

SOLAR POWER

Generation Problems, Solutions, & Monitoring



Peter Gevorkian

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SOLAR POWER GENERATION PROBLEMS, SOLUTIONS, AND MONITORING

Solar Power Generation Problems, Solutions, and Monitoring is a valuable resource for researchers, professionals, and graduate students interested in solar power system design. Written to serve as a pragmatic resource for the financing of solar photovoltaic power systems, it outlines real-life, straightforward design methodology.

Using numerous examples, illustrations, and an easy-to-follow design methodology, Dr. Peter Gevorkian discusses some of the most significant issues that concern solar power generation including, but not limited to:

- Power output
- Energy monitoring and energy output enhancement
- Fault detection
- Fire and life safety hazard mitigation
- Detailed hardware, firmware, and software analytic solutions required to resolve solar power technology shortcomings.

This essential reference also highlights significant issues associated with large-scale solar-photovoltaic and solar power generation technology covering design, construction, deployment, and fault detection monitoring as well as life safety hazards.

Dr. Peter Gevorkian is President of Vector Delta Design Group. His expertise lies in renewable energy sources, such as solar power, fuel cells, and micro turbine cogeneration. He is an active member of the Canadian and California Society of Professional Engineers and the California Society of Energy Engineers. Dr. Gevorkian has taught computer science, automation control, and renewable energy systems engineering at UCLA, UC Irvine, and UC Riverside. He has published many technical papers for national and international symposiums and has authored six technical books on renewable energy systems design, including *Sustainable Energy Systems in Architectural Design*, *Sustainable Energy System Engineering*, *Solar Power Systems in Building Design*, *Alternative Energy Systems in Building Design*, *Large-Scale Solar Photovoltaic System Design*, and *Large-Scale Solar Power Systems: Construction and Economics*.

About the Author

Dr. Peter Gevorkian, PhD EE, P. E. holds a BSCE (Honors) in electrical engineering, an MS in computer science, and a PhD in electrical engineering. His expertise lies in renewable energy sources such as solar power, fuel cells, and micro turbine cogeneration. He has designed more than 50 MW of photovoltaic systems for healthcare, aviation, and regional utility companies across the United States. An active member of the Canadian and California Professional Engineering Society of Engineers, Dr. Gevorkian is an internationally acclaimed engineering consultant and scientist specializing in renewable energy.

Over his career, spanning nearly 40 years, Dr. Gevorkian has received numerous honors and awards and has contributed numerous technology innovations in solar power, process control, and automation systems:

- AIA 2007 Engineering Merit Award for Renewable Energy Systems Engineering Design and Exceptional Contribution to Advancement of Solar Power Co-generation in Building Design
- AIA 2007 Design Honor Award for Outstanding Engineering Design for the Metropolitan Water District's Museum of Water and Life



- AIA 2008 Honor Award for Outstanding Design Achievement in Solar Power Engineering
- AIA 2009 Honor Award for Excellence in Solar Power Design
- 2010 Nomination by the University of Waterloo Faculty of Engineering for the Medal of Honor for Engineering Achievement

Dr. Gevorkian has taught computer science, automation control, and renewable energy systems engineering. He has published many technical papers for national and international symposiums and has authored several technical books on renewable energy systems design. He has received international acclaim as best-selling author, and some of his books have been translated into Chinese and are being used as textbooks in the United States and abroad. His books, published by McGraw-Hill, include:

- *Sustainable Energy Systems in Architectural Design: A Blueprint for Green Design*
- *Sustainable Energy System Engineering: The Complete Design Resource*
- *Solar Power Systems in Building Design: The Complete Photovoltaics Engineering Resource*
- *Alternative Energy Systems in Building Design*
- *Scale Solar Photovoltaic System Design*
- *Large-Scale Solar Power System Construction and Economics*
- *Advanced Solar Energy Generation Systems Design, Process, Issues, Problems, and Solutions*

Dr. Gevorkian is extensively involved in research and development of numerous innovations in solar and energy production technologies. His specific technology innovations in solar power include a high-precision solar power energy management and life-safety control system, energy production prognostication, and econometric analytical software systems.

Dr. Gevorkian is also president of his own company, Vector Delta Design Group, an electrical engineering and solar power consulting organization located in La Canada Flintridge, California, that specializes in industrial, commercial, and residential projects.

Foreword

Solar Power Generation Problems, Solutions, and Monitoring by Dr. Peter Gevorkian have a title that tells it all. What this book does is something that everyone in that area of work needs to do: be creative and innovative from a multitude of dimensions, disciplines, and perspectives. Large and small solar systems today are being recognized as the solution to climate change, and they are also responsible for the creation of new companies and jobs at all levels.

To start with, Dr. Gevorkian and I share many things in common. We are both authors of numerous books, have published many papers, and have conducted extensive seminars and lectures in numerous institutions of higher learning in the United States and abroad. Both of us have multiple advanced graduate degrees, with the only difference being that Dr. Gevorkian's are more in the fields of sciences and engineering, whereas mine are in the social sciences. We both look at the same world, but from complementary perspectives.

Nonetheless, we see the solution to the world's problems in much the same way: through stopping climate change and providing smart, green, sustainable communities. The key here is that his book uses multi-scientific perspectives to examine problems using clear scientific approaches to resolve climate change. What I have done is similar, but using the social sciences, although one of my goals is to turn economics into a science much as this book does.

The use of science and, especially, its processes to solve problems is critical. And that is what Dr. Gevorkian's book does successfully. In my publications, in parallel, I have taken a scientific approach to economics through the use of physics and linguistics and have applied their insights to public policy, government, social media, and social sciences, such as anthropology, sociology, and psychology. I know that in the near future Dr. Gevorkian and I will collaborate to write a book that connects all these fields.

Consider some themes in *Solar Power Generation Problems, Solutions, and Monitoring* that highlight the scientific need for operational safety and reliability of large-scale solar systems. This entire area is critical; Dr. Gevorkian notes how rapidly solar technology has developed and expanded into a global multi-billion dollar industry. However, the proliferation of large-scale solar power system deployment is

also an Achilles heel since, as Dr. Gevorkian states, there is a basic requirement to have “significant knowledge of electrical power engineering, fundamental knowledge in grid power connectivity, power transmission, system design analysis, fault current analysis, system failure and alarm detection, econometric analysis, and much more.”

The issues discussed in Dr. Gevorkian’s book are extremely important and are not being adequately addressed by the solar industry, let alone by government policy makers or the funding and economic financiers. As discussed in the book, there is a long list of issues that reveal the fundamental need for engineering design, planning, execution, and fault detection in photovoltaic modules, as well as energy management analytics, which must be addressed by the industry to render solar power energy production a viable base-load alternative for energy as opposed to polluting forms of electrical energy production. Ignoring the solar power technology problem leads to solar power system failures, which means loss of power, dangers to life safety, and related hazards along with loss of property. These issues are the externalities to economics, which are rarely accounted for in most industries, and must especially be addressed in the “green industrial revolution,” in order to support it and make it a paradigm change for the world. The problems that this book addresses will lead to the prevention of liability problems, as well as serious loss of lives, property, and return on investment, which are all issues not presently addressed by the industry.

In addition, the book examines and explores solutions to these and other problems. The application of science to meet and correct these problems is carried out through the concepts and ideas reflected in the book, such as the implementation of smart grids, which illustrate the multidisciplinary nature of solar power technology and of the approaches that are required to solve global climate problems today, not 20 to 30 years from now. Climate change is threatening the world now. And these scientific solutions are needed now.

Social scientists need to read this book. They need to know what the science is about and to familiarize themselves with how to apply it when looking at large or even small on-site solar power systems. The need to gather qualitative and quantitative data, for example, is extremely important. Hypotheses must be made, tested, and retested with both observable and numerical results. In order for economics, a social science, to be scientific, in the end there must exist sets of well-defined standards and use of methodologies to validate data of the most important energy source. But these standards and methodologies have not yet matured. Above all, such scientific processes, methods, and standards, with their evaluations and conclusions, mean that reuse and testing are valid and predictable. This book and its ideas establish such scientific criteria and standards, which benefit engineers, scientists, economists, and social scientists, as well as educators and government policy makers by allowing them to understand the fundamentals of the solar power energy-generation technology industry.

As Dr. Gevorkian concludes

When considering Earth's limited resources, solar energy is the most viable energy form. Research and development for the deployment of solar power technology is of paramount importance to the survival of mankind, and the promotion of alternative and solar power studies by higher learning institutions worldwide must be an academic priority.

We all need to know, understand, and practice this. In short, solar energy use is our future today. It is one of the most enduring and viable energy sources for future generations.

Woodrow W. Clark II, MA³, PhD
Qualitative Economist
Managing Director, Clark Strategic Partners

Preface

This book highlights some of the significant issues associated with large-scale photovoltaic solar power generation technology from the perspective of design, construction, deployment, and fault detection monitoring, as well as life safety hazards. In addition to a systematic review and analysis, this book includes fundamental engineering design and construction solutions, and a review of technological advancements aimed at overcoming decades of challenges, which have prevented large-scale solar power generation from becoming a dependable and significant source of energy production for present and future generations.

Solar power generation has great potential. However, at present, the technology has serious shortcomings affecting the reliability of systems operations, fault detection, automated production, and control, which all currently affect its economic viability.

In addition to coverage of engineering design, the book covers bidding and system procurement, contract awards, installation, integration tests, commissioning, power production, monitoring, fault detection, maintenance, and numerous hidden issues that can reduce earnings on investment.

This book provides step-by-step descriptions of the complex issues associated with large-scale solar power deployment. The technological challenges and solutions covered in this book are based on the author's two decades of engineering design experience with numerous large-scale solar power systems in the United States and around the world. The principal objective of this book is to provide a roadmap for successful implementation of large-scale solar power generation.

How This Book Differs from Previous Books

In a previous book entitled *Large-Scale Solar Power System Design* (McGraw-Hill 2010) I presented step-by-step guidelines for the design and installation of large-scale solar power plant systems. In a subsequent book, *Large-Scale Solar Power Systems Construction and Economics* (Cambridge University Press 2013), I went into detail on the construction, financing, and econometric aspects of building and operating large-scale solar power systems. In this new work, I cover some of the most

significant issues that concern solar power generation, including power output, energy monitoring, energy output enhancement, and fault detection, as well as fire and life safety hazard mitigation. To date, these major concerns have not been addressed in print, which makes this publication timely and valuable for students and professionals.

This new book also includes a special chapter on the sometimes confusing legal language commonly used in large-scale solar power contracts. These samples of legal terminology give the reader insight into the complexities of third-party solar power financing. While this is not a subject well known or written about in technology books, some understanding will prove valuable.

Today, power system assembly and integration require minimal knowledge of engineering design. The field has almost become a plug-and-play technology. By interconnecting photovoltaic modules in series or tandem and connecting them to a power inverter, direct current is transformed into alternating current as a ready-to-consume source of energy. The simplicity of solar power system integration accounts for the rapid expansion of the technology, which is now a multi-billion-dollar global industry. But the field also suffers from an Achilles heel, since photovoltaic DC-to-AC power conversion on a large scale requires significant knowledge of electrical power engineering and fundamental knowledge of grid power connectivity, power transmission, system design analysis, fault current analysis, system failure and alarm detection, econometric analysis, and much more.

At present, most large-scale solar power installations lack adequate technology to detect and mitigate faults in solar power systems or sub-systems. These faults often go undetected for extended periods, resulting in significant revenue losses. Detecting failures in photovoltaic modules is a difficult task since they do not exhibit visible signs of failure in either active energized or de-energized mode. In general, the only means of verifying solar power functionality is to monitor the aggregate mean power output from an inverter and correlate the output with baseline or historical data which is impossible task. Furthermore, solar power system failures can cause high-voltage electrical shorts and ground faults that can result in life safety hazards, fire damage, and material and property losses.

The main objective of this book is to highlight some of the most important issues associated with large-scale solar power systems, which have always been associated with the technology yet have never been explicitly discussed in print. Well-documented issues, such as solar power fire and life safety hazards, have recently necessitated revision of the National Electrical Code (NEC). The 2014 NEC solar power code (Section 690) now includes a special mandate for solar power ground-fault current (the cause of most roof-mount solar power fires) that must be included as part of all future solar power system installations. Unfortunately, the mandate does not provide concrete guidelines for accomplishing this goal.

As a design consultant on large-scale solar power systems, I have been quite concerned that large-scale solar power energy production viability could become a major deterrent if the present technology hazards are not resolved. This book

includes coverage of important material required for understanding significant issues associated with large-scale solar power generation technologies.

Chapters 1 through 11 of this book include systematic discussion of subjects and topics that must be well understood by industry, government, and educational organizations that are contemplating ownership or deployment of large-scale solar power systems. As mentioned earlier in this introduction, although this book is primarily aiming to highlight some of the technology issues, I have also included some of the important discussions about design and construction methodologies that were in my aforementioned earlier publications. This book is written to provide a systematic review of underlying factors, which include engineering design, solar power construction, and operation and maintenance.

The progression of chapters in this book commences with definitions of types of energies; fundamental laws of energy conservation and entropy; fundamental coverage of types of solar power technologies; common issues and problems associated with design, construction, and maintenance; and economics of procuring, operating, and maintaining solar power-generation systems.

Additional chapters are devoted to advanced solar power energy technologies, peak power energy production, life and fire hazard prevention technologies, and novel research and product development technologies that render large-scale solar power energy generation a viable economic investment. Also included in this book are several appendixes that include specific design reference materials and support literature for various chapters. The book also includes supplemental references to various solar power technology publications and publications on solar power design, construction, and econometrics.

The final chapter of the book is dedicated to alternative and renewable energy studies. I am of the opinion that some of the major issues discussed are a result of the complex nature of photovoltaic solar power system technologies, which require thorough familiarity with multidisciplinary science and engineering subjects. Current engineering curriculums do not include comprehensive alternative and renewable energy studies, and most engineering consultants tasked with designing large-scale solar power systems do not have specialized training on the subject. To fill this knowledge gap, I have outlined a comprehensive engineering curriculum in Appendix F of this book, which covers pragmatic knowledge and methodology for design, construction, and testing for large-scale solar power systems.

Contents of Chapters

Chapter 1 includes discussion of conservation of energy, which is essential for understanding natural laws as to how energy is generated and transformed from one form to another. Discussion is followed by the fundamental concepts of the first and second laws of thermodynamics and of life and entropy (or unidirectional loss of energy). This material is intended to underline the importance as to why mankind should be mindful of conservation of global energy resources and their use. Finally, readers are introduced to the concept of types of energies in various scientific fields.

Chapter 2 highlights the importance of large-scale solar power energy production, which includes specific topics that cover principles of photovoltaic phenomena and electrical energy generation from photons, as well as electrical power generation by conventional technologies. The main objective of this chapter is to familiarize the reader with how conventional photovoltaic (flat-panel system) solar power is integrated with the electrical grid.

Chapter 3 introduces concentrator-type photovoltaic (CPV) power technologies, their differentiation from flat-panel technologies, and the methodology of grid connection. Readers are also provided with a brief overview of third-party power purchase contracts.

Chapter 4 presents some of the most important core issues associated with solar power technologies that are most often overlooked by consumers, owners, and technology providers. Even though technologies for photovoltaic solar power generation have been around for several decades, there are numerous shortcomings and significant issues that are not understood by the public. In addition to technology shortcomings, solar power systems, if they are not designed and deployed properly, can create significant life safety and fire hazards. This chapter highlights issues and problems associated with the technology and provides readers an awareness of how to avoid missteps prevalent in most solar power system installations.

Chapter 5 includes step-by-step guidelines as to what is needed to circumvent some of the shortcomings and hazards associated with solar power technologies. The reader is introduced to fundamental concepts of solar power feasibility studies, design methodology, econometric analysis, and essential measures required for developing proper engineering design plans, technical specifications, and procurement documents.

Chapter 6 includes guidelines for solar power construction, logistics, construction supervision, project management, and required test procedures, which are essential to ensure proper deployment of solar power projects.

Chapter 7 is intended to familiarize users, investors, and owners of large-scale solar power systems with the dynamics of solar power construction economics and financing options. The contents also include significant topics related to various US solar power initiative programs, grid-connection metering requirements, benefits and limitations of feed-in tariffs, and advantages and responsibilities of solar power system ownership.

Chapter 8 discusses in detail the legal language associated with large-scale solar power contracts. These contracts generally include complicated legal terms and conditions that can only be understood by legal professionals. Terms and conditions outlined in the legal documents are convoluted and complex, since they are generally designed to protect the third-party investment or energy-providing organizations. This chapter includes step-by-step synthesis and interpretations of commonly used terminologies.

This segment is of significant importance for organizations that may be contemplating procurement and financing of large-scale solar power contracts through what are known as power purchase agreements (PPAs).

Chapter 9 introduces novel advancements required to mitigate some of the current shortcomings of large-scale solar power system technologies. The chapter includes comprehensive technology innovation proposed by the author. Proposed research and development of advanced products include end-to-end solutions, which include special photovoltaic (PV) module submetering system hardware, firmware, and analytics software developed by the author.

Chapter 10 covers recent advances in various technologies that have been developed to address some of the shortcomings associated with solar power technologies. Technologies covered include microinverters, peak power tracking, and string inverters. Also included are analysis and comparison of the technologies by third-party agencies.

Chapter 11 introduces the reader to advanced solar power generation and integration with the smart grid system. The topics covered include transition of conventional and renewable energy electrical power generation to the smart grid system, issues associated with the future of energy demand and supply, the principal function and architecture of future Super Smart Grid systems, and the future economic impact of smart grid systems.

Chapter 12 includes comprehensive coverage of conventional as well as advancements in large-scale energy storage systems.

Appendix A includes fundamental terminologies used in solar power systems.

Appendix B includes a comprehensive guideline for conducting a solar power feasibility study. Subjects covered include solar power platform analysis, site survey guidelines and logs, preliminary design evaluation, shading analysis, solar power sizing study, environmental factor considerations, and specific guidelines for preparing feasibility study reports.

Appendix C includes comprehensive large-scale solar power system test methodology and dynamic test procedure requirements.

Appendix D describes the Bakersfield, California, solar power fire.

Appendix E includes detailed listings of solar power incentives in the United States and worldwide feed-in tariffs, which are prevalent on all continents.

Appendix F proposes an educational curriculum for advanced degrees in Alternative and Solar Power Sciences and Engineering.

Appendix G includes a line-by-line historical timeline of solar power energy generation.

