Addressing Solar PV Interconnection Challenges: Lessons for Local Government and Utilities

Municipalities and local governments who have renewable energy or solar goals may face challenges with interconnection as more residents and businesses begin to install solar photovoltaics (PV). It is estimated that by the end of 2017, more than 1 million solar energy systems will be interconnected to the electrical grid in the United States[1]. However, the distribution of solar energy is uneven—in 2013 75% of distributed solar interconnections were processed by just 5% of utilities. The interconnection process is time consuming in much of the US. In 2013, SEPA reported that out of 400 utilities surveyed only 15% managed to process high numbers of applications in less than 4 week timeframes. Delays in the interconnection approval process can add to the overall costs of developing solar, which can deter potential customers, especially in residential markets. The fast uptake of solar, combined with this concentration has created challenges for utilities, solar advocates, and local governments:

- Utilities are concerned about maintaining safety and reliability in the face of high distributed generation (DG) penetration, and some have pushed back against new interconnection requests.
- Solar advocates and developers want to ensure transparency and expediency in the interconnection process, and are often frustrated by long approval times that slow the market or add costs.
- Local governments are interested in reaching their renewable energy goals, and advocating on behalf of their residents and local businesses.

Local government can play an important role both educating their constituents on processes related to interconnection, as well as advocating for improvements and coordinating with the utility or Public Utility Commissions. However, local government officials may not be equipped to play this role and desire more information to better engage with their utilitiy. The following paper aims to help local governments better understand the distribution grid, basics around interconnection concerns, and the interconnection screening process. Additionally, three case studies show what utilities have done to streamline and improve their interconnection processes in the face of higher interconnection requests.

Understanding the Grid

In the United States, the supply of electricity is considered an "essential service" provided by electric utilities[2]. The electrical grid has three primary components: generation, transmission, and distribution. The electrical grid was designed so that electricity flowed in one direction—first generated centrally at large power plants, next transmitted outwards, and finally distributed to customers. In some states utilities are "vertically integrated," meaning they are responsible for all aspects of this supply chain. In states that have been "restructured," generation and distribution services are separated and supplied by different utilities. This paper focuses primarily on transmission and distribution level utilities.

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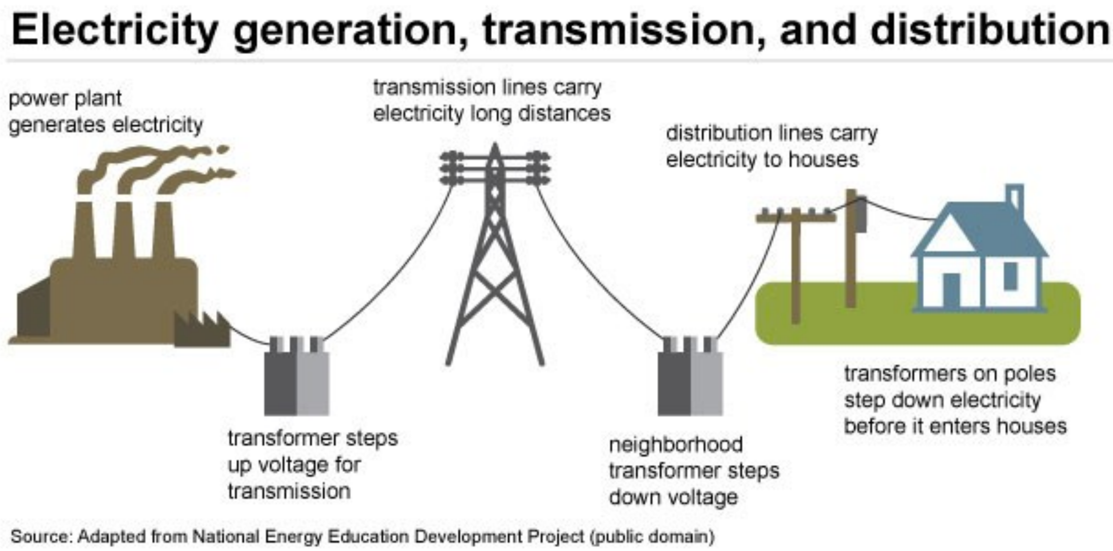
[1] SEPA. 2014. "Distributed Solar Interconnection Challenges and Best Practices". Retrieved from: http://www.growsolar.org/wp-content/uploads/2014/10/SEPA-Interconnection-Report-1014-email.pdf

[2] Lazar, J. (2016). *Electricity Regulation in the US: A Guide. Second Edition.* The Regulatory Assistance Project. Retrieved from: http://www.raponline.org/knowledge-center/electricityregulation-in-the-us-a-guide-2



In the U.S., most electricity is generated centrally at natural gas, coal, or nuclear power plants[3]. Generation sites are often remote from areas where the electricity is used, and is generated at 10,000 to 25,000 volts. To move electricity to customers the voltage is "stepped up" to higher volatges of 230,000 to 765,000 volts, then transported long distances over transmission lines. At transmission substations, the voltage is "stepped down" to usable voltages which then moved to customers on "distribution" lines. Different customers may use different voltages, for instance some commercial and industrial site use a higher voltage of 12,000 to 115,000 volts, while the typical residential customer uses between 120 to 240 volts that require further step down[4]. The lines that serve lower voltage residential customers are sometimes referred to as "feeders." In some networks, particularly in "radial systems" the voltage on these feeders may be stepped down to 4000 volts (or 4 kilovolts (4 kV) before being distributed to customers. Several utilities with 4 kV feeder lines are in the process of upgrading them to 12kV or 13kV lines, tripiling their capacity. The system of feeders and circuits connected to one substation is considered the "substation footprint."

Utility Ownership and Regulation

There are over 3,000 utilities in the United States and each oversees its own interconnection requirements and procedures, which vary depending on state and federal jurisdiction[5]. State Public Utility Commissions (PUC) or Public Service Commission (PSC) ensures that Invester Owned Utilities (IOUs) charge "just and reasonable rates," and guide state regulations which include standards for utility distribution-level interconnection. However, each individual IOU is responsible for establishing their own interconnection procedures within the state requirements set by the Public Utilities Commission.

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[3] U.S. Energy Information Administration. 2016. "Electricity Explained". Retrieved from: https://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states
[4] U.S.-Canada Power System Outage Task Force (2003). *Final Report*. Retrieved from: https://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf
[5] M Bruan et al. 2011. "Is the distribution grid ready to accept large-scale photovoltaic deployment?" Retrieved from: http://onlinelibrary.wiley.com/wol1/doi/10.1002/pip.1204/full

	Investor Owned Utility (IOU)	Municipal Utilities (MOU)
Ownership	Privately owned	Municipal or county
Governance	Governed by shareholders	Governed by an elected board
State Regulation	Held to state regulations determined by the PUC or PSC	Minimal regulation from the state

Concerns around Distributed Generation

Distributed generation (DG) presents several challenges when interconnected to the distribution grid. Instead of electricity originating centrally and flowing through the standard transmission, substation and distribution pathways, small scale DG adds electricity to the grid at the distribution level of homes and businesses (see graphic above). DG solar PV creates additional challenges due to its variable power output, which changes based on the time of day, season, and weather. The technical concerns for utilities include voltage deviations, such as over voltage, decreased reliability in service, and islanding[6]. These issues can damage equipment and can cause safety concerns for both customers, first responders, and utility workers. However, many of these concerns can be addressed through technology upgrades.

- **Voltage deviations**, such as **Over voltage,** are of special concern, as voltage is sensitive to minor changes in power inputon low voltage distribution lines, particularly those that are 4kV (see glossary for explanation of terms). On distribution networks without DG, power is introduced at the substation, and the voltage decreases as power moves outwards. Power is introduced in a similar way at network points were DG solar PV systems interconnect. Under certain conditions, power generated by DG solar PV can cause voltages to rise above normal operating conditions. The location of the solar PV along the feeder line in relation to customer loads, other DG, and substations all impact the concerns around voltage.
- **Voltage deviations**, such as **Over voltage,** are of special concern. Typically, power is introduced onto the distribution network at the substation level, and the voltage decreases as power moves outwards along the feeder lines. When distributed generation is added to the distribution network, power is introduced throughout the network where DG is interconnected. Power generated by DG solar PV can cause voltages to rise above normal operating conditions. The location of the solar PV along the feeder line in relation to customer loads, other DG, and substations all impact the concerns around voltage. Low voltage feeder lines, particularly 4kV feeder lines (glossary for explanation of terms) are particularly sensitive to minor changes in power input.
- **Islanding** describes a portion of the grid that is unintentionally energized. When the grid loses power for intentional (scheduled maintenance) or unintentional (blackout caused by network trip or damaged lines) reasons, interconnected DG solar PV systems will produce power and may feed into the grid. This scenario poses safety concerns for utility line

[6] NREL et al. 2012. Updating Interconnection Screens for PV System Integration. Retrieved from: http://www.nrel.gov/docs/fy12osti/54063.pdf

workers, first-responders, and others that interact with power lines during grid failure, who need to know when lines are energized. Islanding from DG solar PV is unusual, as inverters are designed to disconnect from the grid during power failure events[7]. (See glossary for more definitions).

Interconnection and Utility Screens

When a customer (residential, commercial, or industrial) wants to build DG solar PV and connect to the electricity grid, this process is called interconnection. Customers must get approval from their utility before they can build a solar PV system and interconnect to the grid. The purpose of the interconnection process is to maintain safety and reliability, as well as makes sure that any additional costs such as technology upgrades are accurately allocated[8]. The size and location of the solar PV installation, characteristics of the feeder line, and proximity to other DG solar PV installations and substations all impact the results of the interconnection screen.

The interconnection process often includes a series of "technical screens" to address concerns about safety, reliability, and impacts on the grid. Additional screens or studies may be needed if a proposed system does not pass the initial technical screen; often at the cost to the developer or property owner who is applying for interconnection. These additional screens may include an interconnection feasibility study, an impact study, and a facilities study. Similarly, delayed interconnection processes add to the total time it takes from conception to completion of the project, which increase the soft costs[9] of solar. Some customers may be allowed to interconnect only if they install costly technology or pay for improvements. Potential customers may also be deterred from installing solar if they know that interacting with their utility through the interconnection process may be lengthy, difficult, or ultimately add to the cost of solar.

While the interconnection process is determined by the PUC and the utility, local governments can play the important role of consumer advocate. Local governments who have renewable energy goals, run a solarize campaign, or encourage solar in other ways may find that their residents and business onwers are facing challenges with the utility and interconnection. However, as the case studies below show, utilities can and are already undertaking inititives to improve both the interconnection application process, as well as finding ways to deal with concerns around higher penetration of DG. Local governments can advocate or show their support for these types of utility led interventions that are intended to benefit residenti and bussinessed in their community who desire to installer DG solar PV on their home or busiesns.

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[7] NREL et al. 2012. "Updating Interconnection Screens for PV System Integration". Retrieved from: http://www.nrel.gov/docs/fy12osti/54063.pdf
[8] NREL et al. 2012. Updating Interconnection Screens for PV System Integration. Retrieved from: http://www.nrel.gov/docs/fy12osti/54063.pdf
[9] Soft costs are non-hardware costs that make up the price of solar including the costs associated with permitting, inspections, marketing, and labor.

Case Studies

As more aggressive renewable energy targets are developed, the electrical grid will need to be modernized to address higher levels of DG penetration. In the near term, utilities should work to improve their interconnection processes to encourage DG and improve efficiencies and effectiveness for their customers. The following case studies highlight the issues that utilities are facing related to high DG penetration. These examples point to a host of interventions that can be undertaken by utilities and other stakeholders to address these concerns. Improvements may include:

- Increasing communication and transparency from the utility to the customer
- Adoption of online or expedited interconnection application processes
- Updating the interconnection screening process based on most-recent best practices
- Provide transparent and clear information to customers, such as a mapping tool, that shows where higher penetrations of solar PV would have less of an impact on the grid
- Using advanced smart inverter technology[10]

Hawaiian Electric Company (HECO) [11]**: Research to policy change**		
Vertically integrated investor owned electric utility	*303,000 customers on Oahu*	*2200 MW capacity, 470 MW renewable, 332 MW DG solar PV*[11]

Hawaii has the third most installed solar PV capacity per capita among US states[12]. On Oahu, most of this capacity is generated from customer-sited DG solar PV. The popularity of residential solar PV in Hawaii is driven by high electricity prices and state renewable energy goals. However, high DG solar PV penetration has created challenges for Hawaiian utilities, and in 2014 it was reported by installers that 35.71% of their interconnection requests were denied by HECO based grid reliability concerns, this was the highest percentage of denials in the country[13].

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[10] All grid tied inverters are required by IEEE standards to prevent backflow of power into the distribution line when the grid is down. This prevents unintentional islanding.

[11] Hawaiian Electric Companies. "Power Facts". Retrieved from: https://www.hawaiianelectric.com/about-us/power-facts

[12] SEIA. "Top 10 Solar States". Retrieved from: http://www.seia.org/research-resources/top-10-solar-states.

[13] Chalsea Barnes, EQ-Research. 2015. "Comparing Utility Interconnection Timelines for Small-Scale Solar PV". Retrieved from: http://eq-research.com/wp-content/uploads/2015/07/IC-PTO-Timeline-Report-7-2015.pdf

Under Hawaii's Rule 14H a supplemental review is required for new DG solar PV connected to feeders with 15% or more DG solar PV peak demand penetration. While many HECO feeders exceeded this threshold under previous regulation, smaller residential systems of 10kW or less could interconnect with the grid before final approval of their net metering contract[14]. However, in 2013, HECO announced new requirements (including smaller residential systems) to conduct an additional interconnection requirement study (IRS) on systems connecting to feeders that met both the 15% threshold and were above 100% "gross daytime maximum load" (GDML) penetration[15]. The additional IRS could take up to 4 to 6 months to complete, thus adding significantly to the time and costs of installing solar PV. They found that almost 25% of HECO feeders exceeded the 100% GDML[16] and the new HECO rule significantly slowed solar development. Facing a lengthening interconnection queue and state pushback, HECO contracted with National Renewable Energy Laboratory (NREL) to study the impacts of DG solar PV on distribution system stability.

Distribution Grid Stability Studies

NREL conducted several studies on the stability of feeders in high-DG solar PV penetration scenarios, and assessed technical and policy solutions[17]. The study found that voltage back-feeding and transient overvoltage (TrOV) did not have the level of risk as previously thought and that the 15% threshold and 100% GDML requirements were too conservative. HECO used the NREL recommendations to make policy adjustments to its interconnection process and in 2015 the utility raised the GDML threshold to 250%. The results of the studies are helping HECO prepare for more DG solar PV development including plans to increase solar PV capacity to 650 MW by 2030[18]

Pacific Gas and Electric (PG&E): Customer-facing approach with online tools		
Investor owned electric and gas utility in CA ISO territory	*5.3 million accounts in Northern and Central California*[19]	*7700 MW capacity, 4000 MW utility owned renewable, 2400 MW DG Solar PV*[20]

California has more than 13,000 MW solar PV capacity installed on more than 3.3 million homes, which is more than in any other state. Residents are encouraged to adopt solar PV due to low cost-per-watt and state regulations such as Rule 21, which has helped streamline the interconnection

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[14] Hawaiian Electric Company. 2013. "Hawaiian Electric to help Oahu solar customers caught in transition to new interconnection procedures". Retrieved from: https://www.hawaiianelectric.com/hawaiian-electric-to-help-oahu-solar-customers-caught-in-transition-to-new-interconnection-procedures

[15] J.Simon, T. Tian, C. Liu, and M. Miller, NREL. 2015. "Case Study Analysis for U.S. Policy Solutions to Enable China New Energy Cities". Retrieved from: http://www.nrel.gov/docs/fy15osti/63529.pdf

[16] NREL. 2014. "High Penetration of Distributed Solar PV Generation: Lessons Learned from Hawaii". Retrieved from: https://www.energy.gov/sites/prod/files/2014/12/f19/1-Champley-DEPresentation-Sep2014.pdf

[17] NREL. 2013. "Analysis of High=Penetration Levels of Photovoltaics into the Distribution Grid on Oahu, Hawaii". Retrieved from: http://www.energycollection.us/Energy-Distribution/Analysis-High-Penetration.pdf. NREL. 2013. Hawaii Solar Integration Study: Executive Summary. Retrieved from: http://www.nrel.gov/docs/fy13osti/57215.pdf.

[18] "Response to Hawaii Public Utilities Commission Order No. 32053" August 26, 2014. Retrieved from:

[19] PG&E. "PG&E Overview". Retrieved from: http://www.pgecorp.com/corp_responsibility/reports/2015/bu01_pge_overview.jsp

[20] California DG Stats. "Distributed Generation Interconnection Program Data". Retrieved from: http://www.californiadgstats.ca.gov/downloads/

process[21]. Distribution utilities have also played an important role in the state's solar success; over the past few years PG&E has managed to reduce its average interconnection timeline for customers, despite increased applications[22]. PG&E provides a range of tools, factsheets, and services designed to assist customers with the DG PV interconnection process including:

- **Online Application:** PG&E customers submit interconnection applications through the online Net Metering Interconnection Tool (NMIT)[23], which saves the utility and its customers time and money. Before the online tool was introduced, applicants would fill out a paper form, which were manually transcribed into the database. The NMIT interfaces with PG&E database, which allows PG&E to processes requests quickly, and has reduced the error rate caused by manual transcription from more than 30% to 5%[24].
- **Streamlined Application:** In PG&E territory, installers have the option of submitting interconnection and Permission to Operate (PTO) applications for qualifying systems in one step. A 2014 NREL report found that 70% of residential projects in CA were approved through this streamlined process. The report contrasts this with the interconnection processes in New York and New Jersey, where more than 90% of applications required separate interconnection and PTO paperwork[25].
- **Mapping the Distribution Network:** PG&E provides a free online map of its transmission and distribution network. Feeders are color categorized by their ability to take on additional DG resources. The map includes detailed information about each individual circuit. Before beginning a DG solar PV project, installers can check circuit capacity, projected peak load, existing and queued distributed energy on the circuit, and estimated caps on the circuit. The ability to assess available capacity before beginning projects is valuable to developers and customers, who can understand the likelihood that an interconnection study will be required before applying time and money to a project[26].

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[21]PG&E. "Electric Generation Interconnection: Wholesale Distribution and Rule 21 Export Electric Generation". Retrieved from: http://www.pge.com/includes/docs/pdfs/mybusiness/customerservice/otherrequests/newconstruction/ElectricGeneratorInterconnect.pdf

[22] Aaron Johnson. 2015. "How to reduce solar-grid interconnection time by nearly 80 percent". Retrieved from: https://www.greentechmedia.com/articles/read/How-to-Reduce-Solar-Grid-Interconnection-Time-by-Nearly-80-Percent

[23] PG&E. "Standard Net Energy Metering Interconnection". Retrieved from: https://www.pge.com/solar/nemLanding/build/form1?execution=e1s1

[24] Chelsea Barnes, EQ Research. 2015. "Comparing Utility Interconnection Timelines for Small-Scale Solar PV". Retrieved from: http://eq-research.com/wp-content/uploads/2015/07/IC-PTO-Timeline-Report-7-2015.pdf

[25] K. Ardani et al. NREL. 2015. "A State-Level Comparison of Processes and Timelines for Distributed Photovoltaic Interconnection in the United States". Retrieved from: http://www.nrel.gov/docs/fy15osti/63556.pdf

[26] PG&E. "Use out map to identify potential sites for your project". Retrieved from: https://www.pge.com/en_US/for-our-business-partners/energy-supply/solar-photovoltaic-and-renewable-auction-mechanism-program-map/solar-photovoltaic-and-renewable-auction-mechanism-program-map.page

PG&E's efforts appear to work well. From 2013 to 2014, the number of interconnection requests doubled, but the wait time for customers decreased from 16 to 11 days[27]. In parallel, the utility decreased the cost of interconnection application by 70%[28].

PPL Electric Utilities (PPL): Proactive technology upgrades		
Investor Owned electric distribution utility in PJM territory	1.4 million customers in central and eastern PA	8,000 MW capacity, 8% from renewable energy,

Adoption of DG solar PV has been slower in Pennsylvania than neighboring New Jersey and New York; there is only 300 MW of solar PV capacity installed statewide[29]. However, the State does have ambitious goals, in 2004, Act 213 mandated utility adoption of solar generation resources, and by 2021 the State's solar PV capacity is expected to climb closer to 1,000 MW[30]. PPL has taken a proactive approach towards readying grid infrastructure for the expected increase in DG solar PV. The utility has communicated with customers about key considerations and necessary steps to install DG solar PV systems,[31] which has led to high customer satisfaction ratings[32]. They have recently required costumers to install smart inverters for DG solar PV and will be piloting new software to monitor and control these DG solar PV systems.

- **Smart Inverters**: When electricity is generated by a solar PV system, it is created in Direct Current (DC), however, the majority of appliances and electricyt grid operate on Alternating Current (AC). An inverter is required to convert the DC electricity to AC to be used in the home, business, or sent back the grid. Smart inverters are widely viewed as essential tools for reliably increasing DG solar PV penetration. Most inverters currently deployed prevent DG solar PV from exporting electricity to the grid when local conditions deteriorate, such as voltage deviations or outages. Smart inverters include software that control the unused electricity produced by the solar PV when it is exported to the grid, and can be used to help

[27] Chelsea Barnes, EQ Research. 2015. "Comparing Utility Interconnection Timelines for Small-Scale Solar PV". Retrieved from: http://eq-research.com/wp-content/uploads/2015/07/IC-PTO-Timeline-Report-7-2015.pdf
[28] Aaron Johnson. 2015. "How to reduce solar-grid interconnection time by nearly 80 percent". Retrieved from: https://www.greentechmedia.com/articles/read/How-to-Reduce-Solar-Grid-Interconnection-Time-by-Nearly-80-Percent
[29] SEIA. "Pennsylvania Solar". Retrieved from: http://www.seia.org/state-solar-policy/pennsylvania
[30] PA Department of Environmental Protection. "Pennsylvania's Solar Share" Retrieved from: http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/lib/energy/docs/pa_solar_share_factsheet_010709.pdf
[31] PPL. "FAQ's for PPL Electric Utilities". Retrieved from: https://www.pplelectric.com/-/media/PPLElectric/At-Your-Service/Docs/Customer-Owned-Generation/RenewableenergyFAQs.pdf
[32] "J.D. Power Reports: Communicating with Customers and Higher Price Satisfaction Increase Overall Satisfaction for Residential Electric Utilities". July 15, 2015. Retrieved from: http://www.jdpower.com/sites/default/files/2015104%20Electric%20Residential%20Press%20Release_104_Final2.pdf

stabilize grid conditions. PPL requires that customers install smart inverters along with DG solar PV (requirements dependent on the installation size)[33].

- **Software Solution**: One challenge DG solar PV creates for utilities is the lack of visibility into feeder level voltage conditions. In January 2017, PPL was selected by the Department of Energy to receive a $3.3 million SunShot grant, which will be used to fund a project aimed at using existing grid technologies to optimize high penetration DG solar PV on its network[34]. Through the SunShot project, PPL is aiming to create a platform to monitor and control DG solar PV at the feeder level and give the utility the ability to monitor DG solar PV output in real-time. This network will include the ability to communicate with customers. The project will be piloted on 10 feeders in 2017, and if successful will be deployed across the PPL distribution network.

Summary of Case Studies

While interconnection processes of DG may present a challenge for both utilities and potential DG owners, these case studies show that utilities can take steps to improve the process and increase customer satisfaction, while maintaining a safe and reliable grid.

	HECO	**PG&E**	**PPL**
	Research to policy change	Customer-facing approach with online tools	Proactive technology upgrades
Challenge	• High percentage of denials due to reliability concerns of DG on feeder lines • High numbers of systems needing additional interconnection studies	• Steep increase in interconnection requests • Large error rates in transcribing manual applications	• Increasing demand for and deployment of DG solar PV in PA
Solution	• HECO commissioned research study by NREL which resulted in a policy change and less conservative requirements for additional interconnection studies.	• Adopted an online application • Streamlined process for qualifying systems • Provided an online mapping tool for solar developers	• Require smart inverters • Piloting software to monitor real-time output of DG

[33] PPL. "PPL Electric Utilities Grid Tied Solar Inverter Requirements". Retrieved from: https://www.pplelectric.com/~/media/pplelectric/at%20your%20service/docs/remsi/metering-equipment-tables/grid-tied-inverter-guide.pdf
[34] US DOE. "Enabling Extreme Real-time Grid Integration of Solar Energy (ENERGISE)". Retrieved from: https://energy.gov/eere/sunshot/enabling-extreme-real-time-grid-integration-solar-energy-energise

Role of Local Government

While many of the solutions presented in the case studies were driven by the utility themselves, local government can play an important role in engaging with stakeholders and advocating for solutions. Local governments should take a collaborative approach to working with their utility to identify challenges and offer solutions.

Local governments can:

1. Engage with solar installers to better understand trends or challenges as they arise. This may be through a regular online survey to local installers, focus group, round-table forum, or engaging with local trade groups like state chapters of SEIA.
2. Engage with residents and business owners who have installed solar to better understand trends or challenges as they arise.
3. Engage directly with the utility to talk about challenges, best practices and provide feedback through round-table discussions or public forums.
4. Engage with the PUC or PSC around state regulation and policy changes through letter writing, public forums, and other communication.

Additional Resources

Lazar, J. (2016). *Electricity Regulation in the US: A Guide. Second Edition*. Montpelier, VT: The Regulatory Assistance Project. Retrieved from: http://www.raponline.org/knowledge-center/electricityregulation-in-the-us-a-guide-2

Pathways to 100: An Energy Supply Transformation Primer for U.S. Cities.
Meister Consultants Group. Retrieved from: http://www.mc-group.com/wp-content/uploads/2017/05/MCG-Pathways-to-100-Energy-Supply-Transformation-Primer-for-Cities.pdf

Role of Municipal Utilities on Driving Solar Development. The Solar Foundation.http://static1.squarespace.com/static/56035ff7e4b01dadee1991a1/t/5710f5197da24f41d567f988/1460729113396/TSF+SolarandMunis_FINAL.pdf

Gross daytime minimum load (GDML) is the minimum system load plus solar PV generation at that moment of minimum load, on a defined portion of the grid (usually a feeder) over a defined time-period (usually a year).

Islanding describes a portion of the grid that is unintentionally energized. When the grid loses power for intentional (scheduled maintenance) or unintentional (blackout caused by network trip or damaged lines) reasons, interconnected DG solar PV systems will produce power and may feed into the grid. This scenario poses safety concerns for utility line workers, first-responders, and others that interact with power lines during grid failure, who need to know when lines are energized. Islanding from solar PV is unusual, as inverters are designed to disconnect from the grid during power failure events[35].

Over Voltage is a concern on any distribution network with DG, solar PV or otherwise. On distribution networks without DG, power is introduced at the substation, and the voltage decreases as power moves outwards. Power is introduced in a similar way at network points were DG solar PV systems interconnect. Under certain conditions, power generated by DG solar PV can cause voltages to rise above normal operating conditions. The location of the solar PV along the feeder line in relation to customer loads, other DG, and substations all impact the concerns around voltage.

Penetration: a ratio of the amount of solar PV power over total power at a certain time on a defined portion of the grid. Many studies calculate penetration at the time of annual peak load. This paper usually refers to penetration at a feeder level.

Voltage back-feeding: the condition where electric power flows opposite to its usual direction. In the case of feeders, the opposite flow direction is also different from the intended direction, i.e. towards rather than from distribution substations, and back-feeding can damage grid equipment.

Transient overvoltage (TrOV): short-duration voltage spikes exceeding the upper limit of a circuit. Over time TrOV degrades grid components and can damage electrical equipment.

[35] NREL et al. 2012. "Updating Interconnection Screens for PV System Integration". Retrieved from: http://www.nrel.gov/docs/fy12osti/54063.pdf