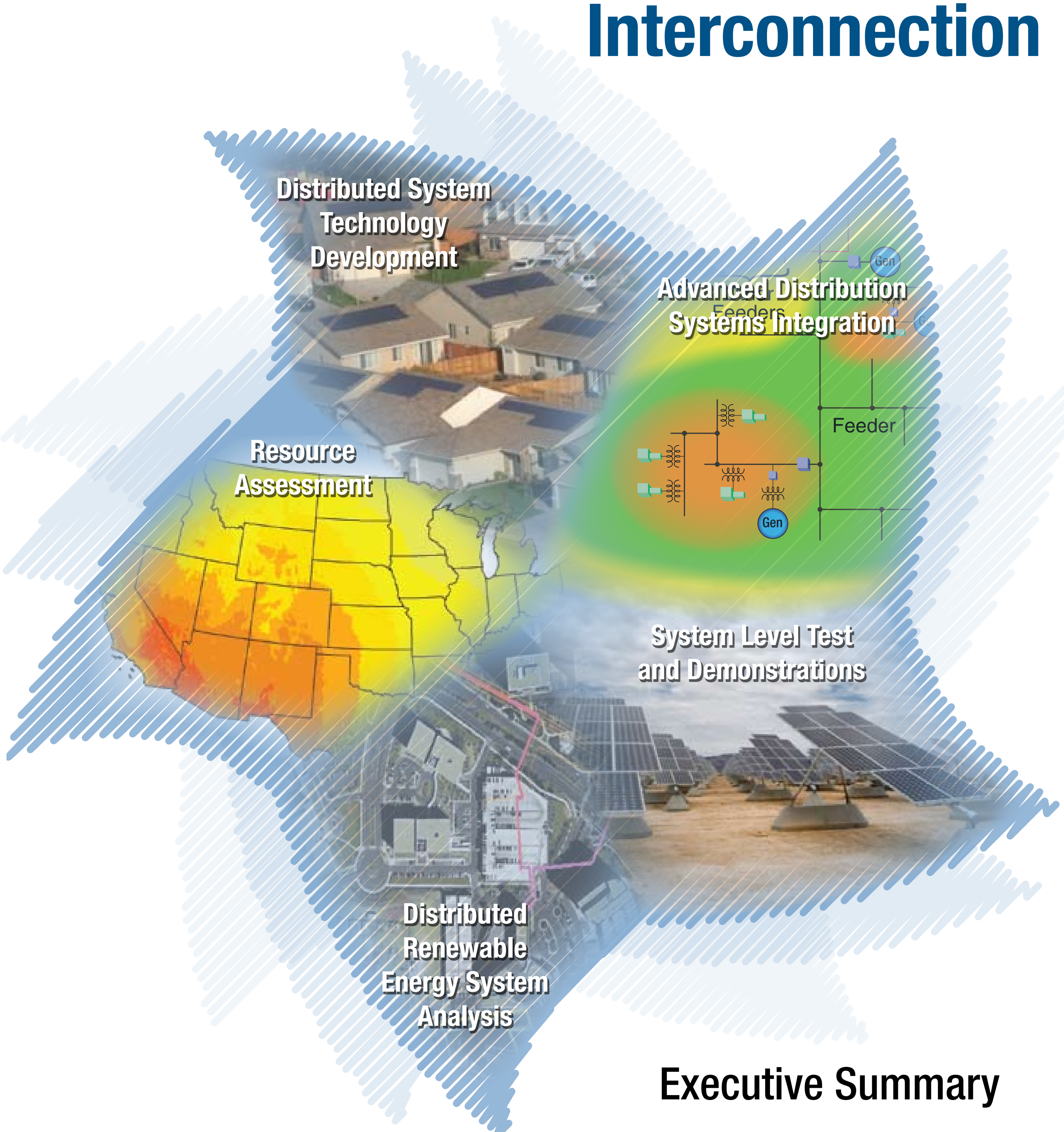
Renewable Systems Interconnection



Executive Summary

February 2008

U.S. Department of Energy
Energy Efficiency and Renewable Energy
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Renewable Systems Interconnection: Executive Summary

Technical Report
NREL/TP-581-42292
February 2008

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Prepared under Task No. PVB7.6401

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Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

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Preface

Now is the time to plan for the integration of significant quantities of distributed renewable energy into the electricity grid. Concerns about climate change, the adoption of state-level renewable portfolio standards and incentives, and accelerated cost reductions are driving steep growth in U.S. renewable energy technologies. The number of distributed solar photovoltaic (PV) installations, in particular, is growing rapidly. As distributed PV and other renewable energy technologies mature, they can provide a significant share of our nation's electricity demand. However, as their market share grows, concerns about potential impacts on the stability and operation of the electricity grid may create barriers to their future expansion.

To facilitate more extensive adoption of renewable distributed electric generation, the U.S. Department of Energy launched the Renewable Systems Interconnection (RSI) study during the spring of 2007. This study addresses the technical and analytical challenges that must be addressed to enable high penetration levels of distributed renewable energy technologies. Because integration-related issues at the distribution system are likely to emerge first for PV technology, the RSI study focuses on this area. A key goal of the RSI study is to identify the research and development needed to build the foundation for a high-penetration renewable energy future while enhancing the operation of the electricity grid.

The RSI study consists of 15 reports that address a variety of issues related to distributed systems technology development; advanced distribution systems integration; system-level tests and demonstrations; technical and market analysis; resource assessment; and codes, standards, and regulatory implementation. The RSI reports are:

- *Renewable Systems Interconnection: Executive Summary*
- *Distributed Photovoltaic Systems Design and Technology Requirements*
- *Advanced Grid Planning and Operation*
- *Utility Models, Analysis, and Simulation Tools*
- *Cyber Security Analysis*
- *Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics*
- *Distribution System Voltage Performance Analysis for High-Penetration Photovoltaics*
- *Enhanced Reliability of Photovoltaic Systems with Energy Storage and Controls*
- *Transmission System Performance Analysis for High-Penetration Photovoltaics*
- *Solar Resource Assessment*
- *Test and Demonstration Program Definition*
- *Photovoltaics Value Analysis*
- *Photovoltaics Business Models*

- *Production Cost Modeling for High Levels of Photovoltaic Penetration*
- *Rooftop Photovoltaics Market Penetration Scenarios*.

Addressing grid-integration issues is a necessary prerequisite for the long-term viability of the distributed renewable energy industry, in general, and the distributed PV industry, in particular. The RSI study is one step on this path. The Department of Energy is also working with stakeholders to develop a research and development plan aimed at making this vision a reality.

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Summary

Because of growing concerns about climate change, the adoption of state-level renewable portfolio standards and incentives, and accelerated cost reductions, renewable energy technologies such as photovoltaics (PV) and wind are expected to become a larger part of our energy portfolio during the next couple of decades. As these technologies mature, they have the potential to supply a significant share of our nation's electricity demand.

As their market share grows, however, concerns about potential impacts on the operation and stability of the electricity grid may create barriers to further expansion. Wind power is already gaining considerable market penetration at the transmission level, and its variable nature increases the complexity of operating the bulk power grid. Additional challenges are likely to emerge as additional nondispatchable sources, such as PV, are added to the electrical distribution network.

To overcome these potential barriers, the U.S. Department of Energy (DOE) launched the Renewable Systems Interconnection (RSI) study during the spring of 2007. DOE brought together a team of industry experts to address the technical, regulatory, and business issues that have the potential to limit the market uptake of distributed PV and other renewable technologies.

One key finding of the RSI study is that grid integration issues are likely to emerge much more rapidly than many analysts expect. In some regions of the United States, grid-integration-related barriers to future growth could emerge within the next five to ten years. For example, in California a number of new homes are currently being built with PV systems as a standard feature (see Figure 1). With these types of developments already occurring in the marketplace, it is clearly time to begin planning for the integration of significant quantities of distributed renewable energy onto the electricity grid.

Source: Sacramento Municipal Utility District

Figure 1. Premier Gardens Subdivision, Rancho Cordova, California

The U.S. grid-connected PV market has been growing rapidly during the past five years. Annual grid-connected PV installations have increased from 10 MW per year in 2001 to about 180 MW per year in 2006, resulting in a cumulative installed base of about 480 MW of grid-connected PV in the United States at the end of 2006.

Yet this accelerated growth of the PV industry is simply the tip of the iceberg. Policy developments at both the federal and state level, coupled with technology improvements funded by DOE's Solar America Initiative, are helping to create a more receptive marketplace for PV in the United States. Indeed, scenarios developed as part of the RSI study indicate that annual installations of grid-tied PV in the United States could reach 1.4–7.1 GW by 2015, resulting in a cumulative installed base of 7.5–24 GW by 2015 (see Figure 2).

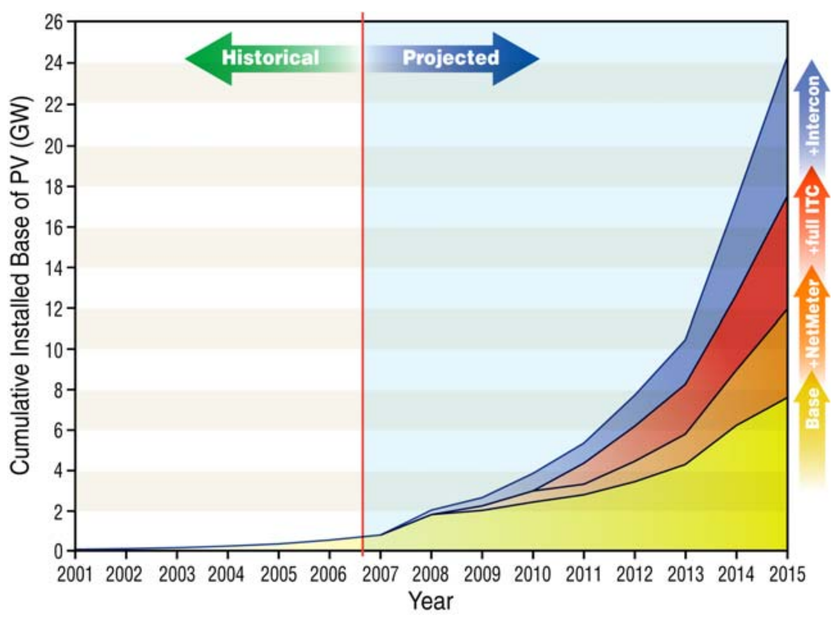
As shown in Figure 2, three key regulatory and policy drivers were found to have a significant impact on PV adoption rates:

lifting net metering caps/establishing net metering, extending the Federal investment tax credit (ITC), and improving interconnection standards.

Lifting net metering caps and establishing net metering had significant effects on projected PV market penetration in some states. In fact, the projected cumulative installed PV in 2015 increased by about 4 GW. As shown in Figure 2, cumulative installed PV in 2015 increased from 7.5 GW in the base case to 12 GW when net metering caps were lifted.

Extension of the federal investment tax credit (ITC) had a critical effect on the PV market and was found to be a prerequisite for the overall success of PV in the marketplace. The federal ITC is set to expire at the end of 2008. However, a number of proposals—including one for a partial extension (i.e., through 2010 for residential installations and 2015 for commercial installations) and one for a full extension (i.e., through 2015 for both residential and commercial installations)—have been introduced in Congress. Projected cumulative installed PV in 2015 increased from 12 GW under a partial extension of the ITC to 17 GW under a full extension of the ITC.

Improving interconnection standards had a significant effect on PV market development. Many states and utilities currently have interconnection standards that inhibit PV adoption. In particular, improving interconnection standards had a significant effect in eight states that were ranked by the Interstate Renewable Energy Council (IREC) as having "fair" or "poor" interconnection rules. These were Connecticut, Florida, Hawaii, Illinois, Maine, Pennsylvania, Washington, and Wisconsin. As shown in Figure 2, combining all three policies is projected to result in a cumulative installed base of about 24 GW by 2015.



Source: DOE RSI study report *PV Market Penetration Scenarios*

Figure 2. Grid-connected distributed PV growth, 2001–2006, projected to 2015

Notes: These scenarios illustrate the impact of policies such as extension of the federal ITC, interconnection standards, and net metering on the distributed PV market. The low end of the growth range (base case) assumes a partial extension of the federal ITC; the high end assumes implementation of a full set of solar-friendly policies.

Overview of the RSI Study

The RSI study is organized into 14 distinct final reports, summarized in this section. In all the reports, the authors identify and discuss the technical and analytical challenges that must be tackled to enable high penetration levels of distributed solar, wind, and other renewable energy technologies that interconnect to the grid at the distribution level.

By combining analysis of renewable technologies, storage, controls, and other appropriate technologies, the RSI study is striving to build the foundation for allowing high penetration levels of renewables while enhancing the operation of the electricity grid. In addition, by directly engaging utilities and other stakeholders in this process, the RSI study can boost the confidence of regulators and utilities in the electricity industry's ability to maximize the use of renewable energy technologies.

The RSI study reports are summarized in the bullets that follow.

- *Distributed Photovoltaic Systems Design and Technology Requirements* develops a set of conceptual system designs that integrate PV, storage, and control technologies for residential and commercial market applications. These solar energy grid integration systems (SEGIS) will incorporate advanced functionality and integration with electrical distribution systems and building energy management systems (EMS), enabling utilities and/or system owners to realize the full value of the systems.
- *Advanced Grid Planning and Operation* describes research and analysis on advanced grid planning and operations needed to facilitate large-scale integration of distributed PV into the distribution system.
- *Utility Models, Analysis, and Simulation Tools* reviews current utility studies, models, and software applications that are used in grid planning. The authors also identify needs for new analytical tools to address high levels of PV integration in the electric grid.
- *Cyber Security Analysis* examines the potential security implications of high penetrations of PV that will utilize high degrees of information technology and control systems. This analysis will provide the basis for designing more inherently secure systems rather than incorporating security as an afterthought.
- *Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics* explores the impact of high levels of PV penetration on standard utility system planning methodologies. The report also explains how these methodologies are changing (or could be modified) to enable effective integration of renewable generation.
- *Distribution System Voltage Performance Analysis for High-Penetration Photovoltaics* analyzes issues with interconnecting various PV penetration levels on the distribution system, focusing on voltage regulation needs.

- *Enhanced Reliability of Photovoltaic Systems with Energy Storage and Controls* examines the use of energy storage and controls in conjunction with PV to improve customer reliability.
- *Transmission System Performance Analysis for High-Penetration Photovoltaics* focuses on the transient stability of the electric power system with high penetrations of PV under various operating scenarios. The scenarios include operating under current regulations and with advanced grid support functionality.
- *Solar Resource Assessment* evaluates the current state of the art and future needs with respect to solar resource characterization and data availability.
- *Test and Demonstration Program Definition* discusses the test and demonstration activities that are required to evaluate the local distribution system impacts of high levels of PV penetration with and without storage.
- *Photovoltaics Value Analysis* provides a detailed methodology for assessing the value of PV on the utility/wholesale side and on customer side. Various PV system configurations, grid architectures, types of ownership, business models, and operational strategies are explored.
- *Photovoltaics Business Models* develops a variety of business models for the ownership and operation of PV—both alone and combined with storage systems or controls—in the residential and commercial sectors.
- *Production Cost Modeling for High Levels of Photovoltaic Penetration* uses (and modifies) standard production cost modeling tools to evaluate the large-scale interaction of solar electricity technologies with the existing and envisioned future grid. The authors focus on displaced generation capacity, fuel saved, and emissions avoided by deploying varying levels of solar electric generation.
- *Rooftop Photovoltaics Market Penetration Scenarios* develops a set of potential scenarios for PV market penetration within the United States between 2007 and 2015. Factors examined in developing the scenarios include net metering rules, interconnection policies, electric rate tariff levels and structures, availability of state and federal financial incentives, system pricing, and carbon legislation.

A critical goal of the RSI study has been to help define a research agenda that will enable DOE to work with utilities and industry to develop the technologies and methods that can allow the widespread market penetration of renewable energy technologies into the U.S. electricity grid. RSI researchers have considered storage systems, advanced power electronics, and controls. Control systems are likely to include improved and innovative ways to manage power demand. The study investigators are also striving to understand the potential impacts on the electricity grid and how to optimize systems based on benefits to both customers and utilities.

The RSI reports identify the following key objectives for DOE, utilities, regulators, and industry:

- Develop SEGIS that incorporate advanced functionality and active integration with electrical distribution systems and EMS, enabling utilities and/or system owners to realize the full value of the systems.
- Improve stand-alone capabilities of distributed renewable technologies with storage to improve customer reliability, enhance power quality, and provide backup power functions.
- Develop and validate remote monitoring and dispatch control platforms that will optimize renewable energy and storage system benefits. These platforms would comprise software, sensors, and demand response controls. They would integrate utility control and financial information in concert with advanced grid technologies to ensure high-quality and stable power delivery.
- Utilize prototype test beds and field deployments to evaluate key characteristics of new renewable energy systems and other distributed technologies that maximize grid value.
- Develop a comprehensive demonstration plan to ensure successful simulation, demonstration, and validation with utilities and industry stakeholders.
- Conduct detailed analysis of renewable energy system performance and grid effects through electrical transmission and distribution (T&D) system modeling and simulation.
- Develop and validate best practices and software tools to facilitate T&D system planning and operation with greater deployment of renewable energy systems.
- Establish grid infrastructure design and operation methods—including utility load and production control methodologies—for integrating renewable energy into localized energy networks, microgrids, and minigrids.
- Establish grid infrastructure requirements for wide-area control of distributed renewable energy systems integrated into the electrical power system.
- Develop secure communications and control protocols that combine high functionality with safety, reliability, and security (surety) features. These protocols are designed to protect against malevolent or unintentional events that could undermine grid integrity.
- Develop new solar resource forecasting capabilities over a variety of time steps, including the very short term (1–3 hours) for load dispatching and a day ahead for system operations. Seasonal and interannual data will be necessary for long-term system planning and cash flow analyses.
- Establish consistent codes, standards, and transparent regulatory implementation practices to ensure safe and effective PV systems integration at high penetration levels.

Detailed Findings

The collective efforts of the 14-report RSI study have generated more than 100 specific objectives. These span a wide range of activities from R&D on new technologies, through field testing of new systems, to ways to reduce existing and potential market barriers to distributed PV. This section presents a high-level consolidation of many of the findings of the individual reports. Drawing on the reports, internal resources, and input from outside stakeholders, DOE is developing a multiyear R&D plan to address integration issues for distributed PV. This work will build on related activities, both within DOE and in key states that are aligned with broader grid modernization efforts.

The key interim findings for achieving the market potential of distributed PV fall into six topical research areas:

1. Distributed PV System Technology Development
2. Advanced Distribution Systems Integration
3. System Level Test and Demonstrations
4. Distributed Renewable Energy System Analysis
5. Solar Resource Assessment
6. Codes, Standards, and Regulatory Implementation

The sections that follow discuss each of these research areas.

Distributed PV System Technology Development

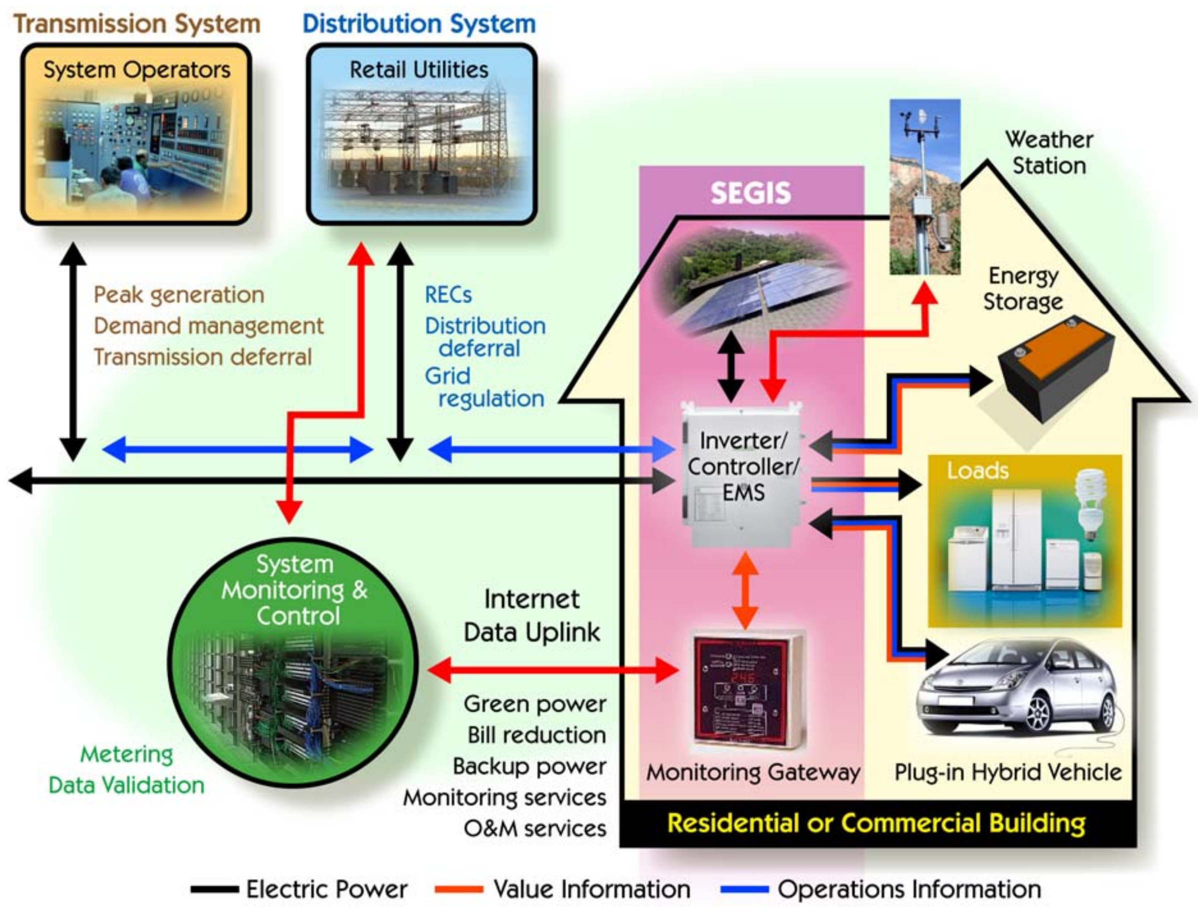
Distributed PV systems currently make an insignificant contribution to the power balance on all but a few utility distribution systems. With the increasing interest in PV systems and the accelerated installation of large PV systems or large groups of PV systems that are interactive with the utility grid, though, utilities must ensure that higher levels of distributed generation are compatible with measures that protect the grid infrastructure. The variability and nondispatchability of today's PV systems affect not only the stability of the utility grid but also the economics of the PV system and the energy distribution system.

Integration issues (e.g., voltage regulation, unintentional islanding, and protection coordination) need to be addressed from the distributed PV system side and from the utility side for high penetration PV scenarios. Advanced inverter, controller, and interconnection technologies development work must produce hardware that allows PV to operate safely with the utility and act as a grid resource that yields benefits for both the grid and the owner. Advanced PV system technologies—including inverters, controllers, related balance-of-system features, and energy management hardware—are necessary to ensure safe and optimized integrations, beginning with today's unidirectional grid and progressing to the smart grid of the future.

Objectives

Research in this area aims to satisfy the following objectives:

- Develop SEGIS (see Figure 3) that incorporate advanced integrated inverters/controllers and EMS capable of supporting communication protocols utilized by energy management and utility distribution level systems.
- Develop advanced integrated inverter/controller hardware with improved reliability and longer lifetimes (e.g., 15 years mean time before failure [MTBF]), along with a 50% cost reduction for equivalent capability. The ultimate goal is to develop hardware with lifetimes equivalent to those of PV modules.
- Research and develop regulation concepts to be imbedded in inverters, controllers, and dedicated voltage conditioner technologies that integrate with power system voltage regulation. The goal here is to provide fast voltage regulation to mitigate flicker and faster voltage fluctuations caused by local PV fluctuations.
- Investigate DC power distribution architectures as an into-the-future method to improve overall reliability (especially with microgrids), power quality, local system cost, and high levels of PV distributed generation penetration.
- Develop advanced communications and control concepts that are integrated with SEGIS. These are the key to sophisticated microgrid operation that maximizes efficiency, power quality, and reliability.
- Ensure that communications protocols include the protections necessary to prevent accidental or unauthorized tampering that could threaten grid integrity.
- Identify inverter-tied storage systems that will integrate with distributed PV generation to allow intentional islanding (microgrids) and system optimization functions (demand control) to increase the economic competitiveness of distributed generation.
- Develop building energy system controllers that can monitor solar resource forecast, utility pricing, building load, and associated building occupant data (workday, weekend, planned vacation) to optimize system value by controlling loads and dispatching storage.



Source: DOE

Figure 3. The SEGIS integrated with advanced distribution systems

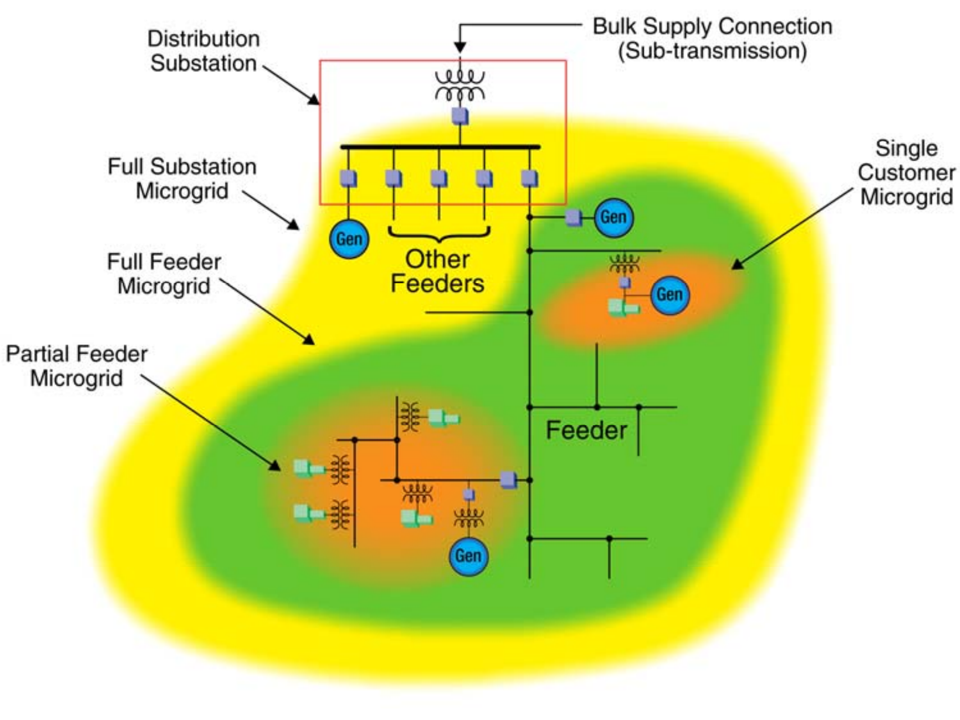
Advanced Distribution Systems Integration

Where net metering exists in the United States, PV-generated electricity can be used on site or delivered to the grid. Under low levels of PV penetration, the grid balances the variations in supply and demand over a wide area, improving the economics of PV and reducing the need for additional energy storage. A critical challenge in deploying widespread PV energy, however, is to modernize the existing distribution system, which was designed, built, and operated for centralized generation. With limited capacity for reverse power flows and without controls and communication at the point of use, the existing grid is not capable of effectively integrating large-scale distributed PV generation.

A strategy is needed, then, for moving from the relatively small PV energy market of "passively interacting" systems to SEGIS, which are an "active partner" in the grid. A key element of this strategy is to configure the PV system to meet system energy demand and control requirements at all grid levels, including transmission and system operation.

Objectives

- In this area, planned and coordinated R&D meet a number of objectives: Seek an evolution of the distribution system that includes increased distribution automation, automated load controls, and facilitation of power quality and reliability-enhancing features.
- Develop business cases that create opportunities on both sides of the meter, leading to a "market-driven response" for reinventing the electric grid.
- Develop distribution systems that allow for interactive voltage regulation and volt ampere reactive (VAR) management, bulk system coordination of PV for market and bulk system control, protective relaying schemes designed for PV, advanced islanding monitoring and control, PV interactive service restoration, improved grounding compatibility, advanced metering with communications, and use of distributed energy storage.
- Develop microgrid technologies that can be applied in a broad range of sizes and configurations. These technologies will allow distributed PV to operate autonomously with islanded resources and the distribution grid to accommodate these types of systems (see Figure 4).



Source: Electric Power Research Institute (EPRI)

Figure 4. Microgrid examples on the distribution system

Notes: This figure illustrates examples of possible microgrid "subsets" that could be derived on a typical radial distribution system. These microgrid subsets include a single customer, a group of customers, an entire feeder, or a complete substation with multiple feeders.

System Level Test and Demonstrations

A wide range of testing and demonstration is required to understand the effects of high penetration of PV systems on the grid. For instance, tests are needed to determine whether a problem exists and to characterize its extent. Other tests can validate the solutions to that problem and identify system benefits. Testing should include controlled laboratory testing as well as field testing and demonstrations.

Controlled-environment laboratory testing allows specific parameters to be accurately characterized and sets up repeatable test conditions that would be difficult to replicate in the field without extensive long-term monitoring. Laboratory-based testing involves developing standard test procedures and requirements, evaluating solutions to emerging problems, and verifying and certifying the performance of new products.

Objectives

Laboratory objectives include the following:

- Develop and validate models for specific PV system equipment, especially inverter performance models, as they relate to the simulation of distribution system impacts.
- Develop laboratory capabilities for testing a variety of high penetration scenarios under conditions that are as close to the real world as possible. Specific tests should be developed to evaluate voltage regulation schemes, unintentional islanding prevention, intentional island/microgrid operation, false inverter trips resulting from utility line transients, reverse power flow in secondary network distribution systems, and system stability factors such as variable cloud cover.
- Establish and carry out test protocols for emerging methods for communications among distributed PV systems, utility grid operations, and EMS. These testing protocols should include methods to evaluate features such as fault tolerance (e.g., loss of communications or malevolent tampering), speed, reliability, and bandwidth.
- Evaluate different control schemes for autonomous VAR compensation in the presence of multiple inverters. For example, evaluate the feasibility of using a voltage-neutral approach. In such an approach, the PV system adjusts VARs to compensate for voltage rise caused by real-power back-feed or a central control signal sent to multiple PV systems to control voltage over a wider area.

Field tests and demonstrations can verify that a problem exists or a solution is effective. They can also point to previously unsuspected issues. Field tests will require identifying candidate locations with high penetration levels of PV systems. These could include new residential subdivisions in which a large number of homes have PV systems, commercial systems where the PV is a significant part of the load, and utility interconnected systems that feed back a significant amount of PV energy at the distribution level.

Objectives

Field objectives include the following:

- Utilize fielded systems to test a variety of nontraditional benefits including voltage regulation support, frequency regulation support, spinning reserve, and customer peak load reduction.

- Test the integration of EMS with PV systems and storage to optimally manage power for commercial facilities. This may include developing predictive algorithms for loads and PV output to effectively manage storage.
- Evaluate the impact of relatively high PV penetration levels on existing distribution systems with intermediate voltage and current monitoring. This type of testing can be implemented very quickly by leveraging current market activities such as the systems being installed at Premier Gardens (Figure 1) and Nellis Air Force Base (Figure 5).
- Investigate voltage impacts, effectiveness of various solutions (especially if SEGIS with VAR capability are installed), fault contribution, and fuse coordination/desensitization.
- Investigate PV installed on undersized or overloaded primary or secondary distribution lines where the substation voltage is elevated to deal with the voltage drop (e.g., an old rural feeder with new large homes).

Source: SunPower Corp.

Figure 5. PV installation (15 MW) on the distribution grid, Nellis Air Force Base, Nevada

Notes: Software such as this could be used to understand voltage profile and load reduction on electric distribution system with new PV installations.

Distributed Renewable Energy System Analysis

Evaluating the impacts of high levels of PV penetration on the electricity grid will require both technical and economic analysis. Analysis will also help identify potential impacts of proposed solutions on the marketplace.

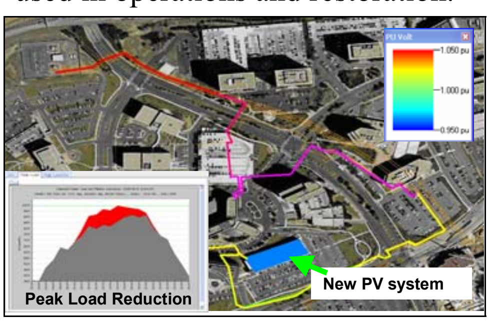
Technical analyses can serve to overcome technical concerns with integrating large amounts of PV into the grid. In this type of analysis, modeling and simulation tools must be updated with appropriate models for PV system components and for distribution system analysis.

Objectives

The following objectives drive technical analyses:

- Solve the problem of ground fault overvoltage on the subtransmission system by investigating the use of grounding bank transformers, special switchgear timing mechanisms, transfer trips in switchgear operations, and upgraded device voltage ratings.
- Find ways to adapt protective relaying and fusing in the distribution system to deal with fault currents that arise from larger quantities of distributed PV.
- Develop new voltage regulation schemes for steady-state (slow) regulation based on communication between load-tap changing transformers, step voltage regulators, capacitor banks, and PV.
- Study the effective grounding compatibility problem associated with PV. This includes determining the equipment technologies and system changes that can be used to most economically reduce the need to effectively ground all PV on the four-wire multigrounded neutral distribution systems.

- Develop enhanced component models. Although some very powerful software tools are available for distribution system simulation, the industry currently lacks detailed modeling information for distributed renewable energy sources. Simulation would benefit greatly from readily available “performance profiles” that would consist of the device’s fault contribution curve, rate of output change, response to small and medium signal steps, and islanding test results.
- Create a set of benchmark cases to facilitate testing of models and associated software. Some of the confusion and unwarranted concerns about PV generation’s impact results from inconsistent and incorrect modeling.
- Develop automated screening tools that will enable the impact of PV on the distribution system to be evaluated. All prospective installations could then be screened and only the ones requiring more detailed assessment would need to be further evaluated by utilities.
- Update commercial load flow and fault current calculation software to handle multiple distributed energy sources on the system. These generally include a data management system that is often integrated with a geographic information system (GIS), which is used in operations and restoration.



Source: National Renewable Energy Laboratory (NREL)

Figure 6. Distributed renewable energy system analysis

In addition to technical concerns, **economic analysis** designed to understand the customer and utility value proposition for distributed PV will be critical for integrating large quantities of PV. In many ways, the solar PV industry is where the wind industry was more than a decade ago, with relatively small penetration and fairly limited understanding of the impacts of large-scale deployment onto the grid.

Objectives

Economic analyses will be designed with the following objectives in mind:

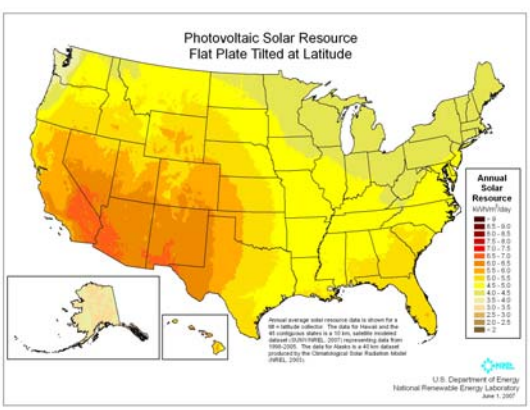
- Develop best practices for quantifying the various potential costs and benefits of distributed PV. These can include avoided generation, transmission, and distribution costs; avoided generation and T&D losses; capacity increase and peak load reduction; voltage and VAR support; phase balancing; harmonic correction; backup power provision and power outage mitigation; equipment upgrade deferral; distribution equipment reliability improvements; reduced reliance on fossil fuels with volatile prices; rapid and easy PV deployment; environmental and health benefits; avoided water use; and job creation.
- Evaluate the extent to which the geographical diversity of distributed PV mitigates the short-term output variability caused by rapidly changing weather conditions (such as the passage of clouds).
- Assess the costs associated with unit commitment errors and the impacts of increased forecasting quality.
- Examine enabling technologies and techniques, including increased spatial diversity, diversity of orientation, and market-based approaches such as time-of-use and real-time pricing.

Technology options such as load shifting, long-distance transmission, and various centralized and distributed energy storage technologies should also be considered.

- Examine the potential for electric or plug-in hybrid electric vehicles to serve as a PV-enabling technology.
- Work with state agencies (such as the California Public Utilities Commission, the California Energy Commission, and others) and utilities to pilot second-generation business models in which utilities own some or all of the PV system. These business models could enable utilities to tap into the value of PV and mitigate concerns about safety, operations, and revenue.

Solar Resource Assessment

Comprehensive knowledge of the temporal and spatial characteristics of the solar resource available to PV systems, as well as key related weather data, is needed. This knowledge will allow system designers to shape operational strategies for PV systems and EMS, to better simulate how PV systems will behave within the grid, and to boost system cost effectiveness.



Source: NREL

Figure 7. High-resolution solar data

Objectives

The following objectives fall under solar resource assessment:

- Develop solar resource forecasting capabilities over a variety of time steps, including the very short term (1–3 hours) for load dispatching a day ahead for system operations. Seasonal and interannual data are necessary for long-term system planning and cash flow analyses.
- Develop reliable, subhourly data sets from measurement systems and model outputs. Data intervals as short as 1 minute (but more typically, 15 minutes) could be used as part of load control and load-following studies under high penetration scenarios with no storage available. Only a few measurement stations in the United States currently make these data available, and all of the National Solar Radiation Database (NSRDB) data are hourly values. Modeled solar resource data are not available at the subhourly time scale.
- Improve the spatial resolution of data sets, which are currently 10 km to 100 km depending on the period of interest. This will allow resource information to be more accurately pinpointed to specific locations where grid-tied PV systems are likely to be installed.
- Develop a user-interactive data archive so that end users can create and access specialized data sets online to meet specific analytical requirements.
- Coordinate closely with modeling software and EMS to focus new solar radiation products in support of RSI requirements and operational strategies.

Codes, Standards, and Regulatory Implementation

In the United States, the electricity grid safety and reliability infrastructure is governed by linked installation codes, product standards, and regulatory functions such as inspection and operation principles. The National Electric Code, Institute of Electrical and Electronic Engineers (IEEE) standards, American National Standards, building codes, and state and federal regulatory inspection and compliance mandates must dovetail to result in a safe, reliable, and robust electricity T&D grid.

Codes, standards, and regulatory (CS&R) implementation has been cited as a major impediment to widespread use of PV on the grid in the United States. Effectively interconnecting distributed renewable energy systems requires careful attention to ensuring compatibility with the existing grid. Traditionally, the electricity grid was not designed for two-way flow of power, especially at the distribution level. Uniform requirements for power quality, islanding protection, and passive system participation (IEEE 1547[1]) could help PV. National requirements for power quality and active participation in power system operation must be developed. In the absence of secure communications and control protocols, cyber attacks could pose serious risks as penetration grows.

Objectives

In the CS&R arena, efforts continue on the following objectives:

- Enable coordinated operation of all equipment on the distribution feeder. The same infrastructure can be used to enable demand-side management, to implement flexible metering tariffs, and to enhance distribution system management.
- Establish recommended practices for modeling high penetration, intermittent renewable energy power sources and energy storage systems embedded in the distribution system.
- Develop consensus best practices that facilitate T&D system planning and operation for grid modernization, which includes provision for greater deployment of renewable energy systems.
- Develop recommendations for consideration by electricity regulators on net metering and rate structures, microgrids, and impact study requirements.
- Improve methods and agreements for local siting, permitting, and inspection of PV systems.

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[1] *Standard for Interconnecting Distributed Resources with Electric Power Systems*, available at http://grouper.ieee.org/groups/scc21/1547/1547_index.html

RSI Study Reports

Distributed Photovoltaic Systems Design and Technology Requirements, Chuck Whitaker and Jeff Newmiller, BEW Engineering; Michael Ropp, Northern Plains Power Technologies; Ben Norris, Norris Energy Consulting

Advanced Grid Planning and Operation, Mark McGranaghan, Thomas Ortmeyer, David Crudele, Thomas Key, and Jeff Smith, EPRI; Phil Barker, NOVA Energy Specialists LLC

Utility Models, Analysis, and Simulation Tools, Thomas Ortmeyer, Roger Dugan, and David Crudele, EPRI; Phil Barker, NOVA Energy Specialists LLC

Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High Penetration Photovoltaics, Jovan Bebic, GE Global Research

Distribution System Voltage Performance Analysis for High-Penetration Photovoltaics, Ellen Liu and Jovan Bebic, GE Global Research

Cyber Security Analysis, Annie McIntyre, Sandia National Laboratories

Enhanced Reliability of Photovoltaic Systems with Energy Storage and Controls, Devon Manz, Owen Schelenz, Ramu Chandra, Sumit Bose, Michael de Rooij, and Jovan Bebic, GE Global Research

Transmission System Performance Analysis for High-Penetration Photovoltaics, Sebastian Achilles, Simon Schramm, and Jovan Bebik, GE Global Research

Solar Resource Assessment, Dave Renné, Ray George, Steve Wilcox, Tom Stoffel, Daryl Myers, and Donna Heimiller, NREL

Test and Demonstration Program Definition, Chuck Whitaker and Jeff Newmiller, BEW Engineering; Michael Ropp, Northern Plains Power Technologies; Ben Norris, Norris Energy Consulting

Photovoltaics Value Analysis, Jose Luis Contreras, Lisa Frantzis, Stan Blazewicz, Dan Pinault, and Haley Sawyer, Navigant Consulting Inc.

Photovoltaics Business Models, Lisa Frantzis, Shannon Graham, Ryan Katofsky, and Haley Sawyer, Navigant Consulting Inc.

Production Cost Modeling for High Levels of Photovoltaics Penetration, Paul Denholm, Robert Margolis, and James Milford, NREL

Rooftop Photovoltaics Market Penetration Scenarios, Jay Paidipati, Lisa Frantzis, Haley Sawyer, and Ann Kurrasch, Navigant Consulting Inc.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
February 2008

2. REPORT TYPE
Technical report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Renewable Systems Interconnection: Executive Summary

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
B. Kroposki, R. Margolis, G. Kuswa, J. Torres, W. Bower, T. Key, and D. Ton

5d. PROJECT NUMBER
NREL/TP-581-42292

5e. TASK NUMBER
PVB7.6401

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-581-42292

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
The U.S. Department of Energy launched the Renewable Systems Interconnection (RSI) study in 2007 to address the challenges to high penetrations of distributed renewable energy technologies. The RSI study consists of 14 additional reports: (1) Renewable Systems Interconnection Executive Summary, NREL/TP-581-42292, (2) Distributed Photovoltaic Systems Design and Technology Requirements, NREL/SR-42293, (3) Advanced Grid Planning and Operations, NREL/SR-581-42294, (4) Utility Models, Analysis, and Simulation Tools, NREL/SR-581-42295, (5) Renewable System Interconnection Security Analysis, NREL/SR-581-42296, (6) Power System Planning—Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics, NREL/SR-581-42297, (7) Distribution System Performance Analysis for High-Penetration Photovoltaics, NREL/SR-581-42298, (8) Enhanced Reliability of Photovoltaic Systems with Energy Storage and Control, NREL/SR-581-42299, (9) Transmission System Performance Analysis for High-Penetration Photovoltaics, NREL/SR-581-42300, (10) Solar Resource Assessment: Characterization and Forecasting to Support High Photovoltaic Penetration, NREL/TP-581-42301, (11) Test and Demonstration Program Definition to Support High Photovoltaic Penetration, NREL/SR-581-42302, (12) Value Analysis, NREL/SR-581-42303, (13) Photovoltaic Business Models, NREL/SR-581-42304, (14) Production Cost Modeling for High Levels of Photovoltaic Penetration, NREL/SR-581-42305, and (15) Photovoltaic Market-Penetration Scenarios, NREL/SR-581-42306.

15. SUBJECT TERMS
renewable systems interconnection; interconnection; photovoltaics; PV; high-penetration; summary; National Renewable Energy Laboratory; NREL

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	UL		19b. TELEPHONE NUMBER (*Include area code*)