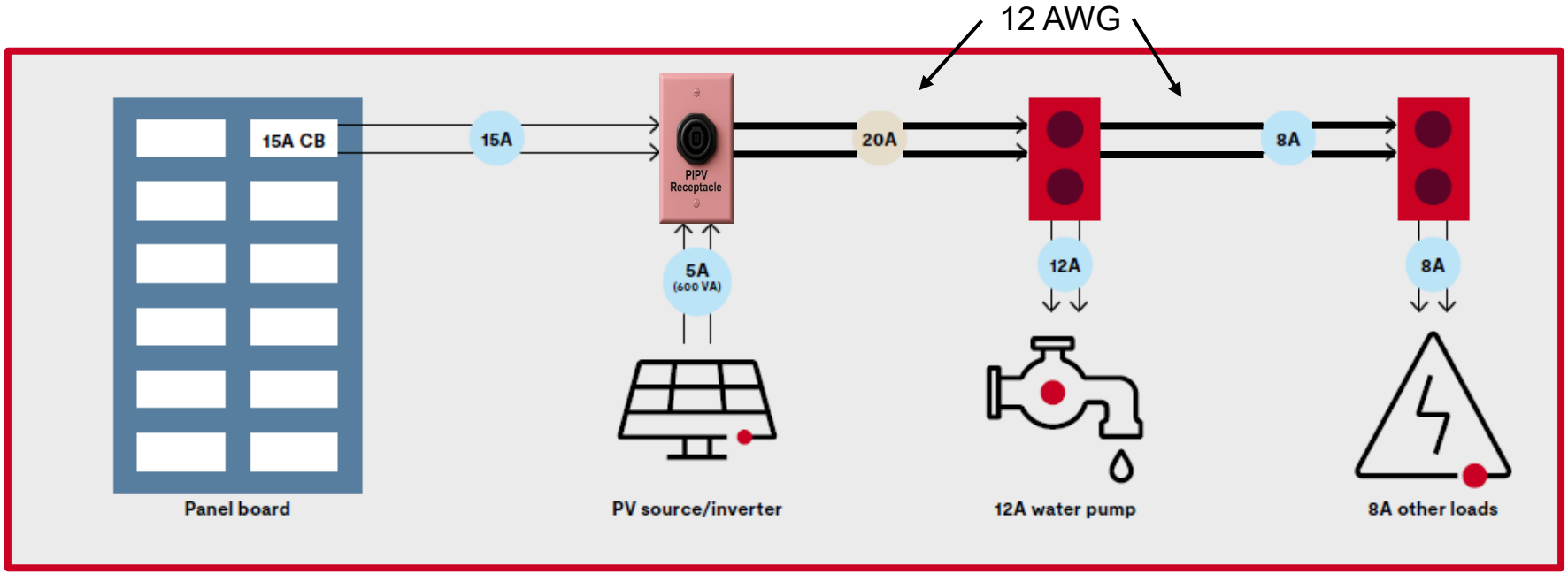
Option 1 – dedicated circuit with unique PIPV receptacle (w/ bidirectional GFCI)

UL 3700 overcurrent hazard mitigation options



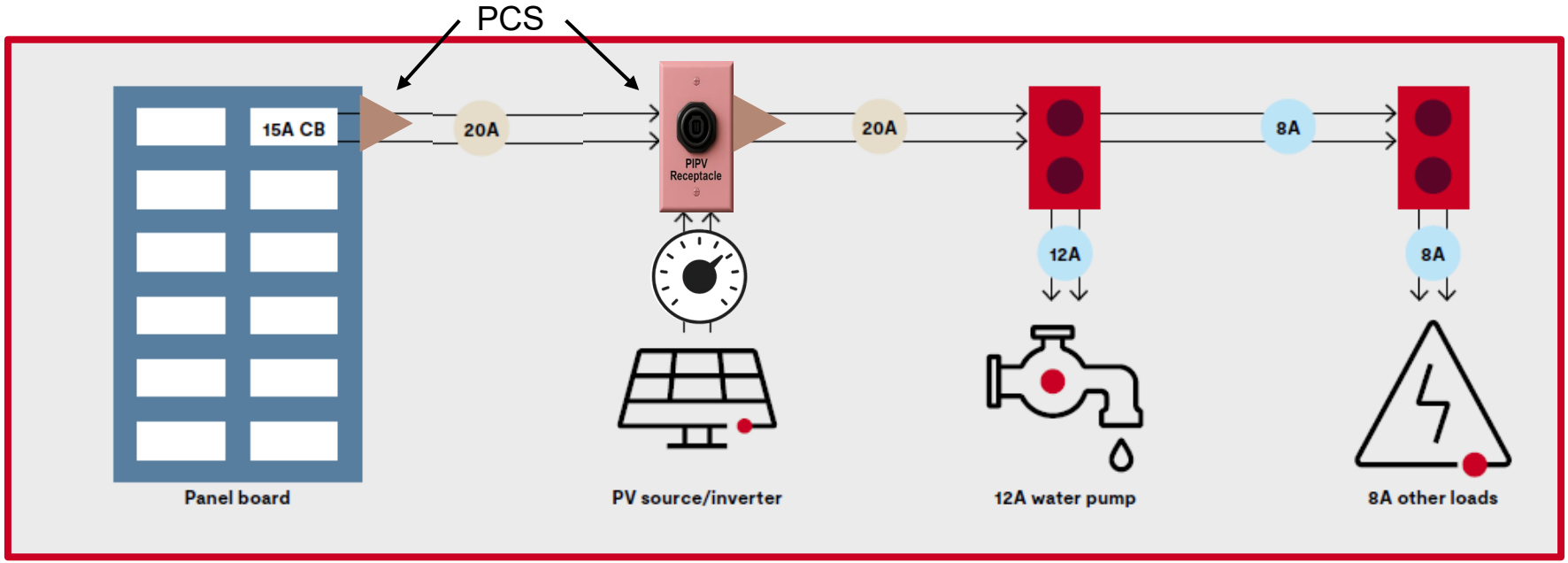
Option 2 - unique PIPV receptacle with bidirectional GFCI at first outlet and integrated, bidirectional GFCI

UL 3700 overcurrent hazard mitigation options



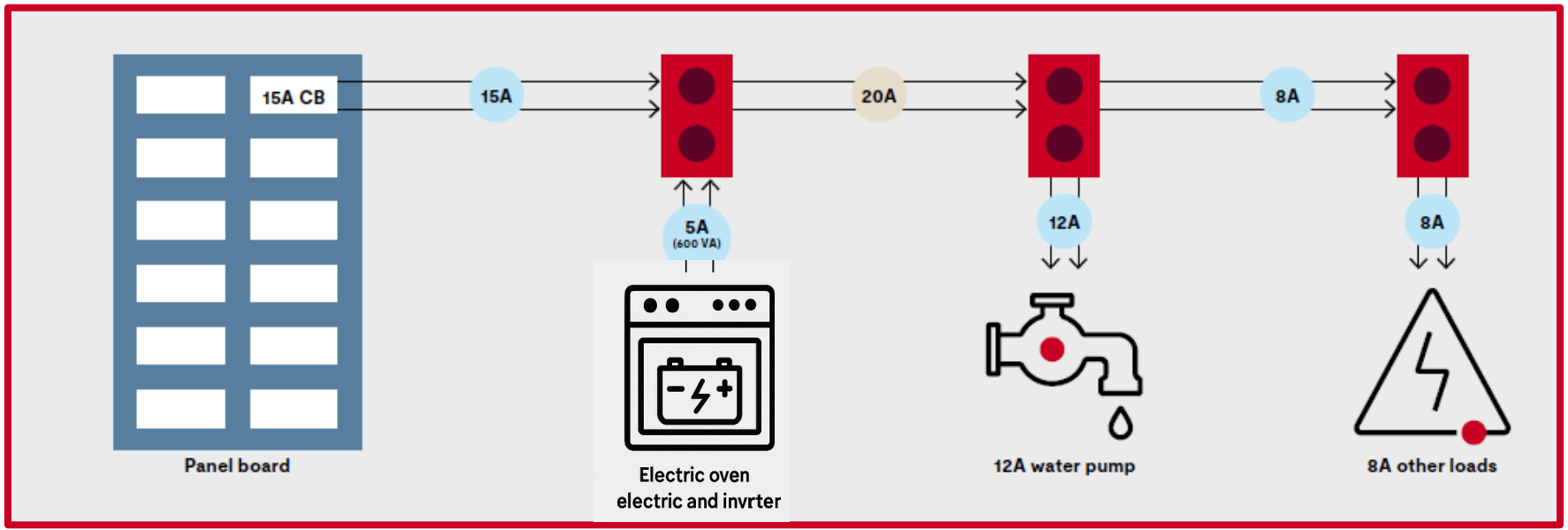
Option 3 - unique PIPV receptacle with bidirectional GFCI at first outlet and upgraded conductor size

UL 3700 overcurrent hazard mitigation options



Option 4 - unique PIPV receptacle with bidirectional GFCI at first outlet and PCS overload control

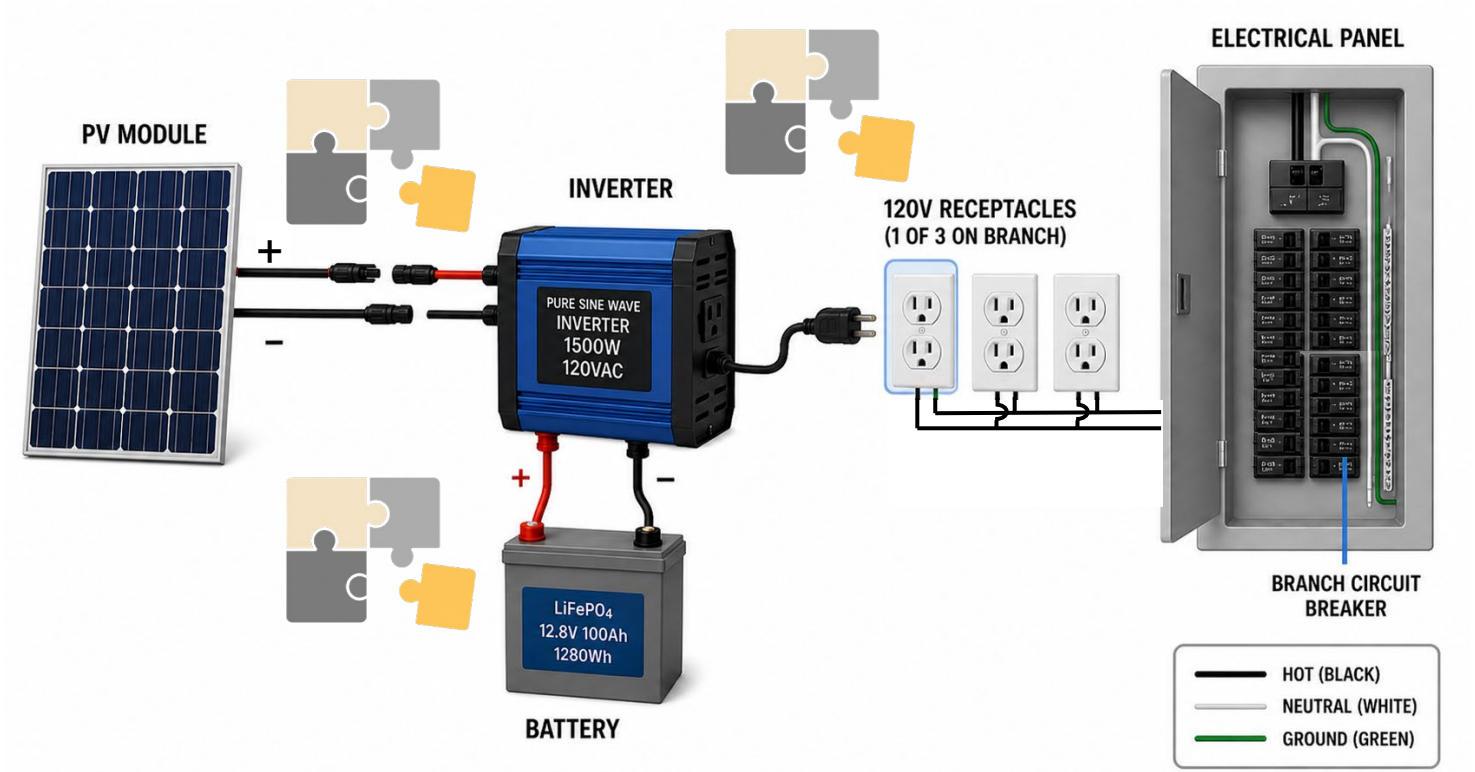
Similar risks with appliances with batteries capable of backfeeding



Miscellaneous FAQs

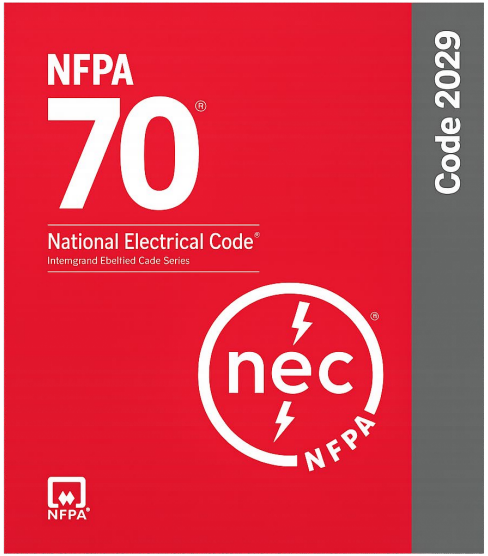
- Is an electrician required?
    - UL 3700 requires that the PIPV receptacle, BD GFCI and OCPD be installed by a qualified person in accordance with the NEC
- How will PIPV impact utility worker safety?
    - Rely on standard practice of grounding out normally energized lines prior to work
- How could PIPV impact utility performance and stability?
    - Grid interactive inverters would still comply with UL 1741 SB and IEEE 1547.
    - If PIPV system size is small, or if total grid penetration is small, impact is expected to be negligible. New legislative or utility rules may be required if there is significant grid penetration of PIPV.
- Can UL 3700 components be purchased separately and assembled by consumers?

Safety considerations – PIPV



Are consumers sufficiently knowledgeable to select compatible equipment?

Select Public Inputs (PI's) for 2029 NEC



Public Input No. 2779-NFPA 70-2026 [Section No. 705.12]

Standard receptacles:
GFCI incompatibility risk
Nothing preventing connection of more than one PIPV system

The new language in 705.12(C)(1) provides for a single 360VA source connection to a single general-purpose branch circuit receptacle. The substantiation for allowing a single 360VA power source connection to these circuits is as follows. The 60°C ampacity of 14AWG wire is 15-amps. The NEC limits the ampacity of NM cable used for general-purpose branch circuits to the 60°C ampacity of a conductor. This is because NM is often bundled in hot attic spaces. Most NM is rated 90°C today, but older homes prior to 1988 have 60°C NM cable, so it is difficult to differentiate this issue for older homes. New homes are a special case that may allow larger systems. The 80% continuous current rating of the 14 AWG, 15-amp conductors is 12-amps. If a PIPV system produces 3-amps the downstream conductor remains within its allowable ampacity of 15-amps (12-amps from the thermal breaker and 3-amps from the PIPV). At 120Vac, 3-amps is 360 Volt-Amps at unity power factor. The 80% factor used for thermal breakers is based on the testing and rating of standard circuit breakers and the heating on the wire caused by the impedance of the breaker. Since the PIPV current is never passing through the circuit breaker, and the wire has sufficient ampacity, a 3-amp PIPV system can never damage a 14AWG copper conductor in a 15-amp general-purpose branch circuit.

Assumes max 12A continuous through 15A breaker – not true

Need to consider terminals and receptacles in addition to conductors

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TITLE OF NEW CONTENT

705.25 (D) Plug and Receptacle Connected Power Production Sources

Plug and receptacle connected power production sources and equipment that operate in parallel with the primary source shall comply with all of the following:

1)The plug and receptacle shall be of a design that is not interchangeable with other wiring devices on the same premises.

Informational Note 1: See ANSI/NEMA WD 6, *Wiring Devices — Dimensional Specifications* , for common types of receptacles.

2) The plug and receptacle connected power production sources and equipment intended for bidirectional power flow shall be listed for interactive bidirectional use.

3) The plug and receptacle connected power production sources and equipment not intended for bidirectional power flow shall be listed for interactive generation.

Informational Note 2: Examples of Plug and receptacle connected power production sources include Plug in PV (PIPV), and induction cooking equipment with batteries and an interactive inverter.

Informational Note 3: See UL3700, Outline of Investigation for Interactive Plug-In PV (PIPV) Equipment and Systems, for requirements addressing plug and receptacle connectors for power production sources, including requirements for cessation of current flow when disconnected.

Informational Note 4: See Article 406 for requirements applicable for wiring devices.

Summary

- Off the shelf PV, inverter output circuits, legacy GFCI and circuit breakers - incompatible with PIPV
- Many state bills / laws require “listing” but not specifically UL 3700, introducing risk
- Connection to standard outlets creates risk of connection to unprotected outlet; accidental connection of many PIPV systems to branch circuits
- DIY integration of PIPV components introduces additional risk due to possibility of using incompatible equipment
- Overlapping risks with power exporting appliances and large, portable power packs
- Many NEC proposals for 2029 edition – likely to align with UL 3700

Thank you!

Please visit https://www.ul.com/services/pv-module-certification for more supporting information.

For more technical questions, please contact: ULRegulatoryServices@ul.com

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