

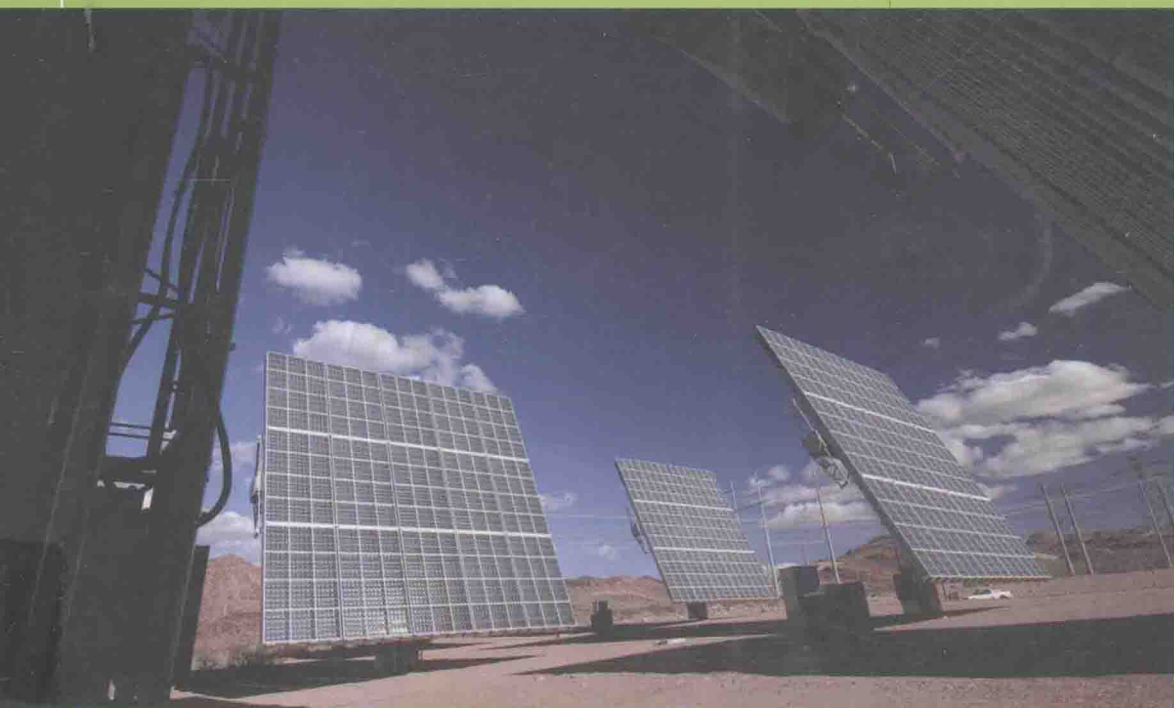
# Large-Scale Solar Power System Design

An Engineering Guide for Grid-Connected  
Solar Power Generation

Peter Gevorkian

## 大规模太阳能系统设计

### 太阳能光伏并网发电工程技术指南



A GreenSource BOOK 影印版

# LARGE-SCALE SOLAR POWER SYSTEM DESIGN

*AN ENGINEERING GUIDE  
FOR GRID-CONNECTED  
SOLAR POWER GENERATION*

PETER GEVORKIAN

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大规模太阳能系统设计  
太阳能光伏并网发电工程技术指南



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Peter Gevorkian

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# **LARGE-SCALE SOLAR POWER SYSTEM DESIGN**

## ***AN ENGINEERING GUIDE FOR GRID-CONNECTED SOLAR POWER GENERATION***

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**PETER GEVORKIAN, PH.D., P.E.**



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## About the Author

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**Peter Gevorkian, Ph.D., P.E.**, is President of Vector Delta Design Group, Inc., an electrical engineering and solar power design consulting firm located in La Canada Flintridge, California. He holds a B.S. in electrical engineering, an M.S. in computer science, and a Ph.D. in electrical engineering. He has been the recipient of numerous awards for engineering merit, design achievement, solar power design, and renewable energy systems.

Dr. Gevorkian has taught computer science, automation control, and renewable energy systems engineering, and has written many technical papers for national and international symposiums. He is the author of the books *Sustainable Energy Systems in Architectural Design*, *Sustainable Energy Systems Engineering*, *Solar Power in Building Design*, and *Alternative Energy Systems in Building Design*, all published by McGraw-Hill.

# FOREWORD

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With the publication of *Large-Scale Solar Power System Design*, Peter Gevorkian once again shows his mastery of a subject matter that, on the face of it, appears arcane and unremittingly esoteric. In Dr. Gevorkian's hands, this encyclopedic examination of solar power system design and implementation comes alive as an indispensable tool in our quest for sustainable, energy-efficient solutions to many of today's most pressing environmental challenges.

This work is a testament to Dr. Gevorkian's power as a communicator. He has a uniquely inspired gift: the facility to take a comprehensive body of knowledge and, without compromise, synthesize its essence for an extraordinarily mixed audience comprising sustainability adherents, engineers, mathematicians, physicists, architects, public officials, building developers, and owners—even lay end users.

Dr. Gevorkian has a big-picture vision of the aspects of this subject matter that appeals to a variety of sectors, including persons with a primarily technical bent, those readers who are conscious of the contemporary public will toward alternative-energy strategies, and those people for whom the business case of solar technology is all-important. Dr. Gevorkian is beyond literate on the subject of solar energy.

His ability to weave a commonsense logic that provides simplified explanations of fundamentally complex issues makes this work eminently readable. Dr. Gevorkian tells a good story, over and over again. What makes this book so important is the nexus of the known and unknown that he continually revisits. Dr. Gevorkian is a teacher throughout this book. He continually defines and redefines, clarifies and reclarifies, and not so much advocates for you to become one of the converted as he offers you the validation—and space—that you need to proclaim what you have already decided to be. He nudges you to feel the impulse in your viscera and to express it with a roar like the New Age intellect that you purport to be.

Any book that evolves from an initial assessment of relevant definitions of subject matter to an exercise in clarifying Max Planck and Einstein, from a repository of how-to applications to a work that ultimately makes a nearly unassailable financial case for large-scale solar energy investment, is a unique and valued instrument. *Large-Scale Solar Power System Design* has offered Dr. Gevorkian the opportunity to craft a masterwork.

Dr. Gevorkian is poised on the precipice of sustainability's future. It is the future of people of common sense, post-excess practitioners of efficiency and

moderation. In the coming years, when the practical application of solar energy to every aspect of the collective life experience is an afterthought, this delightful work will stand the test of time.

*Dr. Lance A. Williams*

*Dr. Lance A. Williams is Executive Director of the U.S. Green Building Council's Los Angeles chapter. He is LEED Accredited Professional who has traveled extensively and viewed sustainability in a wide variety of settings. His primary focus is the relationship between culture and sustainability.*



# INTRODUCTION

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This book is intended to be a comprehensive design reference guide for professionals vested in PV solar power generation system designs, solar power system integration, project management, and system tests and evaluations of large-scale grid-connected solar power systems.

The book may be used as a graduate or postgraduate textbook in alternative energy systems and electrical engineering studies, as well as a professional extension course for individuals interested in pursuing a career in the solar power system industries.

As a design reference manual, this book is intended to set a standard for engineering design and construction guidelines for large-scale solar power system projects. Design methodologies reflected in the book have been based on my years of pragmatic solar power and electrical engineering design experiences.

Currently, there is an acute shortage of engineering design and construction personnel worldwide who possess an in-depth knowledge of large-scale grid-connected solar power systems. It is my hope that people in the field and considering entering the field find this book a valuable resource.

Furthermore, in the past several years, skilled professionals with design and installation experience have been (and, in the near future, will be) in great demand. However, our higher-learning institutions (universities and technical schools) seriously lack teachers and instructors with real hands-on experience. It is these types of educators who are required to respond to the demand created by ongoing large-scale solar power projects worldwide.

*Peter Gevorkian, Ph.D., P.E.*

# ACKNOWLEDGMENTS

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I would like to thank my colleagues and other individuals who have encouraged me and assisted me in writing this book. I am especially grateful to all agencies and organizations that provided photographs and allowed use of some textual material, and to my colleagues who read the manuscript and provided valuable insight. Thanks to Arlen Gharibian for the preliminary edit of the manuscript.

My thanks go to Dr. Lance Williams, Executive Director, U.S. Green Building Council, Los Angeles Chapter; Ken Touryan, Ph.D.; Gabriel Paoletti, EATON Corporation; Dr. Vahan Garboushian, President, AMONIX Inc.; Robert McConnell, Ph.D., Sr. V.P., AMONIX Inc.; Nancy Hartsoch, V.P., SolFocus; Hagob Panossian, Ph.D.; Dr. Subhendu Guha, United Solar Ovonic; Dr. William Nona, Architect, National Council of Architectural Registration Boards; Behzad Eghtesady, P.E., Chief Electrical Engineer, Los Angeles Department of Building and Safety; and Eddie Alahverdian, P.E., Sr. Engineer, Solar Power Systems Design, Los Angeles Department of Water and Power.

My thanks also go to AMONIX Inc., Torrance, California; Atlantis Energy Systems, Inc., Sacramento, California; California Energy Commission, Sacramento, California; Museum of Water & Life, Center for Water Education, Hemet, California; Solar Integrated Technologies, Los Angeles, California; U.S. Green Building Council, Los Angeles Chapter; U.S. Department of Energy, National Renewable Energy Laboratories; Wikipedia, for coverage of the fuel cell and hydrogen industries; Sandia National Laboratories; and Solargenix Energy, Newport Beach, California.

## **DISCLAIMER NOTE**

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This book examines large-scale solar power system design, with the sole intent to familiarize the reader with the design guidelines of existing solar photovoltaic technologies in order to encourage engineers, educators, solar power integrators, and management personnel to promote deployment of solar power energy systems.

The principal objective of the book is to emphasize solar power co-generation design, application, and economics. Also, Chap. 11 covers passive solar systems that have in the past few decades undergone notable improvements throughout the industrialized world.

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# **LARGE-SCALE SOLAR POWER SYSTEM DESIGN**

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# **SOLAR POWER SYSTEM TECHNOLOGIES**

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## **Introduction**

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Solar or photovoltaic (PV) cells are electronic devices that essentially convert the solar energy of sunlight into electric energy or electricity. The physics of solar cells is based on the same semiconductor principles as diodes and transistors, which form the building blocks of the entire world of electronics.

Solar cells convert energy as long as there is sunlight. In the evenings and during cloudy conditions, the conversion process diminishes. It stops completely at dusk and resumes at dawn. Solar cells do not store electricity, but batteries can be used to store the energy.

One of the most fascinating aspects of solar cells is their ability to convert the most abundant and free forms of energy into electricity without moving parts or components. Also, they do not produce any adverse forms of pollution that affect the ecosystem, as is associated with most known forms of nonrenewable energy production methods, such as fossil fuels, hydroelectric power, or nuclear energy plants.

In this chapter, we will review a number of solar power PV system technologies, manufacturing processes, and the intercellular connectivity of basic flat-panel technologies.

## **Solar Cell Electronics**

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An electrostatic field is produced at a PN junction of a solar cell by impinging photons that create 0.5 to 0.6 V of potential energy, which is characteristic of most silicon-based PN-junction photovoltaic technologies. Voltage potential generated by the cells is analogous in function to a small battery. When connecting the positive and negative leads in parallel or series combination, similar to conventional batteries, the PN-interconnected cells could generate higher currents and voltages.