Solar and Grid Stability: A Primer for Local Governments

As America's energy demand continues to grow during an era increasingly concerned with energy security, energy independence, and the global environmental impact of conventional forms of energy generation, electricity derived from solar technologies – both photovoltaic (PV) and concentrating solar power – is playing an important role in how we meet this demand. The growth in domestic solar energy has grown precipitously over the past several years. Currently, the U.S. has over 4,129 megawatts (MW)[i] of operating PV capacity and over 500 MW of concentrating solar power capacity.[1] This growth is not limited to large solar farms. By the end of 2011, commercial and residential PV systems accounted for over 70% of the nation's total installed PV capacity.[2] An increasing number of states, communities, and homeowners have realized the many benefits of increased solar penetration – reductions in environmentally damaging emissions, long term energy cost savings, and booming job creation. As prices continue to decline, more of the population comes to understand and appreciate these benefits, and as state and local governments continue to adopt policies that mandate, facilitate, or incentivize the installation of solar energy systems, solar energy capacity in the U.S. will continue to rise steeply.

While these factors are strongly in favor of a large increase in grid integrated solar energy systems, some observers have expressed concern that rapid growth in grid-connected solar energy systems poses significant challenges to grid safety and reliability.[3] Written for energy and environmental managers and those overseeing municipal utilities, this short paper presents an overview of the potential challenges of increased solar penetration to the electric grid and explores the recent technological and organizational advances that have been made to help obviate these concerns. It also discusses what can be done on the local level to reap the benefits of the widespread use of solar while ensuring grid reliability and safety are maintained.

The Electric Grid in the United States

The electric grid is a vast network by which power is transmitted from sources of generation to the various points of demand, and it is the responsibility of those operating the grid to ensure the delicate balance between electricity supply and demand is maintained every instant the grid is operational. The grid can be broadly divided into two major components: a high-capacity *transmission* network that transmits electricity over long distances, and local *distribution* systems that deliver this electricity to end users. The relationship between the two can be thought of as analogous to the nation's interstate transportation infrastructure. The "high-capacity", multi-lane interstate highways are like the transmission network – they link major centers and are designed to transport large volumes between these centers. As one continues to branch off from the freeway towards towns or cities, traffic is *distributed* toward its final destination. Routes become narrower, shrinking down to two-lane residential streets that have a smaller *capacity* for this traffic.

[i] Capacity figures are quoted in megawatts of alternating current capacity (MWac). SEIA and GTM Research found that operating PV capacity was at 5,161 MWdc at the time this issue brief was published. At an 80% derate factor, these 5,161 MWdc can produce 4,129 MW of AC power.

In the U.S., an agency known as the Federal Energy Regulatory Commission (FERC) is responsible for setting standards governing solar energy systems connected at the transmission level. Though the FERC intends for its policies to be used as a model for developing interconnection standards for distribution networks, this portion of the grid is ultimately regulated by state, and in some cases local, authorities.[4]

As the number of solar energy systems connected to these lower capacity lines continues to increase, so too will concerns that the electricity generated by these systems will exceed the ability of the grid in these areas to handle this additional load. For local governments with control over interconnection standards within their jurisdiction (as in the case of municipal or "public power" utilities), a complete and accurate understanding of the impact solar has on the grid will be essential to developing standards that protect grid reliability without unduly hindering solar development.

Solar and Grid Stability Concerns

As noted above, the FERC has established a set of standards to protect grid stability at the interconnection level, and to serve as a model for state and local governments developing their own standards. In its Small Generator Interconnection Procedures (SGIP), solar distributed generation (DG) systems must meet a number of criteria (called "screens") before they are allowed to be connected to the grid. One of these screens limits the total electricity sourced from solar to 15% of peak load on any particular distribution circuit.[ii, iii] This 15% screen was implemented to protect grid safety and reliability by guarding against "unintentional islanding" and voltage fluctuations that can negatively affect the quality of the electric power delivered through the grid.[5]

Unintentional Islanding

"The possibility of unintentional islanding is a major concern for utility system planners when evaluating interaction issues between solar photovoltaic distributed generation and the power system."

– U.S. Department of Energy[6]

As anyone who has experienced a loss of electric service during a severe weather event - or has suffered through rolling blackouts during periods of extraordinarily high electricity demands - already knows, the electric grid is susceptible to outages. During these outages, whether the utility is supplying any electricity to the grid or not, a distributed generation source (such as a rooftop solar unit) could still be generating power and feeding electricity into the local feeder. This is often visualized as an island of electricity in a sea of dead power lines, and is referred to as "islanding". Under controlled circumstances, islanding may be used to test specific sections of the line or for research purposes, but when it occurs unintentionally it poses a serious safety hazard. One must understand that, in a large grid which is managed remotely (for the most part) by the utility, it can be difficult to identify an islanding occurrence, let alone isolate or resolve it.

[ii] For an explanation of the 15% screen and how it is calculated, see the National Renewable Energy Laboratory's report entitled *Updating Interconnection Screens for PV System Integration*, available at energy.sandia.gov/wp/wp-content/gallery/uploads/Updating_Interconnection_PV_Systems_Integration.pdf

[iii] It should be noted that an ever-growing contingent of knowledgeable stakeholders from the public, private, and non-profit sectors view this 15% screen as arbitrary and not based on the observed realities of the grid. A very brief summary of these arguments and some states' solutions is available at www.ilsr.org/wp-content/uploads/2012/08/archaic-utility-rules-barriers-infographic-ILSR.png

An undetected island, especially in cases of natural disasters and power outages, creates unsafe working conditions – including an increased risk of electric shock – for those repairing or replacing sections of the grid which are not functioning properly. Another concern is that, once service has been restored, the power flowing through these lines might be "out-of-phase", potentially causing damage to equipment at supply and demand locations as well as to the utility's transmission infrastructure.[7]

It is now required in most states for solar power plants, irrespective of their size, to comply with certain technical requirements before they can be connected to the grid. Strategies and technological improvements have been developed specifically to minimize the risk of unintentional islanding. Upgraded inverters with enhanced computing capability, and feedback devices that can analyze the smallest fluctuations in characteristics of the power, can be used to identify the existence of an island, and to cut off electricity supply as necessary. The UL 1741 Certification is provided to power plants whose inverters and other grid-connection equipment satisfy design prerequisites that have been established to prevent islanding.[iv] Though effective at minimizing islanding risk in PV systems isolated from others, the tests performed under this standard do not assess what, if any, interference occurs between multiple inverters in close proximity that could disable these anti-islanding features.[8] Despite this, the fact that unintentional islanding is an extremely rare occurrence in reality, even in areas with high solar penetration, has led the National Renewable Energy Laboratory (NREL) to conclude that the actual risk of islanding is very low.[9] In addition to the UL standard, the Institute of Electrical and Electronics Engineers' (IEEE) 1547 Interconnection Standard clearly defines the minimum technical requirements that will ensure safety on the grid.[v]

Much success has been realized over the past several years in the development of Grid Smart Inverters and Architecture (GSIA), which allow for increased grid operator control over inverter functions. The Solar Energy Grid Integration Systems (SEGIS) project, a research and development effort led by Sandia National Laboratories that includes key public, private, academic, and utility stakeholders, recently announced the successful development of a prototype grid-smart inverter that not only provides reliable anti-islanding protection, but can be remotely disconnected by the utility (or "curtailed") if necessary to protect the safety and reliability of the grid.[10] While the existence of an unintentional island continues to be a safety hazard (at least in theory), current and forthcoming precautionary measures can greatly reduce the probability of such an occurrence.[11]

Intermittency and Voltage Fluctuations

> *"A single large installation…fluctuated from making 700 kilowatts to making nothing on a second-by-second basis as clouds passed by. That caused the voltage on the circuit to which it's connected to fluctuate beyond the standards"*
>
> *- U-T San Diego, March 2011*[12]

Another commonly cited concern with grid-connected solar is the potential consequences of solar's intermittency on the quality of power transmitted through the grid. These potential consequences are primarily the result of the *variable* and *unpredictable* nature of solar resources. To say that solar is a *variable* resources means that its power

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[iv] For more on the UL 1741 Certification, please see www.ul.com/global/eng/pages/offerings/industries/energy/renewable/photovoltaics/balance

[v] Learn more about the IEEE 1547 Interconnection Standard at grouper.ieee.org/groups/scc21/1547/1547_index.html

output can change dramatically at a moment's notice. Solar is also *unpredictable*, in that it is difficult to forecast future system output due to the technology's sensitivity to weather conditions.[13] Both of these components of solar's intermittency can cause sudden fluctuations in voltage output, and thus power quality.[14]

Changes in voltage pose a theoretical hazard for appliances and other devices connected to the grid, as well as to the power lines themselves. Electrical appliances are designed and rated for specific values of power and voltage; when the power entering the device exceeds these thresholds, the devices have an increased risk of burning or blowing out. When the voltage is lower, the device may simply not function properly. Even within the safe range, if the fluctuations are large or rapid, the devices could be damaged. Power lines too, are rated for a certain power value. The heat generated from the transmission of power in excess of this could damage, or in some cases even completely melt the lines. Transformers and other such devices on the transmission network are also at risk of blowing out.

In addition to serving as a key preventative measure against unintentional islanding, inverters specially designed for grid-connected solar have also been developed to overcome these issues with voltage fluctuation and power quality.[15,16] With software and minor hardware upgrades to inverter designs, these devices can be recalibrated to regulate PV system voltage and provide for communication between the grid operator and the PV inverters, allowing for improved control over voltage fluctuations.[17] However, it should be noted that the aforementioned voltage regulation measures were not in compliance with the IEEE Standard 1547 as of this paper's publication. At the time of this writing, the IEEE was in the process of developing Standard 1547.8 to address these voltage and power issues, among others.[18]

Voltage control also becomes an issue at high levels of solar PV penetration[vi] (i.e., when solar accounts for at least 20% of the electricity flowing through a section of a distribution circuit). At penetration levels below this threshold, PV units with inverters set to "voltage following" mode (which prevents them from regulating distribution system voltage and is a required setting under IEEE Standard 1547) will have only a small impact on system voltage – causing manageable fluctuations of only a fraction of a percent. At high levels of PV penetration, however, these voltage fluctuations become much more significant and of greater concern for utilities.[19] However, the impact PV inverters have on distribution system voltage presents an opportunity for these devices to *contribute* to voltage regulation, rather than complicating it. As power is transmitted through the distribution system, the voltage of this power drops. To ensure that the desired voltage is delivered to a certain point in the system, utilities use a number of technological methods to adjust this voltage. Because PV inverters affect feeder voltage, they can not only be used instead of conventional means to control this voltage, but demonstrate a couple of advantages over current control methods. First, the distribution system's reactive power[vii] needs (the additional power required to maintain voltage quality) change continuously, while voltage control systems only provide additional power in discrete blocks, making it difficult to exactly match reactive power demand. Because PV inverters can supply continuous reactive power, they have the potential to better match this continuous demand. An additional advantage is that PV inverters operate much faster than current control technologies, the slower speed of which can result in short-lived voltage spikes.[20]

[vi] While no standard definition of "high penetration" exists, the SunShot Initiative's High Penetration Solar Portal notes that the International Energy Agency (IEA) defines this phrase as "the level where PV has an impact on the electrical power system." Learn more at solarhighpen.energy.gov/what_is_the_definition_of_high_penetration

[vii] An easy-to-understand explanation (by analogy) of reactive power is available at www.slideshare.net/sustenergy/reactive-power

Planning for the Future

"But if we are able to fundamentally shift the planning paradigm to include variable renewables as a non-negotiable piece of our energy mix…the prospect of integrating high levels of solar onto the grid becomes eminently manageable"
- Vote Solar, February 2011[21]

While very few (if any) sections of the electric grid currently face this concern, increased attention has been given to the need to upgrade the nation's transmission and distribution infrastructure, along with the methods used to manage the grid. Though grid-connected solar is a small driver of this need, prudence dictates that we should start planning for a solar-powered grid now. In a high penetration scenario, the variable nature of this energy source can impact the grid operator's ability to balance electricity supply with demand. When generation from renewable resources drops off, system operators will need to rely on electricity from conventional power plants to meet demand, and these power plants must be flexible and ramp up and down quickly, as needed.[22] The variable and unpredictable nature of solar means that grid operators will have to work harder, and require more accurate predictions of solar output, in order to balance supply with demand.[23]

These concerns, however, should by no means suggest that widespread use of renewables is out of reach. In June 2012, the National Renewable Energy Laboratory (NREL) released its *Renewable Electricity Futures* report, in which it concluded that up to 80% of all the electricity on the grid could come from renewable resources by the year 2050, through the use of technology that is currently commercially available. The study takes into account the intermittent nature of renewable resources, along with potential grid instability issues, and has concluded that technology is sufficiently advanced as to allow the U.S. to safely draw 80% of its power demand from grid-connected renewables. The study's authors note, however, that additional investment in transmission capacity, grid storage, flexible conventional power plants, and improved grid operations will be required to achieve such a high penetration of renewables.[24] However, in most states there should be no trouble integrating increasing amounts of solar into the grid.

Advanced forecasting models with the ability to predict cloud cover (and other factors that impact solar resource availability) to within minutes will be an increasingly essential component of maintaining grid reliability in a high penetration scenario. With the proper levels of accuracy and precision, these forecasts will allow grid operators to plan for periods of decreased solar energy output, arranging for other sources of generation to meet demand until solar output resumes.[25, 26] An equally important element of maintaining a solar-rich grid will the continued trend towards larger *balancing areas* (the area in which total supply must "balance" with total demand).[27] In a small balancing area, a large weather event with significant cloud cover can reduce solar output for an entire area. The larger these balancing areas, the greater the possibility that at least some portions of the area will remain clear and continue generating solar electricity.

Additionally, researchers at NREL used complex mathematical models to evaluate the effects of high solar penetration under different scenarios and found that growth in grid-connected solar will eventually be constrained by the nation's current electric power distribution and transmission system.[28] However, new investments in "PV Enabling Technologies" on the grid – technologies that could allow for power storage or load management – could increase, or even entirely remove, these limitations.[29]

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Benefits of Grid-Connected Solar

Peak-Shaving Benefits

Solar power generation, when connected to the grid, can contribute to a stable power supply by better managing peak demand for power. During the course of a day, especially during summer months when air-conditioning is used heavily, electricity demand tends to rise during the first half of the day, peak near the middle of the day, and then slowly drop down again into the late afternoon and evening. This peak demand is usually many times higher than the regular off-peak demand. With this rise in demand comes a rise in electricity prices, as utilities bring expensive peak generators online (or import power from other companies)[30] and pay additional costs to overcome transmission line congestion.[31]

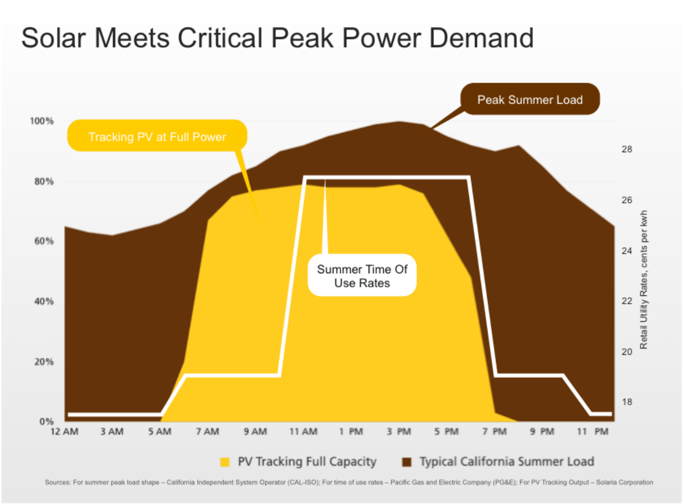

Figure 2: Solar Energy Production Mirrors Peak Demand
Source: Sungevity

As demonstrated in Figure 2, the amount of electricity generated by solar energy systems quite closely resembles this demand curve, with output peaking during mid-day when the sun is brightest. If solar plants are connected to the grid, the power that they generate during peak hours can match increased demand without the need for additional costly peak load generators, stabilizing the grid by bridging the gap between supply and demand. This can provide an economic advantage to both the utility and the consumer of between $0.06 and $0.11 per kilowatt-hour of distributed solar generated.[32] A real-world example of this phenomenon is shown in Figure 3 below. The graph on the left represents electricity prices for a typical day in Germany in 2008. The graph on the right, from four years – (and nearly 20 gigawatts of solar (about four times the current U.S. capacity) – later, shows how solar has brought down peak electricity prices.

Figure 3: High Solar Capacity Can Bring Down Peak Electricity Prices
Source: Epex Spot Auction; John Farrell (Institute for Local Self-Reliance) www.ilsr.org/lots-solar-power-reduce-increase-electricity-prices

Other Utility and Ratepayer Benefits

Distributed solar PV confers a number of additional benefits to utilities and their ratepayers. The peak-shaving benefits covered in the last section help relieve grid congestion, reducing the need to take costly measures to free up transmission and distribution capacity. Because solar DG systems are located closer to the loads they serve than centralized generators, energy losses associated with transmitting this electricity over long distances are reduced. Finally, solar can provide a hedge against future fuel price increases. The fuel upon which solar depends is free and essentially limitless – the same cannot be said for conventional fuels, which can be subject to short-term price volatility and long-term resource availability.[33]

Environmental and Societal Benefits

Solar power has significant environmental benefits. It is entirely renewable – not dependent on a finite supply of fuels for the generation of power – and clean, allowing it to reduce the environmental impact of electricity generation when it displaces more polluting sources of energy. Additionally, solar's ability to match peak demand and to be located near points of demand help reduce the chance that the grid will become overloaded and cause power outages. This brings stability and security to the grid. Finally, solar is a strong economic growth engine, currently producing more jobs per unit of energy created than many other energy sources.[34] This economic development potential is reflected in the 100,000 jobs supported by the U.S. solar industry in 2011, a figure that represents a 12-month growth in employment that was ten times greater than job growth in the overall economy.[35]

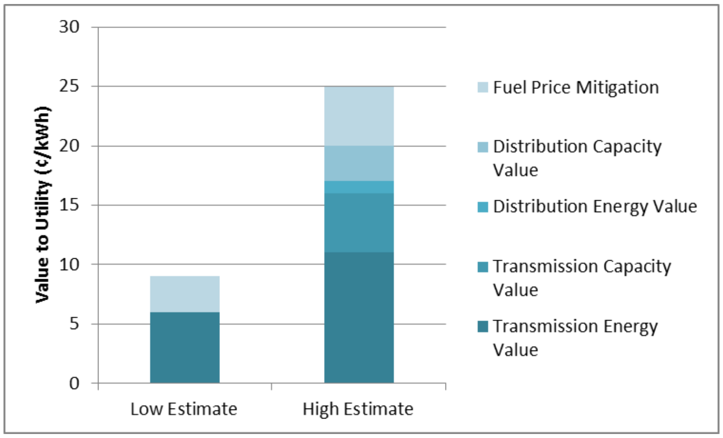

Figure 3: Value of Solar to Utilities and Ratepayers
Source: Perez, Zweibel, & Hoff. 2011
www.asrc.cestm.albany.edu/perez/2011/solval.pdf

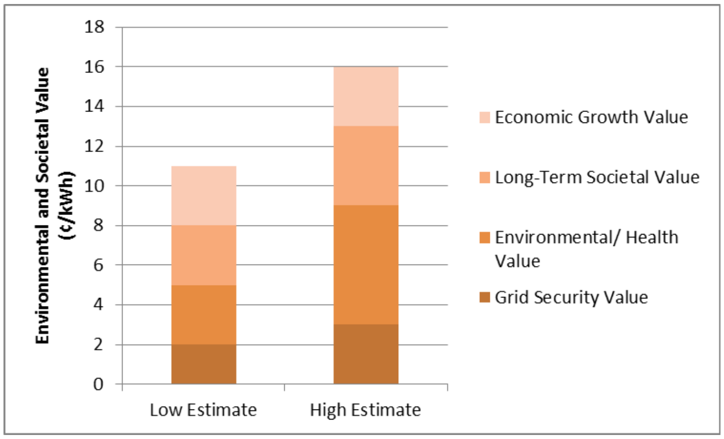

Figure 4: Environmental and Societal Value of Solar
Source: Perez, Zweibel, & Hoff. 2011
www.asrc.cestm.albany.edu/perez/2011/solval.pdf

What Your Local Government Can Do

In order to promote the safe development of a local solar market, local governments must be actively involved in creating an environment that is conducive to adding more solar to the grid. Part of this effort means addressing barriers to the efficient, though still safe, interconnection of solar energy systems. Local government officials can address these barriers primarily in two ways: (1) by removing informational barriers through promoting awareness of,

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and providing access to, information on the interconnection standards that apply to solar energy systems within their jurisdiction, and; (2) by advocating for updated interconnection regulations that reflect the most current understanding of solar's impact on grid stability, or (when possible) by adopting and implementing new standards themselves.

Promote Awareness and Access to Information

Difficult or incomplete access to information on interconnection standards and, perhaps more importantly, presenting this information in a manner that is confusing for consumers or installers, can add unnecessary costs and delays to the interconnection process. Local governments can help residents and solar contractors overcome these informational barriers by facilitating access to interconnection standards written, as much as possible, in clear and simple language. This information can be disseminated through fact sheets, webinars or in-person presentations, local government websites, or by other media that enable the quick and effective consumption of information. Some examples are provided in Table 1 below.

Table 1: Sample Outreach and Educational Materials

Resource Type	*Provider*	*Title*	*Description*
Webinar	PG&E www.pge.com	Interconnection Process Simplification Webinar[viii]	Provides information on PG&E's interconnection process, documentation requirements, and common pitfalls.
Handbook	SCE www.sce.com	Net Energy Metering: Interconnection Handbook[ix]	Provides specifics on interconnection documentation and processes, equipment safety requirements, and technical definitions.
Fact Sheet	U.S. EPA www.epa.gov	Standardized Interconnection Rules[x]	This fact sheet provides a great example of the structure and type of information a local government might provide to its citizens.
Video	The Energy Foundation www.ef.org	How the Lights Stay On[xi]	Explores current and future grid management practices that can help minimize the impact intermittent energy sources have on total electricity supply.

Update Interconnection Standards

In cases where power supply is controlled by a municipally-owned utility, the local government may update or adopt regulations that provide a better balance between solar penetration and grid safety and stability. Though setting up well-defined and streamlined interconnection standards will likely require great effort on the part of the local government, including time spent on researching existing standards and best practices, drafting new regulations or adapting existing regulations to suit the local government's needs, determining requirements for different levels of review, and application processes, this effort could greatly increase amount of solar that is safely and conveniently connected to the grid. See Table 2 on the following page for a collection of resources that should serve as the starting point for your local government's efforts to update interconnection standards under its control.

[viii] Available at www.pge.com/includes/docs/pdfs/shared/solar/solareducation/interconnection_process_simplification.pdf
[ix] Available at asset.sce.com/Documents/Shared/NEM_Interconnection_Handbook.pdf
[x] Available at www.epa.gov/chp/documents/interconnection_fs.pdf
[xi] Available at www.youtube.com/watch?v=gSiCRZcJnfE

Table 2: Useful Resources for Updating Interconnection Standards

Provider	*Resource Title*	*Description*
Interstate Renewable Energy Council	Model Interconnection Procedures, 2009 Edition[xii]	Describes the standards utilities should use when evaluating a solar energy system's eligibility for grid interconnection, varying these requirements across four different levels of review based on system size and complexity. Also provides model application processes and supplemental requirements, and sample interconnection applications.
California Public Utilities Commission	California Rule 21: Generating Facility Interconnections[xiii]	Provides the actual text of the three variants of the rule governing interconnection of systems within the state. Gives detailed information on interconnection applications and processes, and outlines the requirements for a "simplified interconnection" that speeds eligible systems through the approval process.*
Network for New Energy Choices, Interstate Renewable Energy Council, Vote Solar Initiative, NC Solar Center	Freeing the Grid: Best Practices in State Net Metering Policies and Interconnection Procedures[xiv]	Outlines best practices in interconnection procedures (as well as net metering policies), assigning scores and grades to each state based on their performance in each of these areas.

*** It should be noted, however, that standards that are fine for California may not be appropriate elsewhere. States and utilities can follow this example by conducting their own studies that lead to the development of rules tailored to their specific circumstances.

Conclusion

As this brief has shown, there is much controversy surrounding the integration of solar into the electric grid. However, standards for solar equipment and regulations governing how solar energy systems are connected to the grid have to a large extent been able to overcome these concerns. For low levels of solar penetration (less than 30% of capacity) technological and operational solutions are available to ensure grid safety and reliability are maintained at a relatively low additional cost (between $0.00 and $0.05/kWh).[36] When weighed against the benefits of grid connected solar mentioned in this paper, though, it can be seen that the benefits far outweigh these costs. For higher levels of penetration, greater investment in infrastructure and shifts in planning and operations will be necessary. However, these concerns are still far down the road for most areas in the U.S. Proactive planning and research, such as that underway now by our national labs, will help to ensure that the transition to a high penetration scenario is done both economically and with grid safety and reliability in mind.

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[xii] Available at www.irecusa.org/wp-content/uploads/2010/01/IREC-Interconnection-Procedures-2010final.pdf
[xiii] Available at www.cpuc.ca.gov/PUC/energy/Procurement/LTPP/rule21.htm
[xiv] Available at www.newenergychoices.org/uploads/FreeingTheGrid2011.pdf

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