NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Interconnection of Distributed Energy Resources

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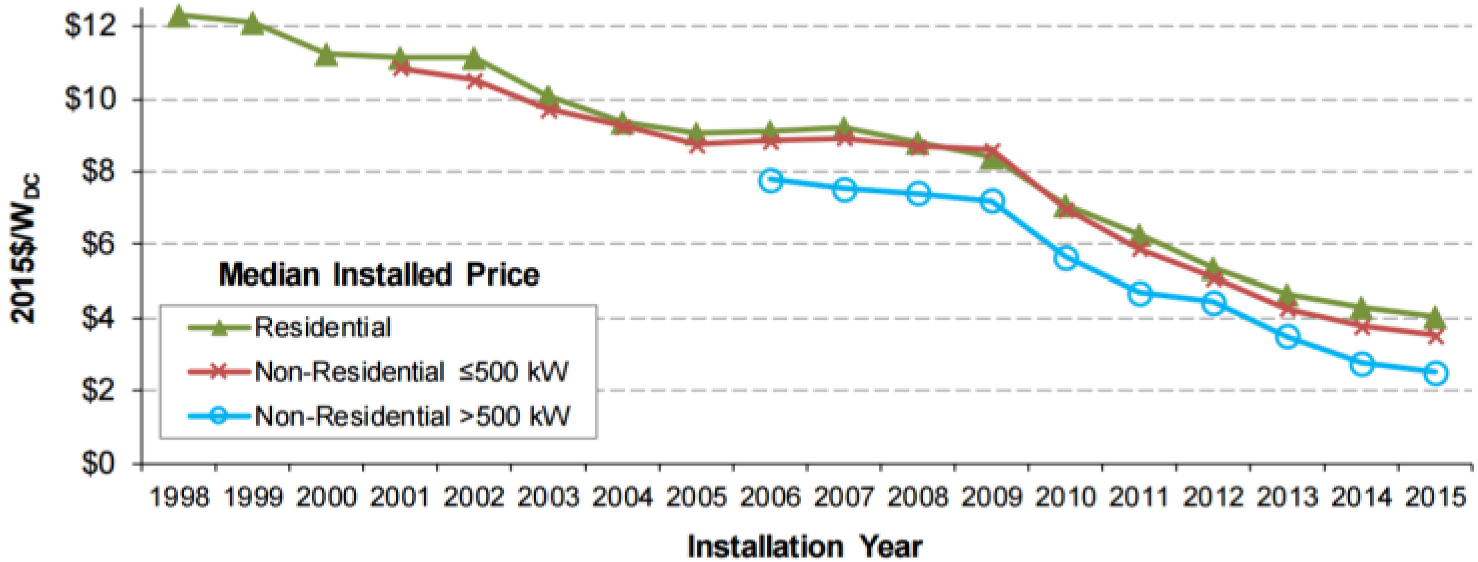
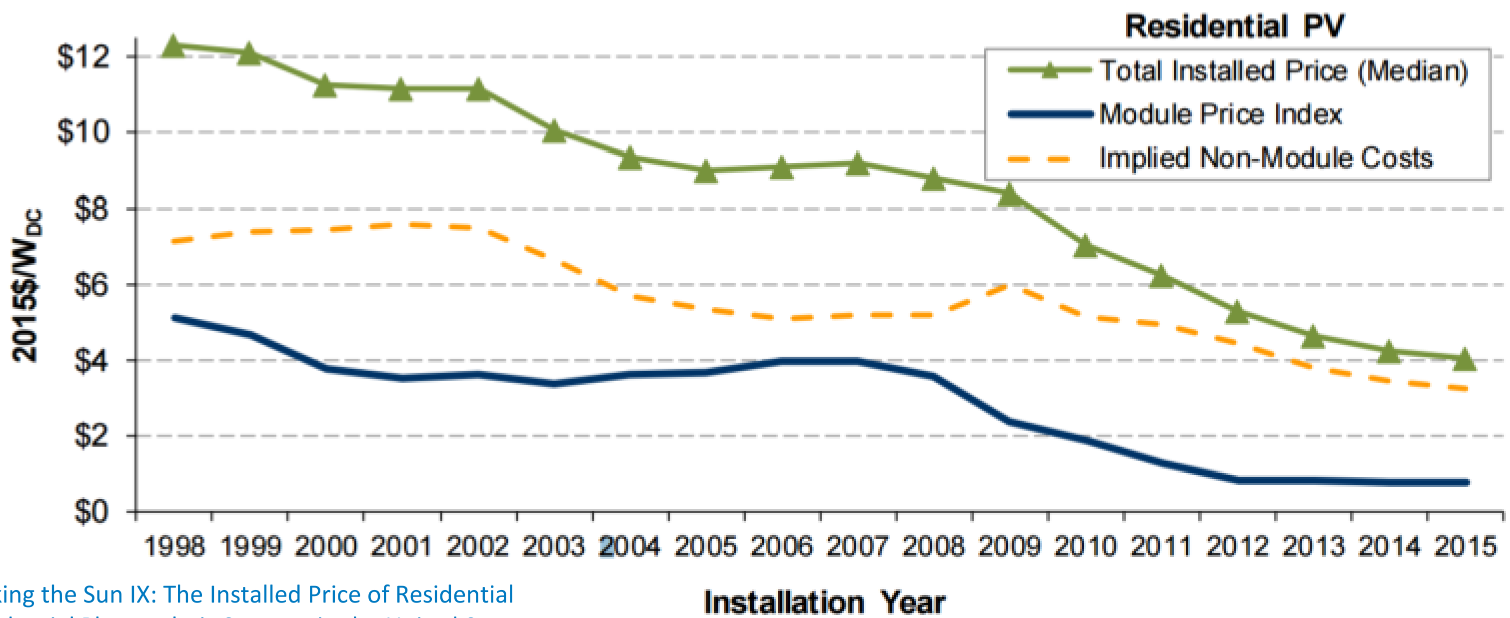
Goals for this Session

- Understand the relationships between different aspects of interconnection
- Discuss best practices and lessons from US states and utility territories
- Provide an update on technical advances and standards for interconnection

Motivations

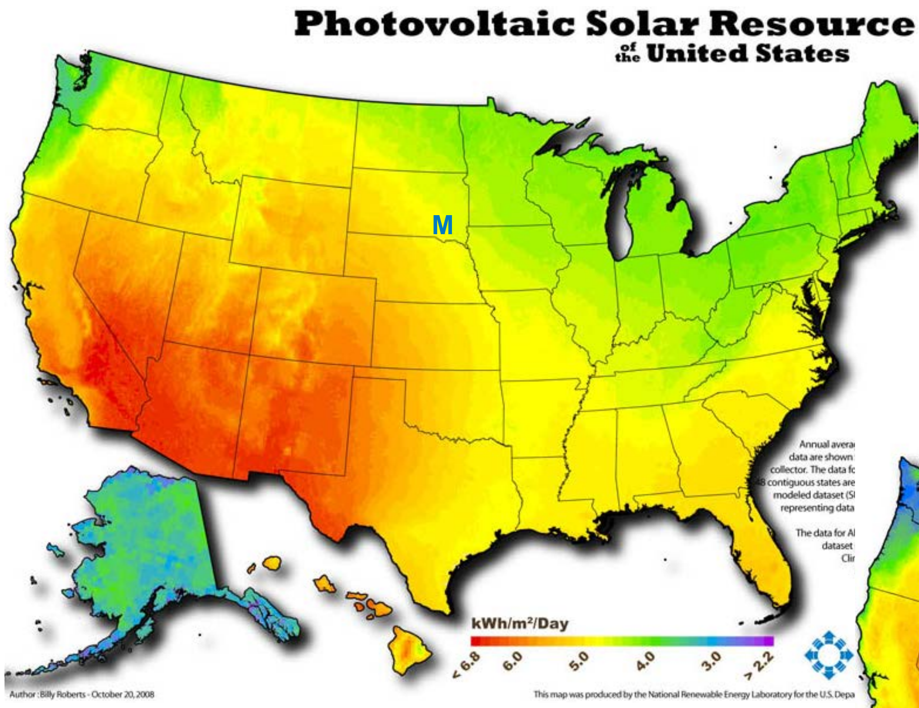
Solar Energy: Cost

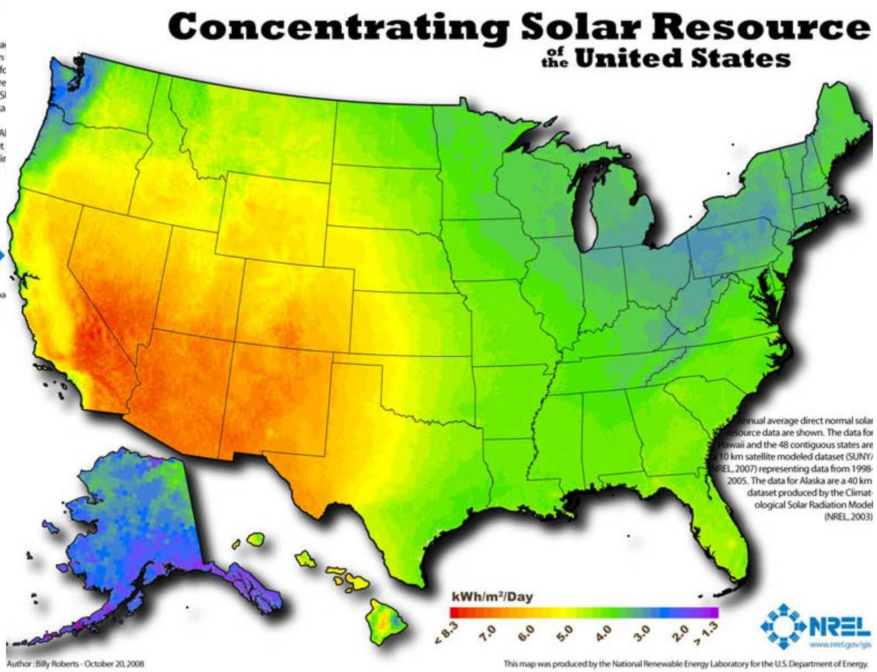




Source: Tracking the Sun IX: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States

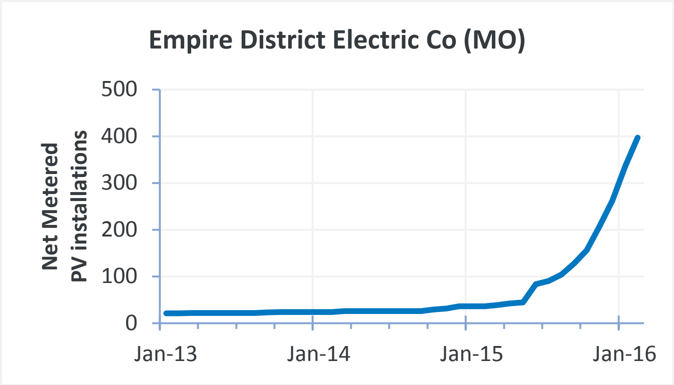
Solar Energy: Resources



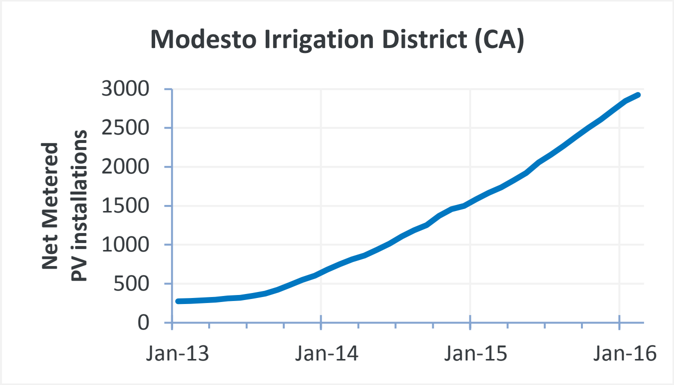


Type of system determined by local solar resource

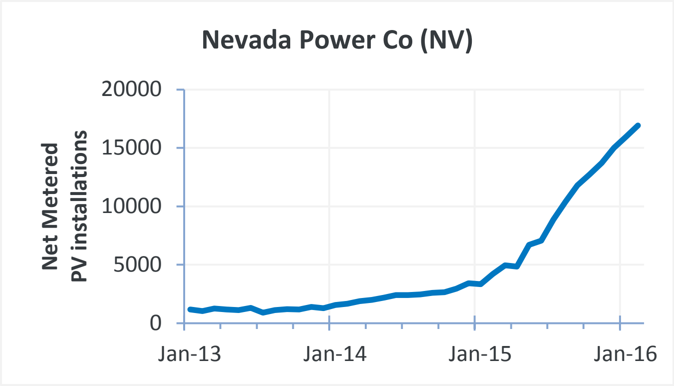
Solar Energy: Utility Experiences of 10x Growth



Story: Strong rebates, implemented in May 2015, push solar into wide viability.



Story: Growing economic viability overcomes decline in state incentives to drive steady growth.



Story: Solar reaches economic "tipping point" in late 2014, attracting scale from national installers. Pre-Dec 2015 installs were granted grandfathering.

Solar Energy: TVPPA Context

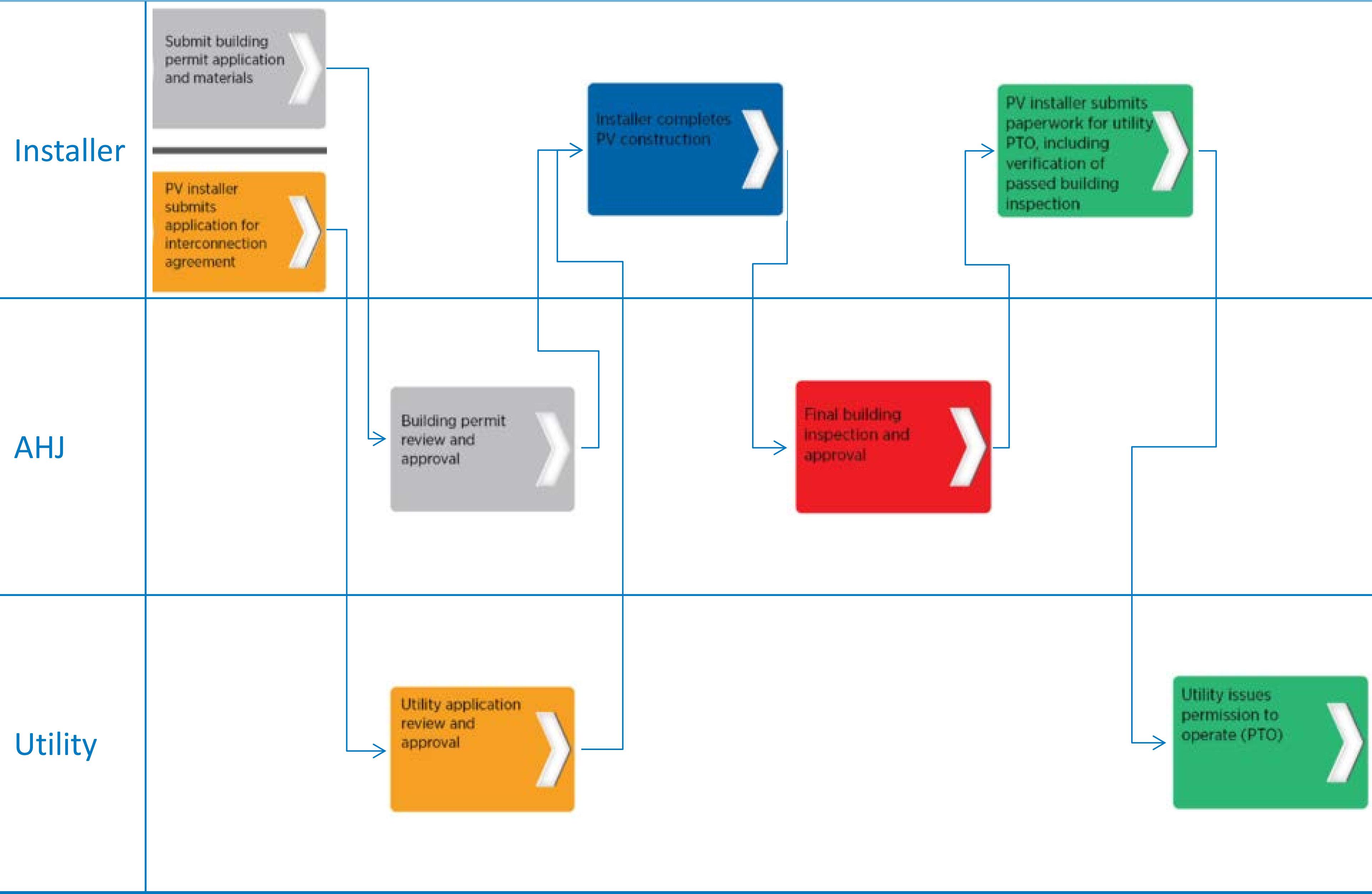
Utility Name	Total Customers	Additional DG systems/mo for 10x growth over 3 yrs
Nashville Electric Service	378,117	62
Johnson City - (TN)	77,025	18
Southwest Tennessee E M C	49,589	5
Joe Wheeler Elec Member Corp	42,812	2
Gibson Electric Members Corp	34,436	5
Fort Loudoun Electric Coop	31,571	8
Decatur Utilities	26,492	1
City of Newport	21,497	6
Tennessee Valley Electric Coop	19,442	2
Tri-State Electric Member Corp	18,475	12
City of Rockwood - (TN)	14,566	2
City of Hopkinsville	12,874	1
Bolivar Energy Authority	11,058	1
Forked Deer Electric Coop, Inc	9,871	1
McMinnville Electric System	8,002	0
Guntersville Electric Board	6,331	1

Intro to the Interconnection Process

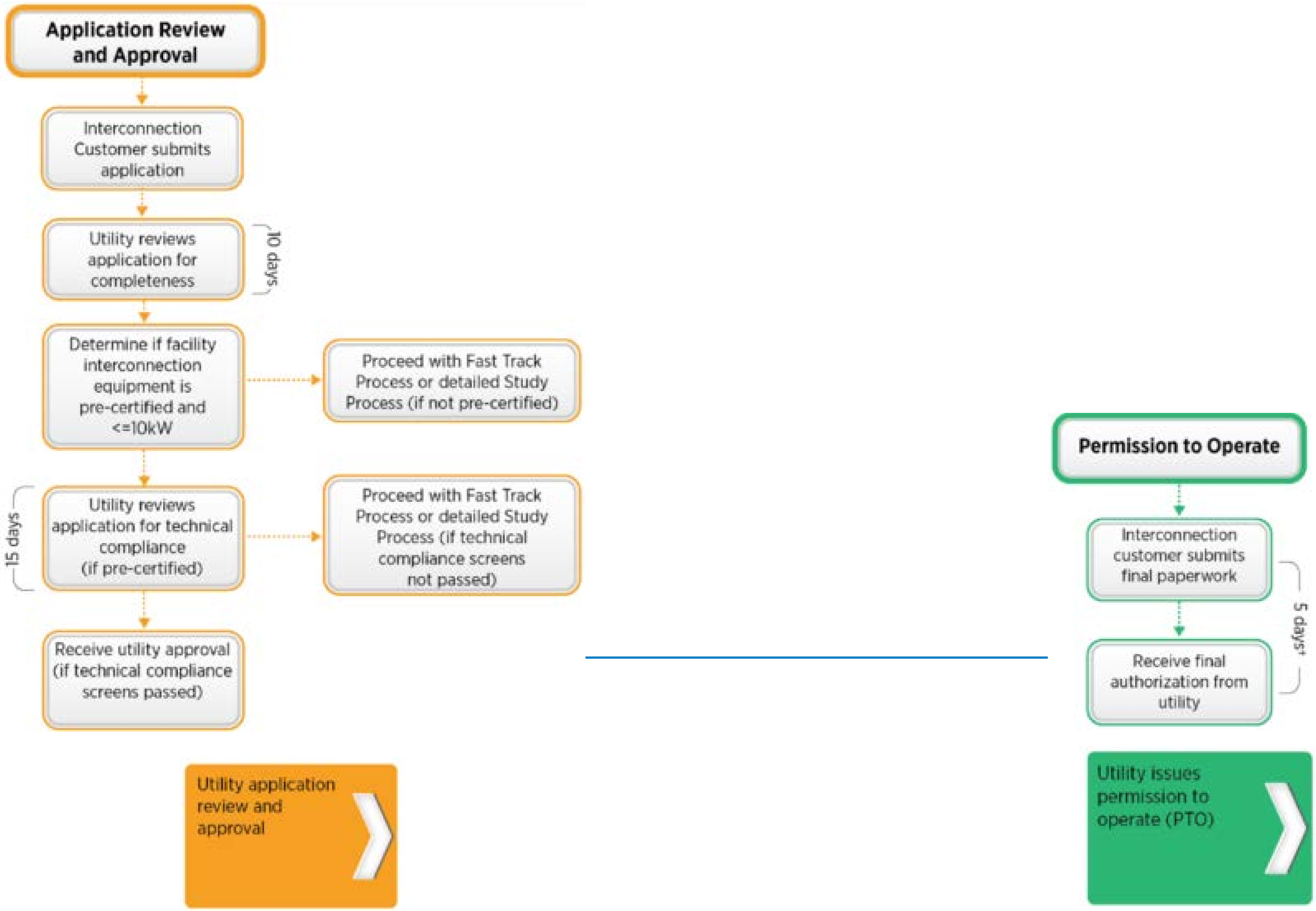
What is the Interconnection Process?

- Outward-facing, customer service activity
- Technical assessment by the utility
- Internal business process for utility
- Coordination effort with local AHJ

Who does what?



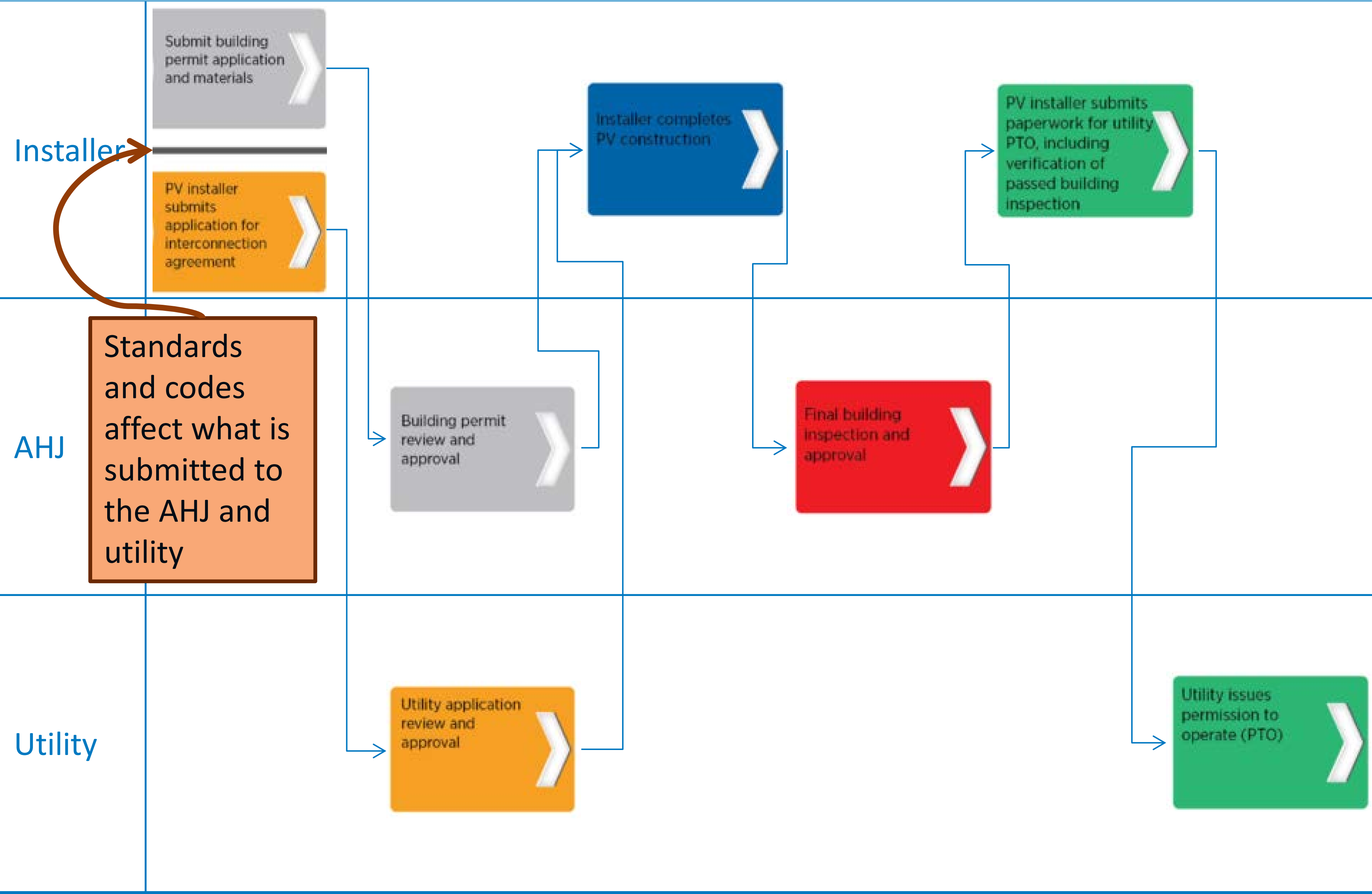
What are the utility's typical responsibilities?



Utility

Standards, Codes, and Interconnection Requirements

Standards & Codes are Foundational

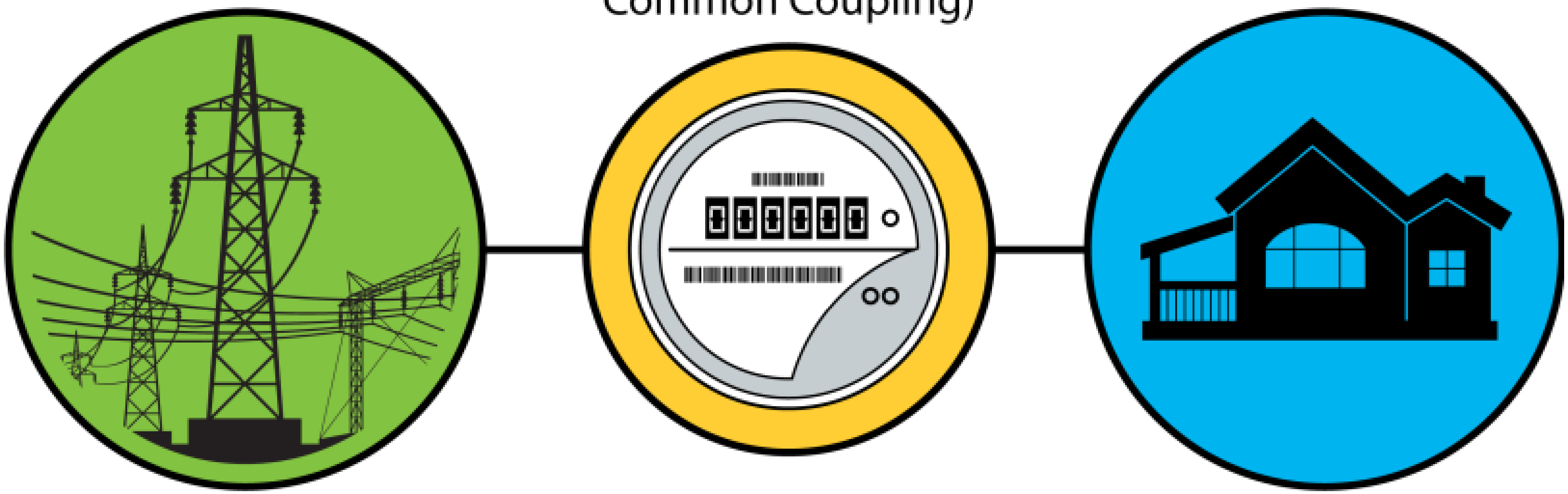


Interconnection Codes & Standards

Electric Utility T&D Systems

PCC (Point of Common Coupling)

Industrial, Commercial, Residential Buildings



National Electrical Safety Code (NESC) and Utility Manual of Safe Practices

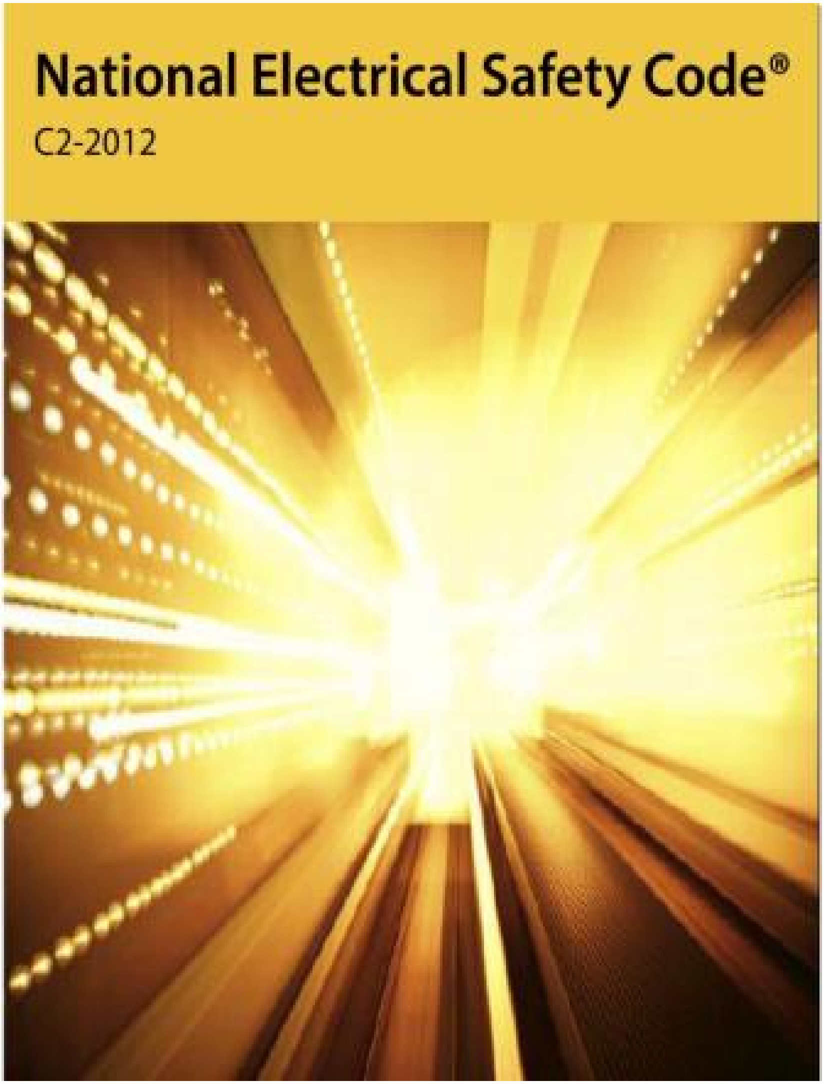
ANSI C84.1

IEEE 1547 & Family of Stds

National Electrical Code (NEC)

UL 1741
UL 1703

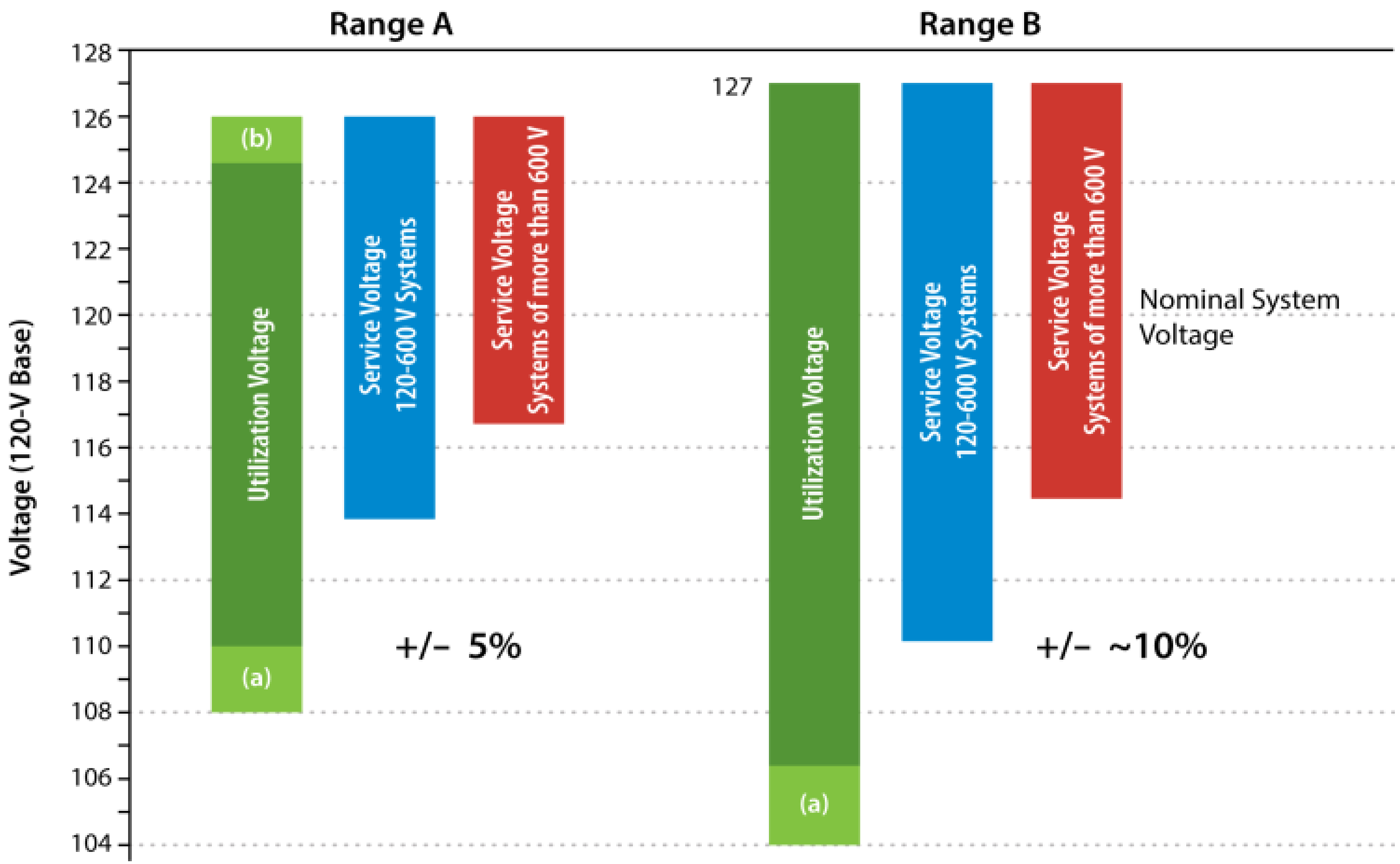
NESC – Minimizing Contact Risks



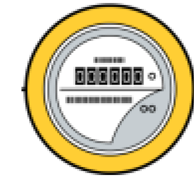
- Often used as Utility Manual of Safe Practices
- Covers basic provisions for safeguarding persons from hazards arising from installation, operation, and maintenance of conductors
- Typically applies to utilities and industrial users under the control of qualified persons
- Note: Section 444 of the NESC details "De-energizing equipment of lines to protect employees"

ANSI C84.1

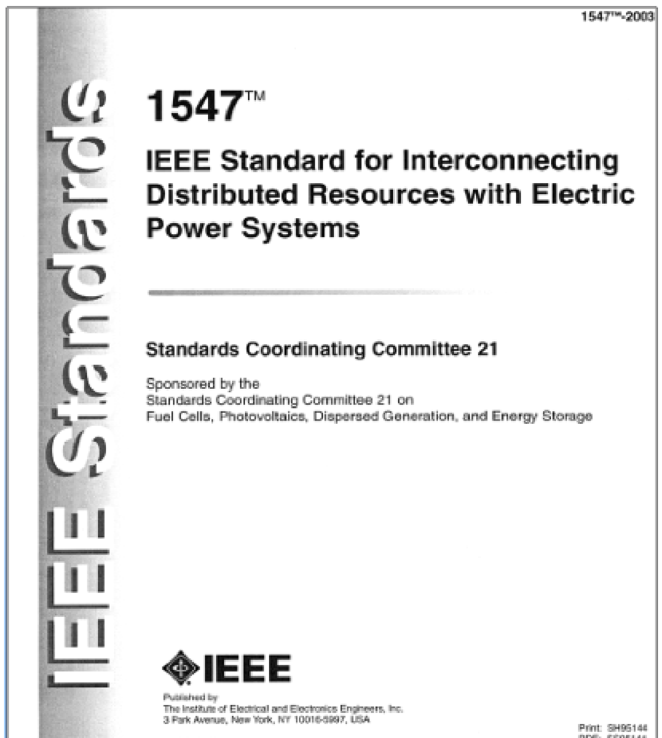
- Service Voltage – voltage at the point of delivery
- Range A (114-126V) is favorable, Range B (110-127V) is tolerable



IEEE 1547™ (under full review/revision)



- Provides a uniform standard for interconnection of DR with EPS
- Set of standards govern performance, operation, testing, and safety



1547™-2003

IEEE Standards

1547™

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

Standards Coordinating Committee 21

Sponsored by the
Standards Coordinating Committee 21 on
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE

Published by
The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

28 July 2003

Print: SH95144
PDF: SS95144

- **IEEE Std 1547™(2003 and 2014 Amendment 1) Standard for Interconnecting Distributed Resources with Electric Power Systems**
  - **IEEE Std P1547™(full revision)** Draft Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
  - **IEEE Std 1547.1™(2005 and 2015 Amendment 1)** Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
    - **IEEE Std P1547.1 (full revision)** Draft Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces
- **IEEE Std 1547.2™(2008)** Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems
- **IEEE Std 1547.3™(2007)** Guide for Monitoring Information Exchange, and Control of Distributed Resources with Electric Power Systems
- **IEEE Std 1547.4™(2011)** Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems
- **IEEE Std 1547.6™(2011)** Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks
- **IEEE Std 1547.7™ (2013)** Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection
- **IEEE Std P1547.8™** Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Std 1547-2003

National Electrical Code (NEC)

National Fire Protection Association (NFPA) 70

- Adopted as law in most U.S. states, other areas
- Applies to Residential, Commercial, and Industrial facilities
- Often used in utility power plants, service centers
- Articles 690 (*PV systems*) & 705 (*Interconnected Electric Power Production Sources*)
- New Article 691 in next code cycle (*Utility-Scale PV*)

UL 1741

Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources

- Adopted as Legal Requirement in most U.S. states
- Applies to the inverter and interconnection equipment
- Inverters should be “listed” to this standard
- Harmonized with IEEE 1547
- Underwriters Laboratories – Standard for Safety
- UL 1741 has been updated for “Smart Inverter Use”
    - UL 1741 Supplement A (SA)

Dependencies in Technical Standards

Equipment Safety

Prior to Supplement A, **UL 1741** did not have a testing procedure for advanced inverters

Without a developed testing program under UL 1741, advanced inverters could not achieve **UL listing**

Installations using advanced inverters which are not UL-listed cannot comply with the **National Electrical Code**

Installations which do not comply with the National Electrical Code will violate **state or local building codes**

Interconnection Performance

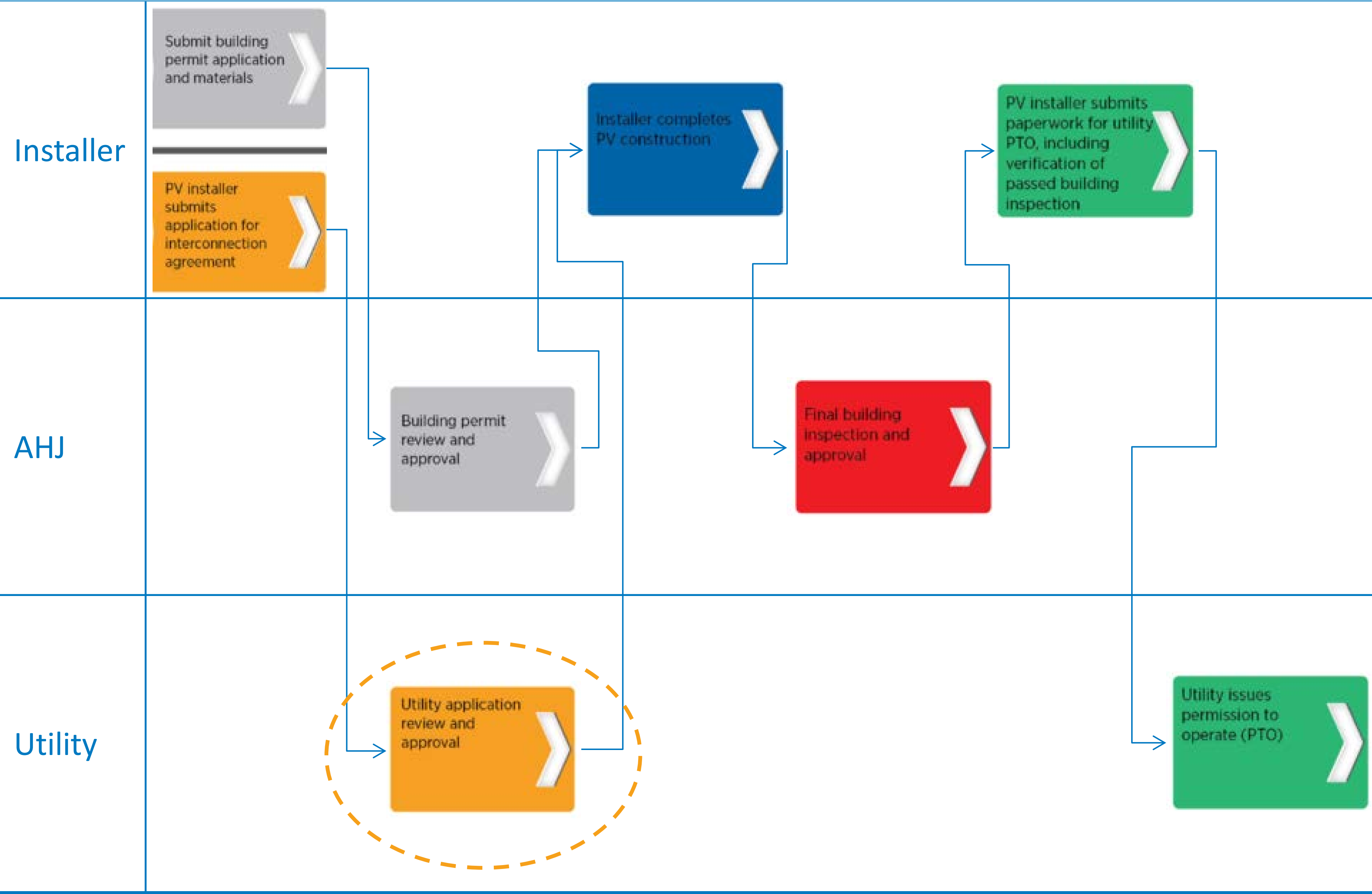
IEEE 1547-2003 does not allow inverters to perform "advanced" functions beyond those in IEEE 1547a-2014

In most states, an inverter which violates IEEE 1547-2003 does not meet **state interconnection standards**

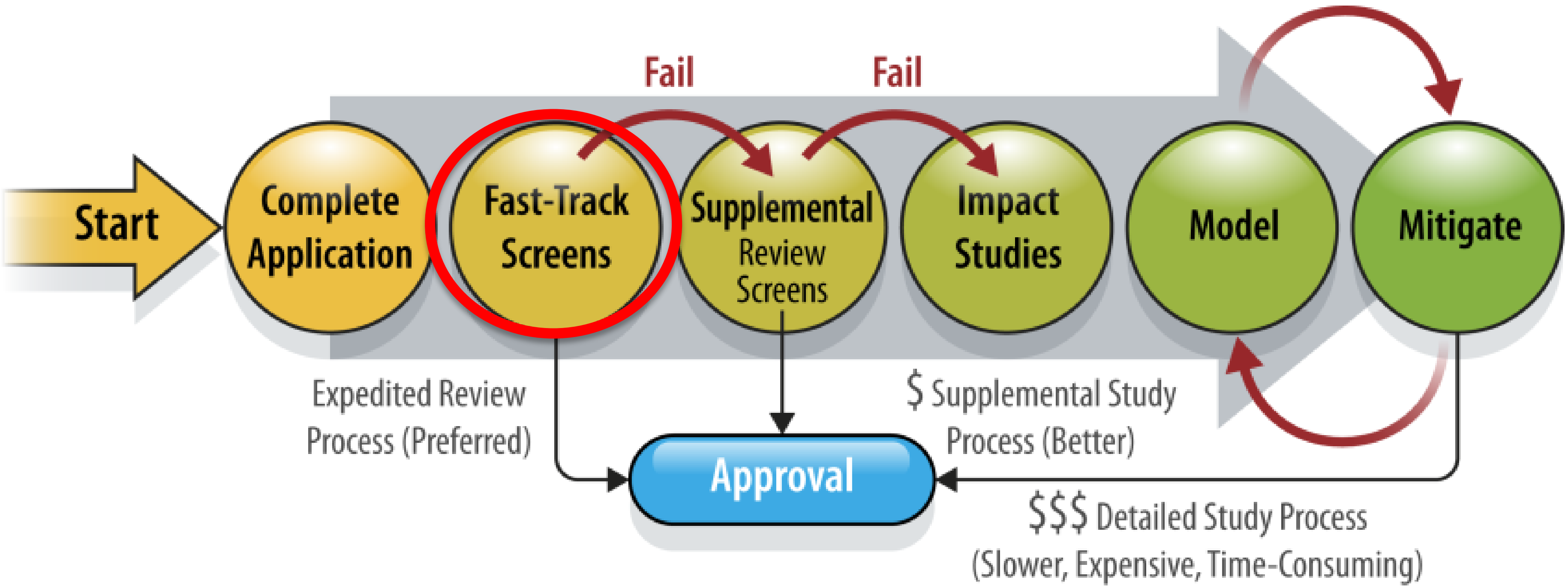
Inverter deployments which do not meet state standards will not pass **utility interconnection processes**

Technical Screens

Technical Screens are Key to Application Review



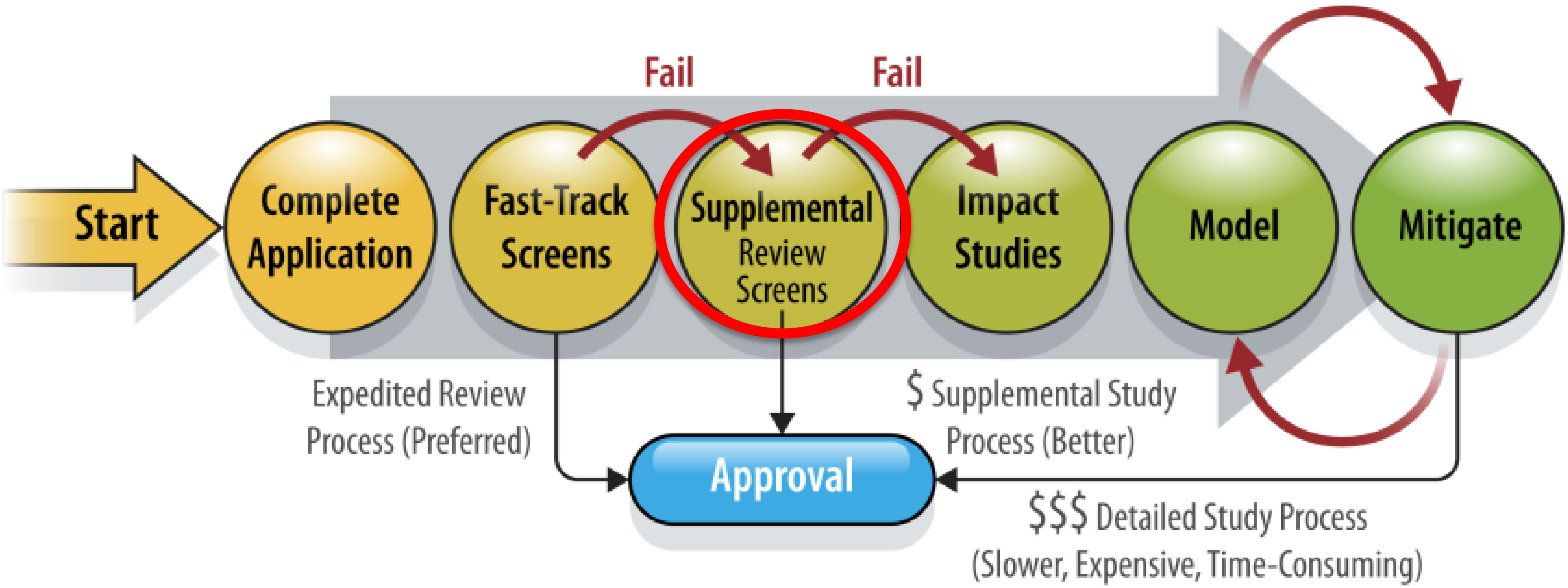
Generic Utility Interconnection Review Process



Fast Track Screens (from FERC SGIP)

1. Aggregated DG <15% of peak load on line section (Penetration Screen)
2. For connection to a spot network: DG is inverter-based, aggregated DG capacity is <5% of peak load & <50 kW
3. Aggregated DG contribution to maximum short circuit current is <10%
4. Aggregated DG does not cause protective device to exceed 87.5% of short circuit interrupting capability
5. DG interface is compatible with type of primary distribution line (Wye/Delta)
6. For a single-phase shared secondary, aggregated DG capacity <20kW
7. Resulting imbalance <20% of service transformer rating of 240 V service
8. Aggregated transmission connected DG capacity <10 MW for stability-limited area
9. Construction not required for interconnection

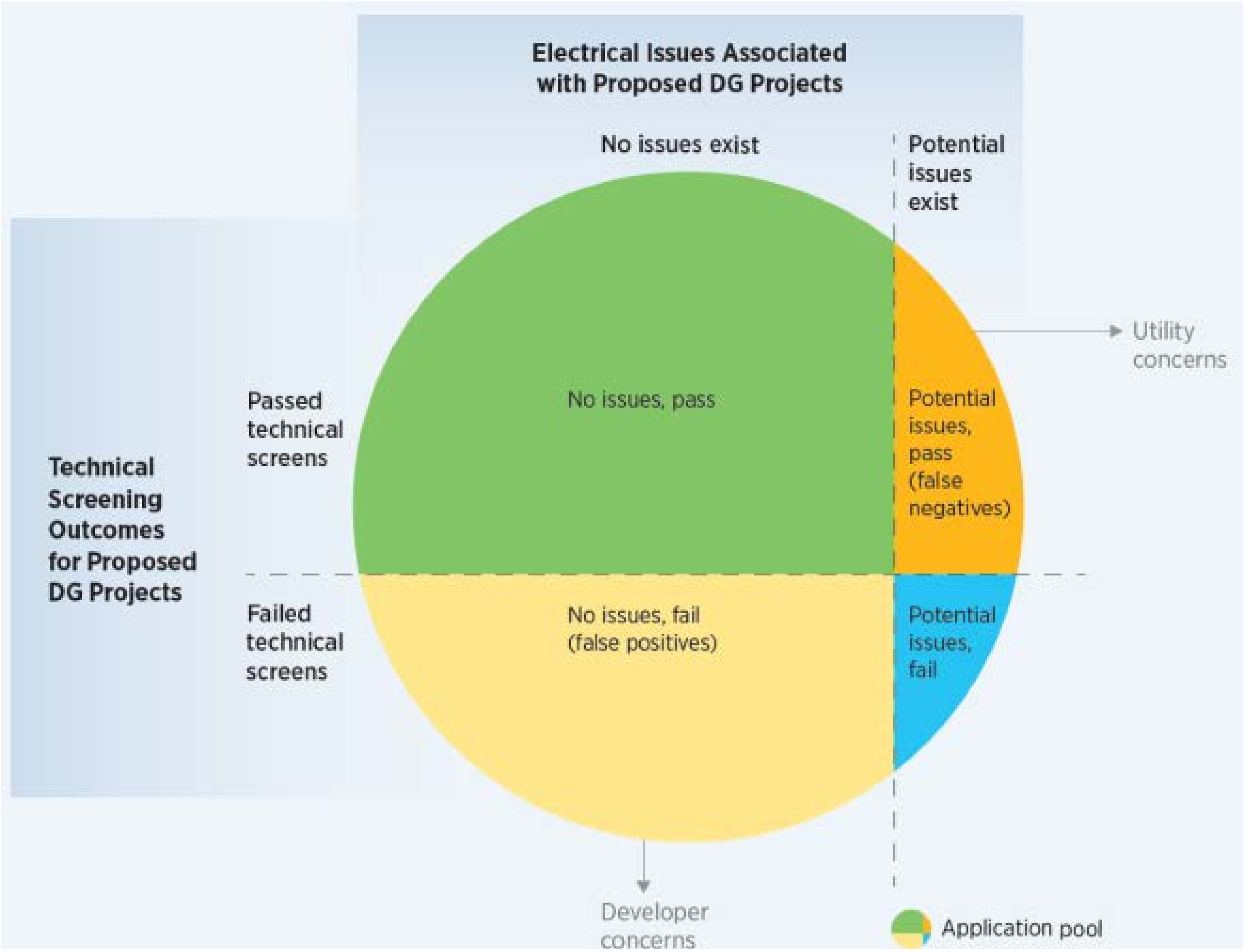
Supplemental Review May Occur if Fast-Track not Achieved

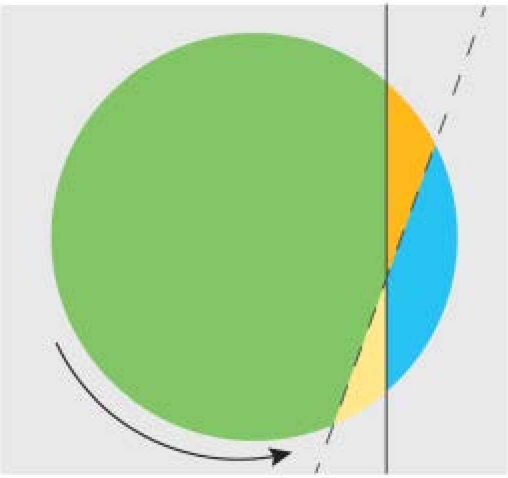


Supplemental Screen Examples

- Evaluate transformer serving customer (Is it sufficient, can it be easily changed)
- Evaluate secondary lines serving customer
- Consider location of proposed PV to substation (short distance, large conductors, etc.)
- If Penetration Screen failed, consider other metrics such as 100% of minimum daytime load on line section (recommended by FERC)

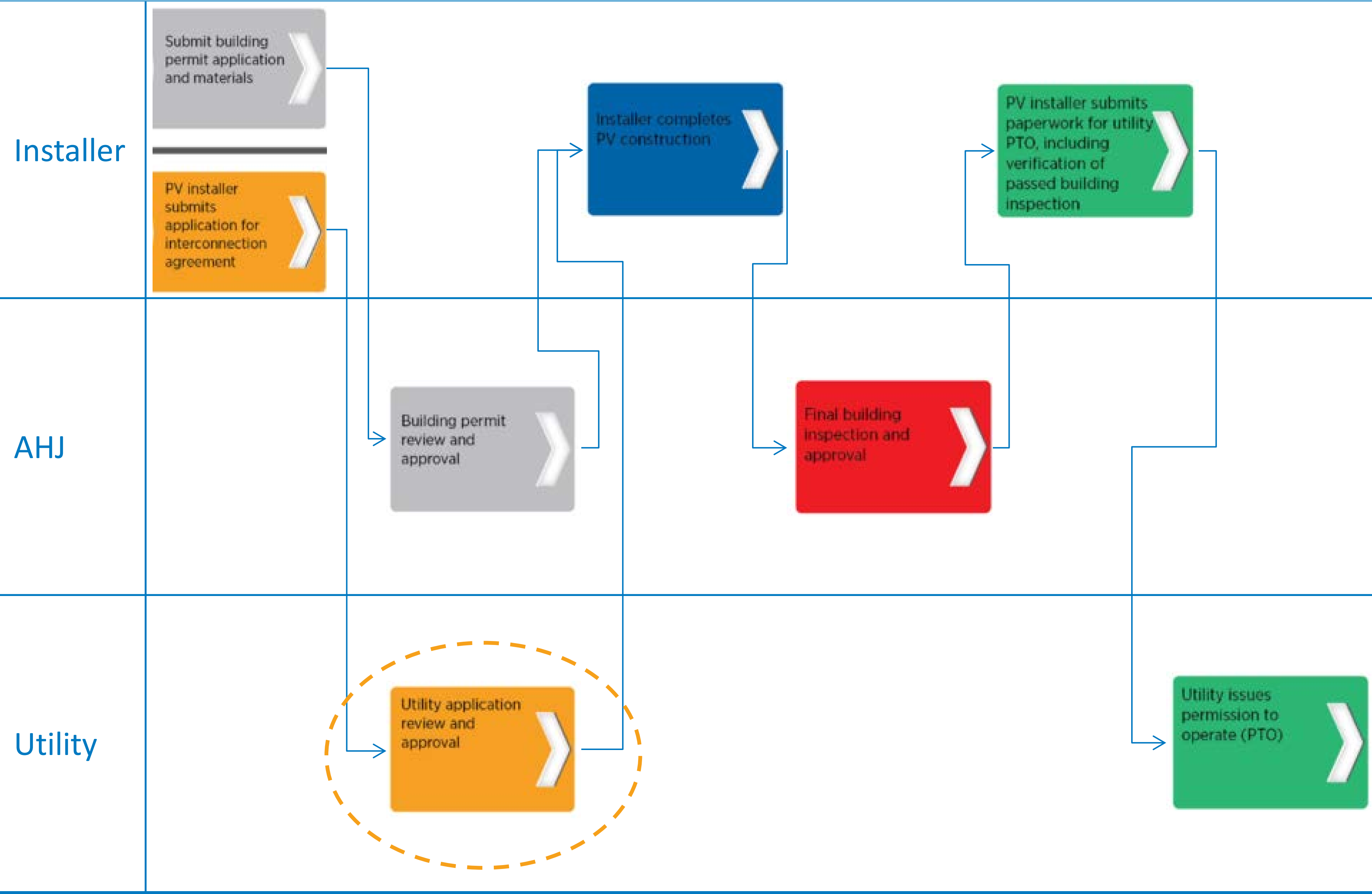
Tension in Screening Process



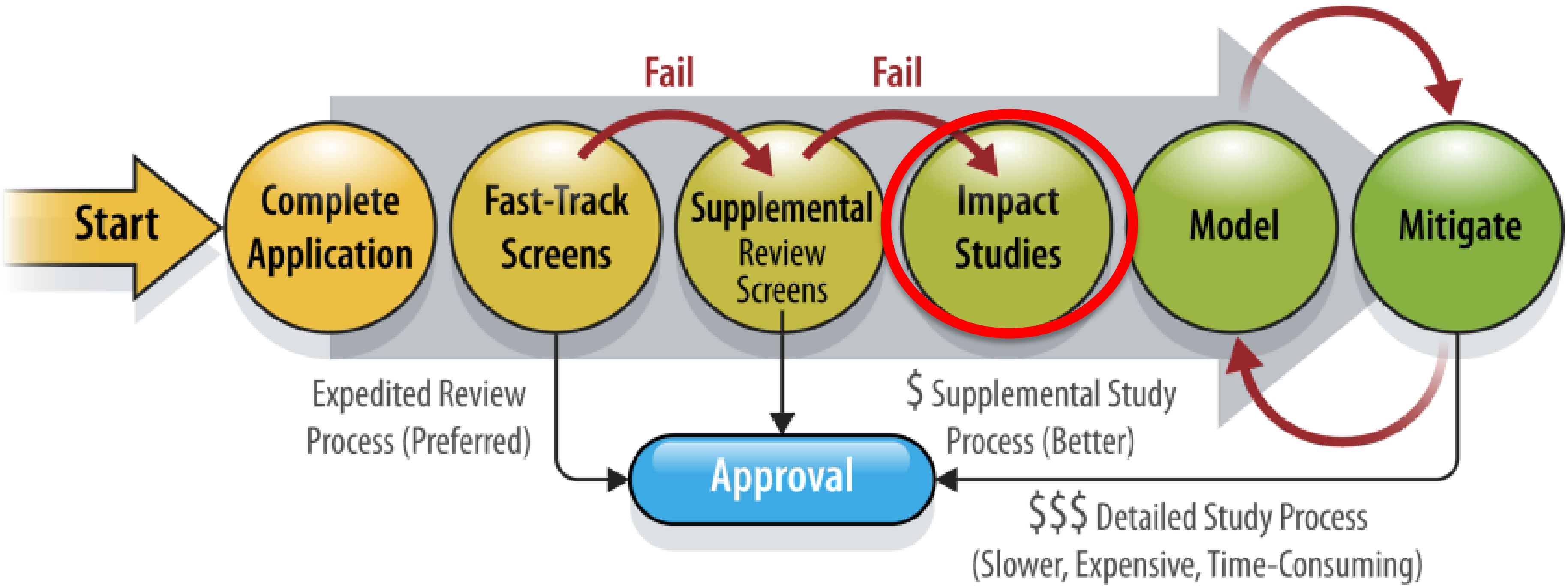


Interconnection Studies and Mitigations

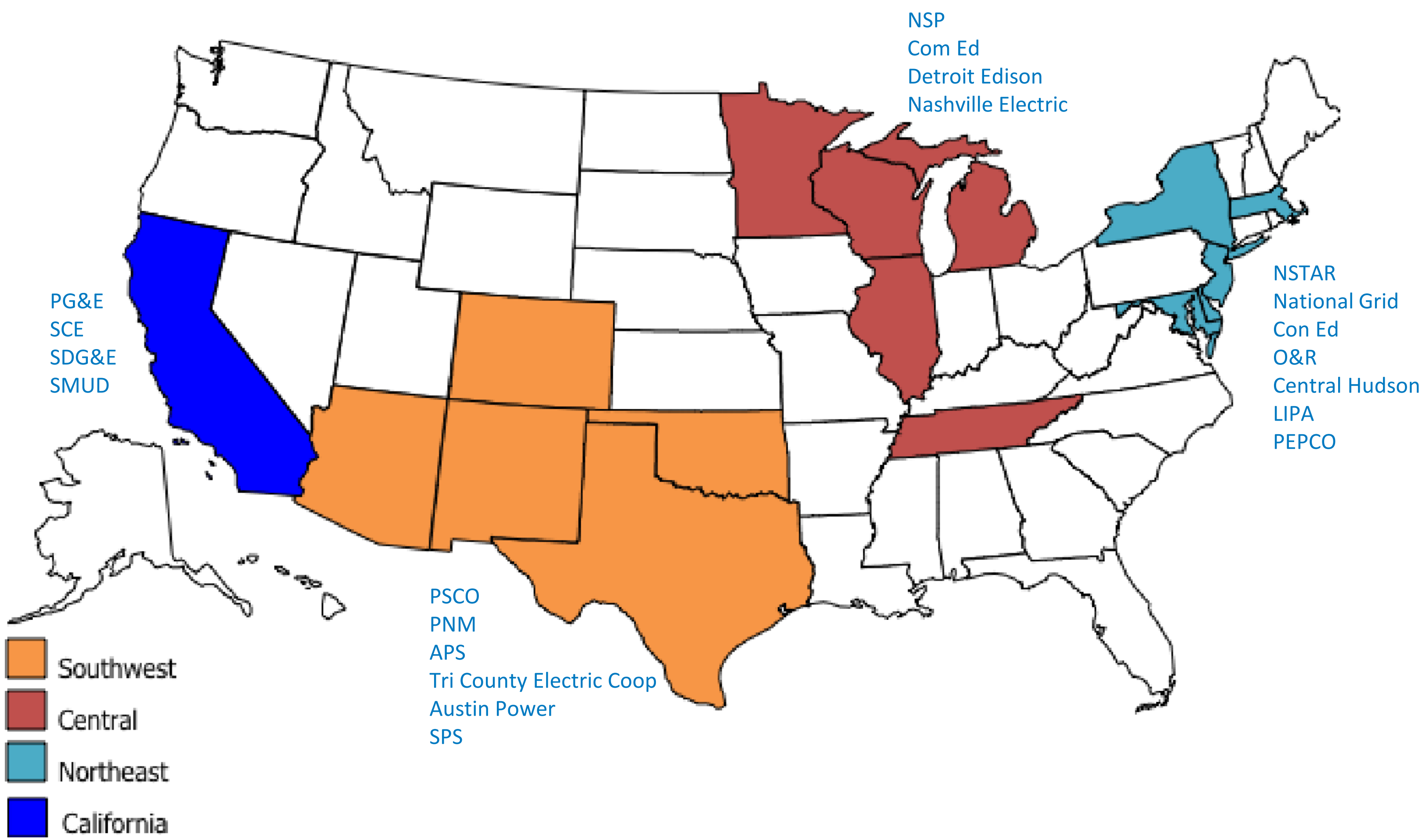
Detailed Studies Can Occur in Application Review



Impact Studies Are Triggered if Screens are Failed



21 Utility Survey (SGIP Focused)



Major Utility Concerns

Voltage Regulation 76%

Reverse power flow 52%

Protection system coordination 48%

Increased duty of line regulation equipment 38%

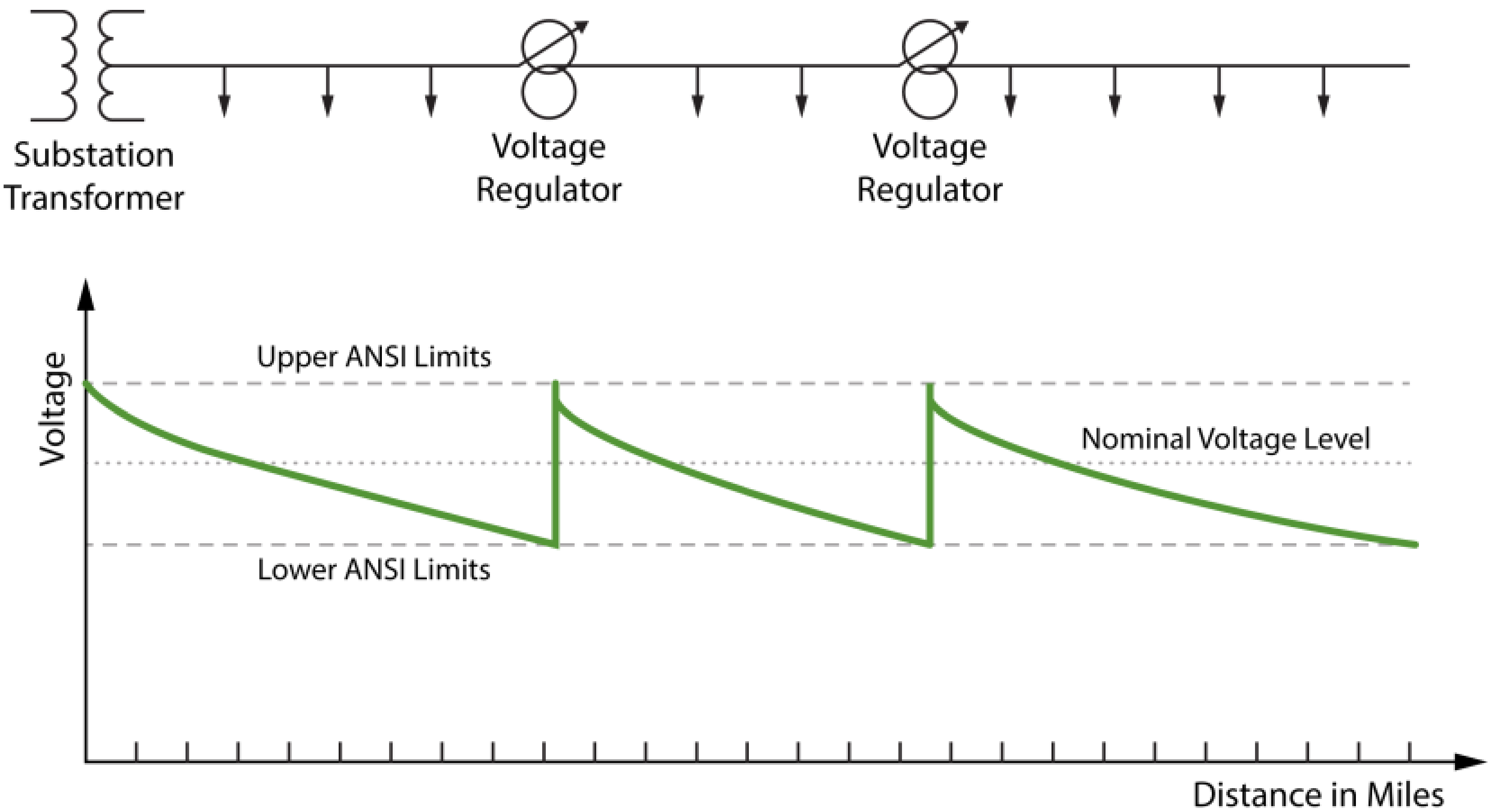
Unintentional islanding 38%

Secondary network protection 29%

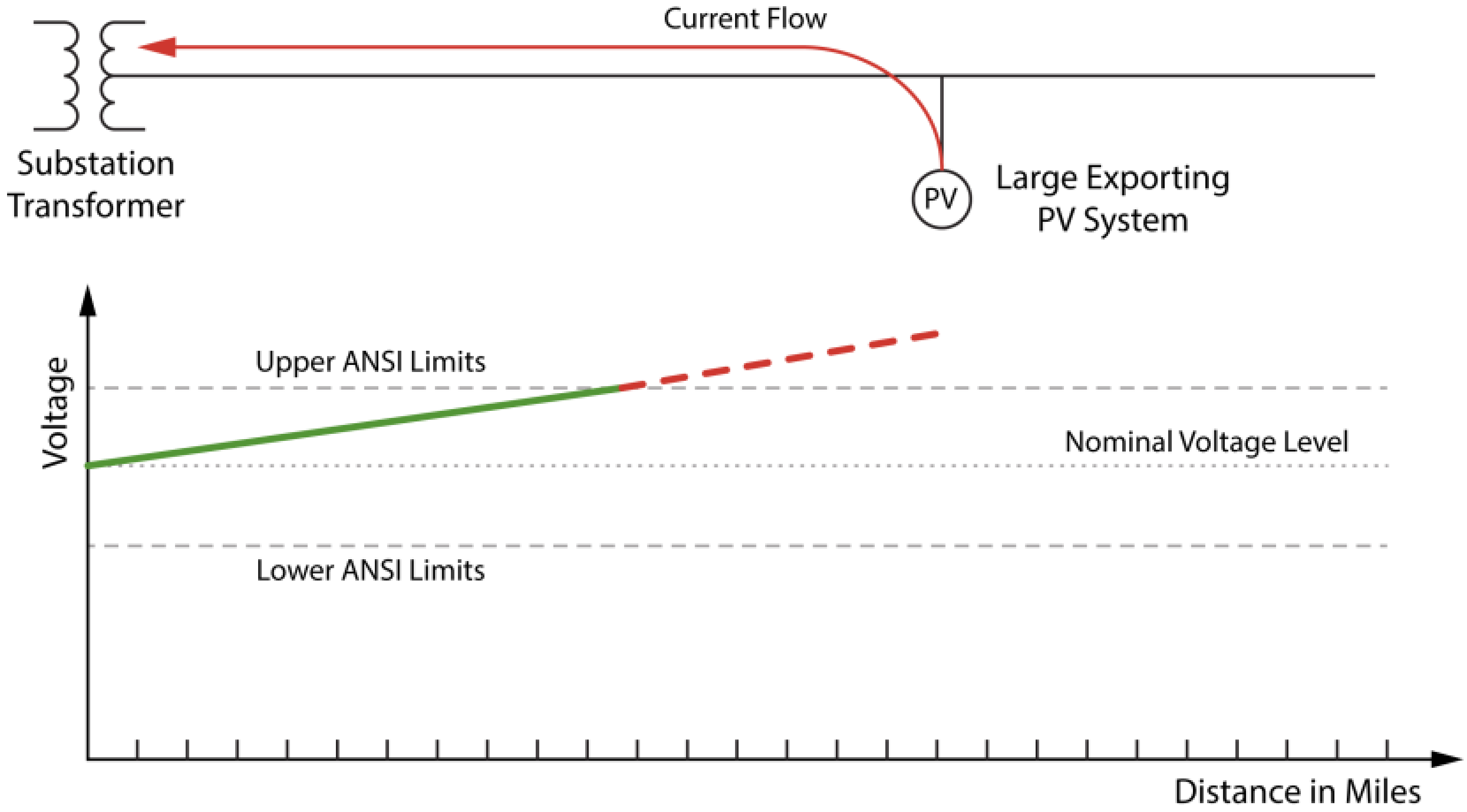
Variability due to clouds 24%

Increased switching of capacitors 19%

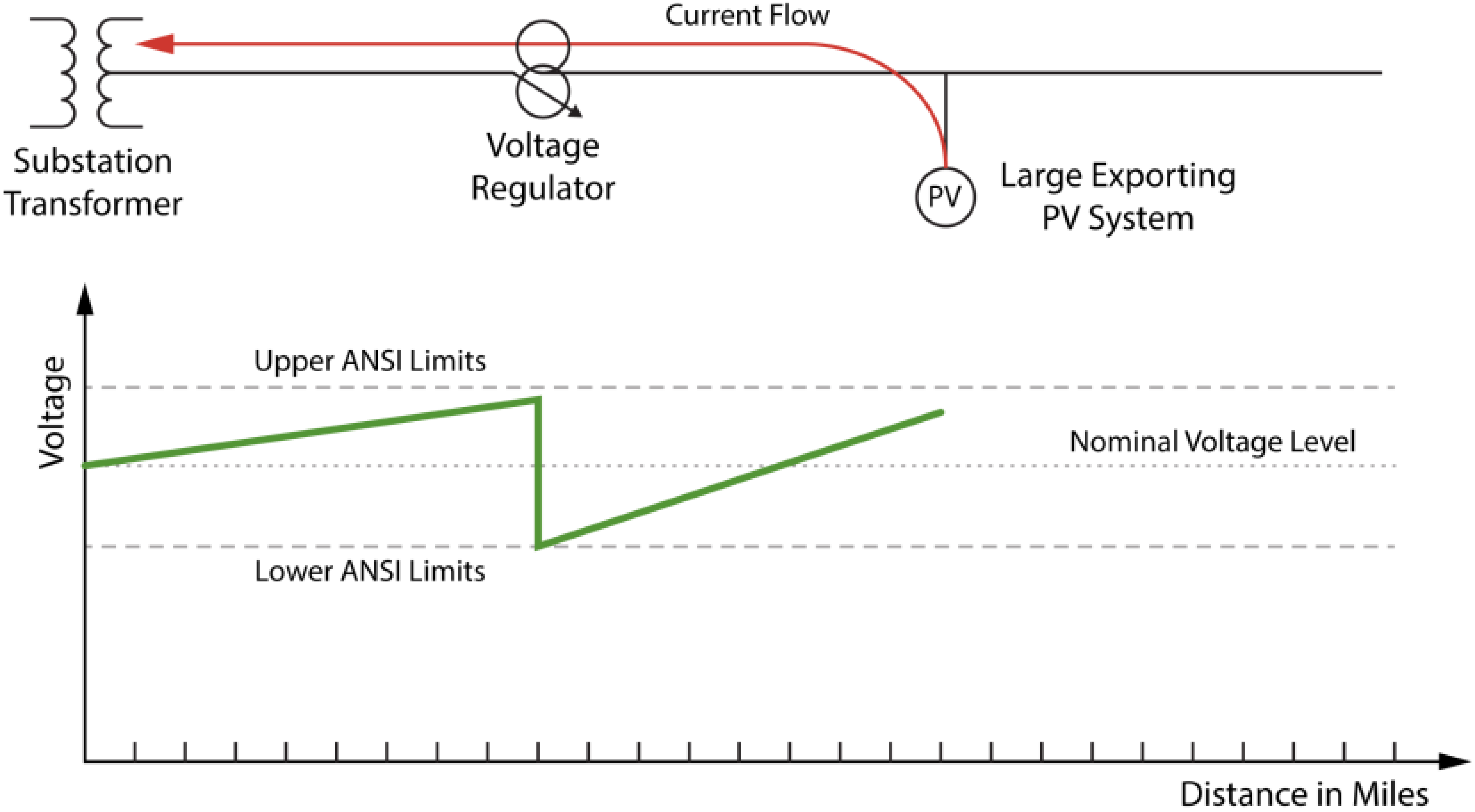
Voltage Regulation – No PV



Voltage Regulation – w/ PV



Voltage Regulation – w/ PV



Detailed Impact Study Types

Most utilities employ one or more of the following;

- Power Flow (common)
- Short Circuit (common)
- Voltage (common)
- Feasibility
- Facility
- Flicker
- Power Quality

- Dynamic/Transient Stability
- Electromagnetic Transient

Most Commonly used Distribution Software

- SynerGi
- CymDist
- Milsoft Windmil
- ASPEN

Mitigation Tools Available

Tools in the "Toolbox"

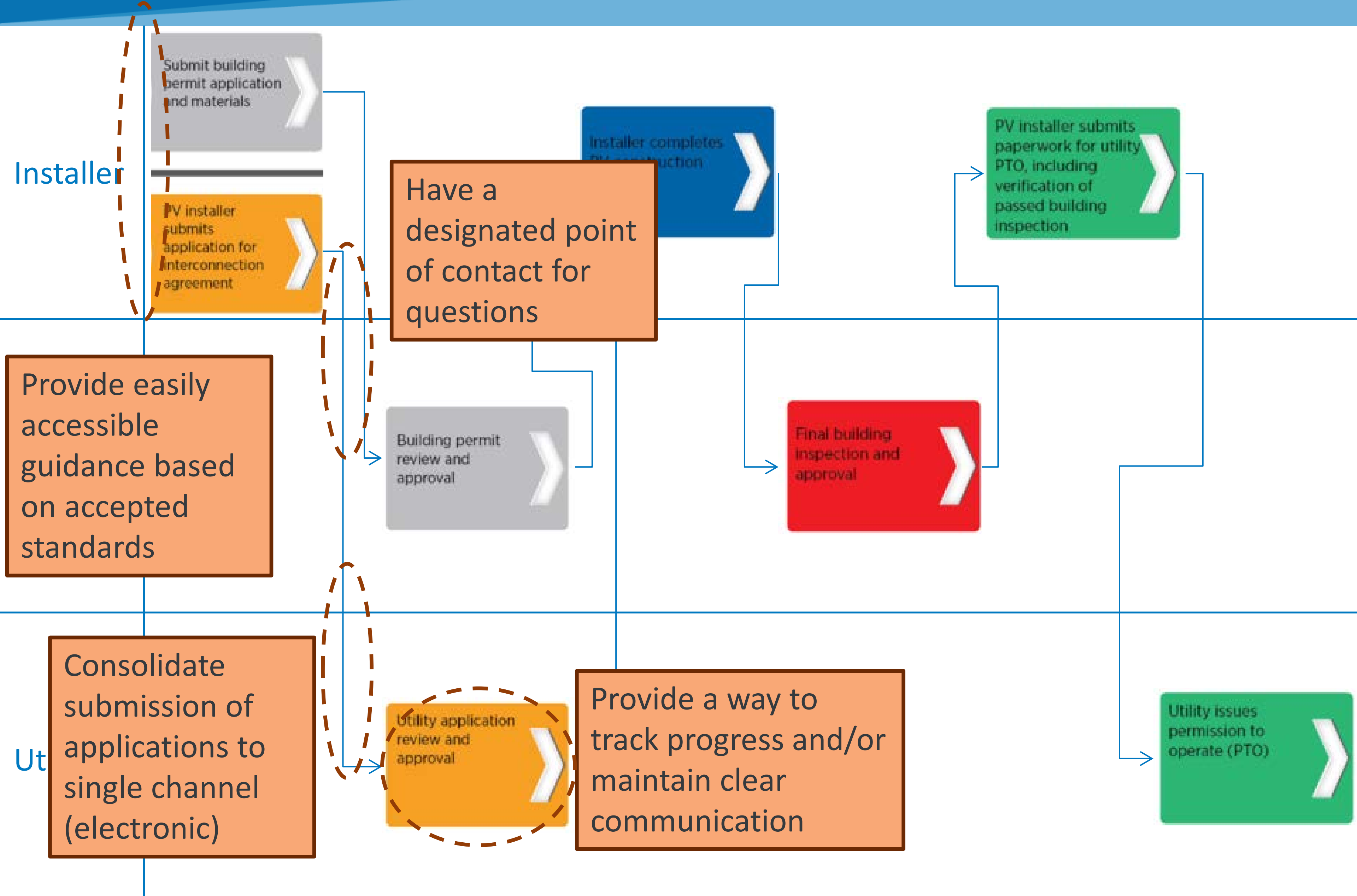
- Upgrade Line Section
- Modify Protection Scheme (breakers & fuses)
- Voltage Regulation Devices (Add or chance control)
- Direct Transfer Trip
- Advanced Inverters Required
- Communication & Control Technologies
- Power Factor Controls (Often advanced inverters)
- Grounding Transformers
- Static VAR Compensators
- Capacitor Control Modifications
- Volt/VAR Controls

Interconnection as Business Process

How Can a Utility Improve Customer Service?

1. Be clear
2. Be quick

1. Be Clear


Installer
Ut
Submit building permit application and materials
PV installer submits application for interconnection agreement
Installer completes
Have a designated point of contact for questions
PV installer submits paperwork for utility PTO, including verification of passed building inspection
Provide easily accessible guidance based on accepted standards
Building permit review and approval
Final building inspection and approval
Consolidate submission of applications to single channel (electronic)
Utility application review and approval
Provide a way to track progress and/or maintain clear communication
Utility issues permission to operate (PTO)

How Can a Utility Improve Customer Service?

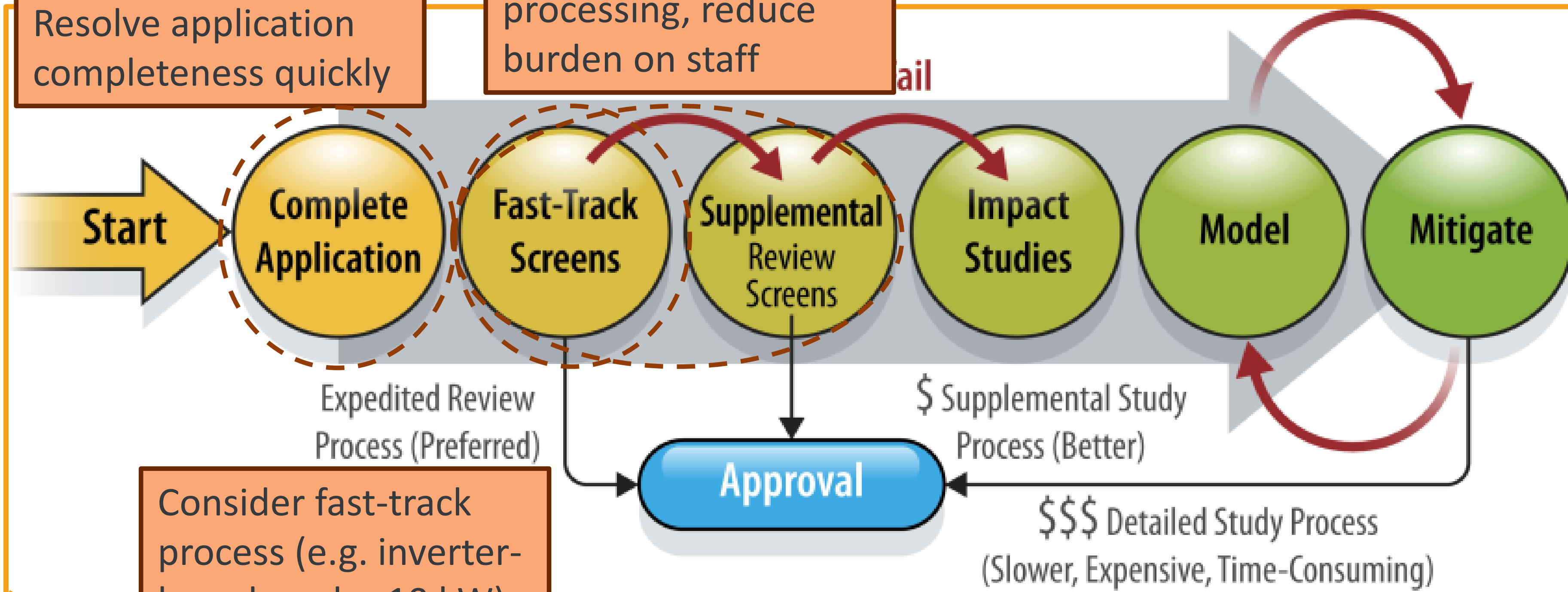
Be clear

- Easily accessible interconnection guidelines based on accepted standards
  - Model procedures: FERC Small Generator Interconnection Procedure (SGIP), IREC
- Designated points of contact at utilities
  - Ideally, a real person, not a generic inbox
- Single channel for submission of application materials (electronic)
  - Eliminates coordination of mail, fax, e-mail applications
- Provide a way for installers to track progress and/or clear communication of decisions, timelines, and cost
  - Email templates of standard updates

2. Be Quick

Resolve application completeness quickly

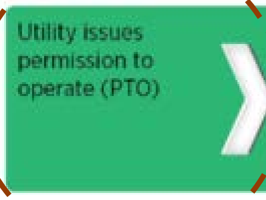
Use screens to speed processing, reduce burden on staff



Consider fast-track process (e.g. inverter-based, under 10 kW)

Utility

Process PTO paperwork quickly, last touch-point in the process



How Can a Utility Improve Customer Service?

Be clear

- Easily accessible interconnection guidelines based on accepted standards
- Designated points of contact at utilities
- Single channel for submission of application materials (electronic)
- Provide a way for installers to track progress and/or clear communication of decisions, timelines, and cost

Be quick

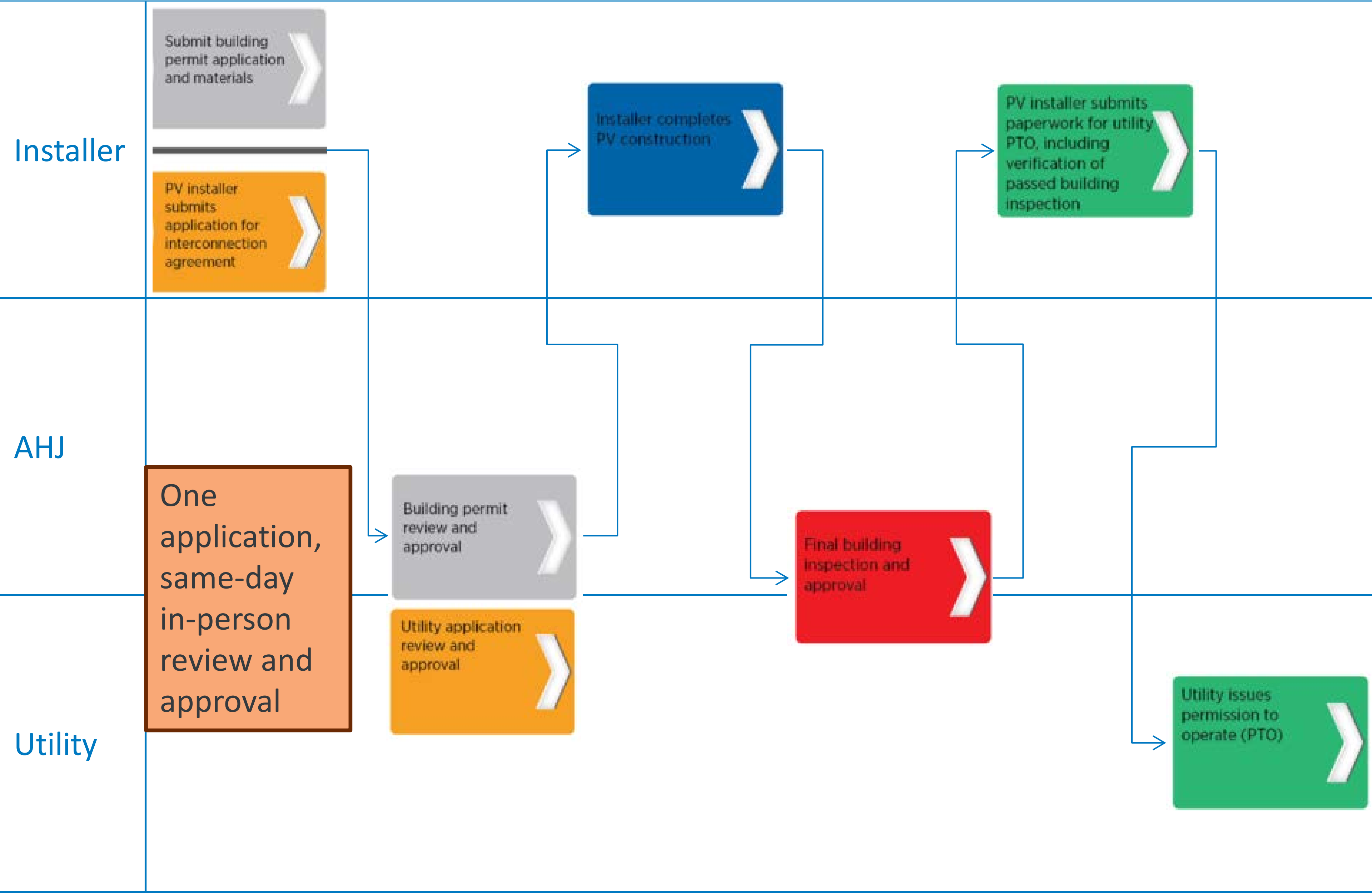
- Use checks for completeness
  - Engaging installers quickly can avoid long, frustrating waits
- Fast-track process (e.g. inverter-based systems under 10 kW)
  - Included in FERC SGIP and IREC model procedures
- Use screens to analyze systems quickly, reduce analytical burden on staff
- Move paperwork quickly and efficiently
  - Permission to Operate is simply confirming documents received and in order, last touch-point with customer in the process

- Bonus points: coordinate with local permitting process

Reducing Time and Cost of Interconnection

Municipal utilities may have unique opportunities to streamline the interconnection, incentive and building permit approval process as a result of having one centralized authority in control of the processes

Municipalities Can Merge Permitting and Interconnection



Advanced or “Smart” Inverters

What is a "Smart" Inverter - Functions

Multiple efforts have been made to standardized function set for smart inverters

Key capabilities include (but not limited to):

Function	Description
Connect/disconnect	Electrically connects to or disconnects from the grid
Maximum generation limit	Constrains real power output
Volt-VAR function	Adjusts reactive power output based on service voltage
Volt-Watt function	Adjusts real power output based on service voltage
Frequency-Watt function	Adjusts real power output based on service frequency
Low/high frequency ride-through	Defines frequency range for which inverter remains on-line
Low/high voltage ride-through	Defines voltage range for which inverter remains on-line
Event/history logging	Log and report standardized set of events
Status reporting	Report current device status

For More:
EPRI, Common Functions for Smart Inverters, Version 3, Report # 3002002233
http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002233
Distributed Energy Management (DER): *Advanced Power System Management Functions and Information Exchanges for Inverter-based DER Devices, Modelled in IEC 61850-90-7*
http://xanthus-consulting.com/Publications/documents/Advanced_Functions_for_DER_Inverters_Modeled_in_IEC_61850-90-7.pdf

What is a “Smart” Inverter - Benefits

- Increased grid stability
  - Local – voltage control from volt-VAR and volt-Watt functions
  - System – greater resiliency during frequency deviations
- Increased visibility into distribution system conditions via data collection
- Potential to defer investments in other distribution system hardware

Key Barrier – Technical Standards

Key Standards for Advanced Inverters

- UL 1741
  - Developed by Underwriter's Laboratory (UL)
  - Primarily an *equipment safety* standard
  - Sets design requirements and testing procedures
- IEEE 1547
  - Developed by Institute of Electrical and Electronics Engineers (IEEE)
  - Primarily an *interconnection performance* standard
  - Governs how inverters affect electrical conditions at the point of common coupling (PCC) with the grid

Key Barriers – Technical Standards

Standards acted as a barrier because other regulations rely on these measures

Equipment Safety

Prior to Supplement A, **UL 1741** did not have a testing procedure for advanced inverters

↓

Without a developed testing program under UL 1741, advanced inverters could not achieve **UL listing**

↓

Installations using advanced inverters which are not UL-listed cannot comply with the **National Electrical Code**

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Installations which do not comply with the National Electrical Code will violate **state or local building codes**

Interconnection Performance

IEEE 1547-2003 does not allow inverters to perform "advanced" functions beyond those in IEEE 1547a-2014

↓

In most states, an inverter which violates IEEE 1547-2003 does not meet **state interconnection standards**

↓

Inverter deployments which do not meet state standards will not pass **utility interconnection processes**

UL 1741 Supplement A (UL 1741 SA)

Updated to include advanced functions

Approved September 2016

Several inverters have been certified to date

The UL 1741 SA consists of the following advanced inverter grid support utility interactive test plan:

Required Tests *(utilized by all SRDs)*
Anti-Islanding *(with advanced features active during test)*
Low/High Voltage Ride Through
Low/High Frequency Ride Through
Must Trip Test
Ramp Rate *(Normal & Soft-Start)*
Specified Power Factor
Volt/Var Mode
Optional Tests *(depends on SRD being utilized)*
Frequency Watt
Volt Watt

IEEE 1547 full revision

Complete overhaul of interconnection requirements

New content on:

- Reactive power
- Ride-through requirements
- DER on secondary networks
- Interoperability and communications
- Test and verification requirements

In balloting now, publication anticipated summer 2017

Key Barriers - Communications

Communications bring challenges and benefits

Challenges

- Many layers of physical and software infrastructure
- Standardization to maximize value requires coordination across many parties

Benefits

- Enables certain high-value functions
  - E.g. real power curtailment
- Supports more frequent updates to otherwise-autonomous functions
- Increases visibility for distribution management

Key Barriers - Communications

Communications Level		Inverter Functions	Proceedings and Standards	
Autonomous	– No communications architecture needed – Behavior controlled by operating parameters – Parameters defined at system commissioning – Parameters can be adjusted, behavior activated or deactivated at later date via remote or on-site changes	Low- / High-voltage ridethrough	SIWG Phase 1	IEEE 1547a-2014
		Low- / High-frequency ridethrough		
		Volt-var control		
		Anti-islanding		
		Ramp-rate controls		
		Provide reactive power (via fixed power factor)		
		Reconnect via "soft-start"		
		Frequency-watt	SIWG Phase 3	
		Voltage-watt		
		Dynamic current support		
		Smooth frequency deviations		
Non-Autonomous	– Communications and control infrastructure required – Direct control of inverter behavior – Control from remote operator commands or feedback, based on conditions at point of common coupling	Command DER to connect/disconnect	SIWG Phase 3	
		Limit real power		
		Set real power		
		Provide black-start capability		
		Respond to real power pricing signals		
		Participate in automatic generator control (AGC)		
		Provide spinning reserves or bid into market		
		Update static set points for autonomous functions (fixed power factor, volt-var curves, voltage ride-through, frequency ride-through)		

Adapted from: http://www.pjm.com/~/media/committees-groups/committees/pc/20140428-advance/20140428-item-04-sma-smart-inverter-grid-support-capabilities.ashx

Distributed Generation Interconnection Collaborative

- Funded by DOE SunShot Initiative
- Peer exchange on interconnection
- 17 webinars produced to date
- Next webinar: May 18, 2017 on interconnection for small utilities

Utilities

Southern California Edison
Pacific Gas and Electric (PG&E) (x2)
San Diego Gas and Electric (SDG&E)
Sacramento Municipal Utility District (SMUD)
Hawaiian Electric Companies (HECO) (x2)
Arizona Public Service (APS) (x2)
Salt River Project (SRP)
Tucson Electric Power (TEP)
Xcel Energy
PEPCO
Con Edison
National Grid
Pasadena Water and Power
Fremont (NE) Dept of Utilities

Research Organizations

RMI
EPRI
SEPA (x2)
City Univ. of New York (CUNY)

National Laboratories

NREL (x2)
Sandia

Utility Associations

NRECA
WAPA

Other Presenters

Borrego Solar (x2)
Enphase Energy
ERCOT

www.nrel.gov/dgic/

SunShot
U.S. Department of Energy

Thank You!

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