

Renewable Energy Grid Integration

Building and Assessment

Thomas Georgiadis
Editor



RENEWABLE ENERGY

RESEARCH, DEVELOPMENT AND POLICIES SERIES

NOVA

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RENEWABLE ENERGY: RESEARCH, DEVELOPMENT AND POLICIES

RENEWABLE ENERGY GRID INTEGRATION

BUILDING AND ASSESSMENT

THOMAS GEORGIADIS
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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. As distributed PV and other renewable energy technologies mature, they can provide a significant share of our nation's electricity demand. 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 book addresses the technical and analytical challenges that must be addressed to enable high penetration levels of distributed renewable energy technologies. This book consists of public domain documents which have been located, gathered, combined, reformatted, and enhanced with a subject index, selectively edited and bound to provide easy access.

Chapter 1 - 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. The study addressed the technical and analytical challenges that must be addressed to enable high penetration levels of distributed renewable energy technologies. This RSI study addresses grid-integration issues as a necessary prerequisite for the long-term viability of the distributed renewable energy industry, in general, and the distributed PV industry, in particular.

Chapter 2 - 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. The study addressed the technical and analytical challenges that must be addressed to enable high penetration levels of distributed renewable energy technologies. This RSI report discusses the tests and demonstrations needed to better understand the issues and solutions associated with the high penetration levels of photovoltaics (PV) expected in future utility distribution systems. It identifies areas in which testing needs to be conducted and recommends specific tests needed to understand high-penetration PV scenarios and promote effective solutions. These tests will be conducted in both controlled laboratory settings and field demonstrations.

Chapter 3 - 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. The study addressed the technical and analytical challenges that must be addressed to enable high penetration levels of distributed renewable

energy technologies. This RSI report focuses on the need for advanced distribution engineering analytical tools. High-penetration PV will change the way that distribution systems perform and provide both new capabilities and challenges for reliable, quality performance. The most fundamental change is the presence of generation on a system designed strictly to serve loads.

Chapter 4 - 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.

Chapter 5 - Study Area #4 focuses on the current availability of solar radiation resource data to support distributed grid-tied PV analyses, and the types of data and products needed to support future analysis and operations of significant grid-tied PV penetration. The study also is the impetus for a 5-year research and development plan to assure delivery of these products to end users. Much of the information derived in this study was obtained through interaction with other study-area authors, and with analysts, utility representatives, and solar resource data providers.

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Chapter 1

RENEWABLE SYSTEMS INTERCONNECTION STUDY:
ADVANCED GRID PLANNING AND OPERATIONS*

*Mark McGranaghan, Thomas Ortmeyer, David Crudele,
Thomas Key, Jeff Smith and Phil Barker*

ABSTRACT

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. The study addressed the technical and analytical challenges that must be addressed to enable high penetration levels of distributed renewable energy technologies. This RSI study addresses grid-integration issues as a necessary prerequisite for the long-term viability of the distributed renewable energy industry, in general, and the distributed PV industry, in particular.

LIST OF ACRONYMS

ΔV	voltage change
ANSI	American National Standards Institute
BPL	broadband over power line
CAES	compressed air energy storage
CERT	Consortium for Electric Reliability Technology Solutions
AEP	American Electric Power
CHP	combined heat and power
CT	combustion turbine
DER	distributed energy resources

* This is an edited, reformatted and augmented version of a U. S. Department of Energy publication dated February 2008.

DG	distributed generators or generation
DOE	U.S. Department of Energy
DR	distributed resources
DUIT	Distributed Utility Integration Test
EEN	energy exceeding normal
EMS	energy management systems
EPRI	Electric Power Research Institute
FCC	Federal Communications Commission
HV	high voltage
I^2R	power flow losses
IA	IntelliGrid Architecture
ICE	internal combustion engine
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGBT	insulated gate bipolar transistors
ISO	independent system operator
IUT	intelligent universal transformer
LCOE	levelized cost of energy
LTC	load tap changing
LV	low voltage
MCFC	molten carbonate fuel cells
MEM	Microgrid Energy Management
MV	medium voltage
NREL	National Renewable Energy Laboratory
NTUA	National Technical University of Athens
OMS	outage management system
PAFC	phosphoric acid fuel cells
PHEVs	plug-in hybrid electric vehicles
PURPA	Public Utility Regulatory Policies Act (1978)
PV	photovoltaics
PWM	pulse-width modulated
RSI	Renewable Systems Interconnection
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
SEIA	Solar Energy Industries Association
SMES	superconductive magnetic energy storage
SNL	Sandia National Laboratories
T&D	transmission and distribution
TC	Technical Committee (of the IEC)
UL	Underwriters Laboratories
VAC	volts alternating current
VAR	volt ampere reactive
WG	Working Goal (of the IEC TC)

EXECUTIVE SUMMARY

The electric grid enables PV generation by delivering available renewable power system output to the larger energy market. The grid simplifies the balancing of variations in supply and demand of individual distributed generators over a wide area. This service improves distributed generator economics and reduces the requirement for adding energy storage. A critical challenge—and the subject of this study—is that significant deployment of PV energy requires modernization of the distribution grid. Grid change needs depend on the level of deployment, the existing distribution configuration, and the PV system design. R&D is needed to define what future electric distribution will look like and how the existing distribution system can evolve to this new design.

This chapter looks at issues and options for increasing the penetration of renewable generation. The distribution grid was designed and built and is operating for centralized generation. With limited capacity for reversing power flows and without control and communication at the point of use, our existing distribution grid is not equipped to realize the full potential of distributed PV generation. Gradual—and not necessarily system-wide—evolution is needed and should be appropriate for the level of penetration at a substation or feeder level. Other opportunities to improve the distribution and use of electricity such as load management, advanced metering, and demand control are considered in this chapter, along with distributed renewable generation.

Two evolutions are envisioned. The first is distributed PV systems that operate interactively with available solar resources, varying conditions on the grid, and other local resources, including load control and future generation and storage resources. The second, and perhaps more challenging, evolution is that the distribution grid will need to be reinvented to interact with and in some cases control distributed generation and load demand. This will in turn make the grid more compatible with “grid-ready” distributed PV systems.

To support this vision, a strategy is needed to move from the relatively small PV energy market of “passively interacting” systems to a PV system that is an “active partner” in the grid. A key element of this strategy is that the PV system will help to meet system energy demand and control requirements at all grid levels, including transmission and independent system operators. Another element is recognition of the large existing capital investment in distribution, which will require a long-term and deliberate effort to change.

A key conclusion of this work is that significant coordination, planning, and related R&D will be required to ensure that the evolution is done intelligently. This “smart” evolution includes other necessary system changes, such as allowing for increasing distribution automation, automated load controls, and greater facilitation of features that enhance power quality and reliability. These features can be part of a 21st-century grid that is more reliable, has improved long-distance power transaction flexibility, and is ready for widespread PV energy systems.

Three areas are addressed in this chapter:

- Evolutionary change to enable high penetration
- 21st-century power distribution and PV compatibility
- The future for microgrids.

Evolutionary Change to Enable High Penetration

In the history of efforts to deploy and apply distribution generation, significant progress has been made with interconnection standards and with the recognition that changes must be made in power distribution design and operation in the future. This began with the Public Utility Regulatory Policies Act (PURPA) of 1978, which provided a framework and allowed cogeneration with the electric grid. Larger conventional types of distributed generators (DG) were installed on a case-by-case basis. With a wider variety of smaller generators, more uniform connection rules were developed. As penetration levels increase, however, traditional grid system operation and controls require change (with a few exceptions). In general, distributed resources passively interact with the grid.

With the growth and success of wind generation and aggregation into large wind farms at transmission and subtransmission levels, the operating rules have evolved to more active interaction with and support of the grid. As distribution-level distributed generation grows to higher penetration levels, two evolutions are seen. The first is that distribution generation begins to operate interactively with both the conditions on the grid and with other local resources, including load control and, in the future, other generation and storage resources. The second and perhaps more challenging evolution is that the distribution grid will need to be redesigned and rebuilt, perhaps reinvented, to be more compatible with the new requirements of distributed energy systems.

Table ES-1. Evolution of Distribution Energy

Parameter of Interest	Fossil Fueled Cogeneration (PURPA)(1978 to mid-1990s)	Emerging Gas and Renewable DG (mid-1990s to present)	Maturing Renewable DG and Load Control (near future and beyond)
Penetration Level	Less than 2% of bulk generation energy	Less than 10%	Growing to 20% and greater
Deployment Strategy of Distributed PV	To provide initial legal and technical framework to allow grid connection of independent power producers	To facilitate a developing market for small to midsized passively interacting DG	DG becomes an active partner in helping to meet system energy demand and control requirements at all grid levels
Level of System Where Strategy Is Focused	Not addressed	Distribution system level	Distribution and bulk system levels
Level of PV Compliance with the Electric Power System	Location-specific requirements; main concerns are trip limits, safety, and protection	System-specific requirements for power quality, islanding protection, and passive system participation	Uniform requirements for power quality and active participation in power system operation
Electric Power System Changes To Enable Penetration	No special proactive design considerations	Some proactive design considerations, mostly minor changes such as slower reclosing	Significant protection, control, grounding, and communication design changes to implement high penetration