Solar energy refers to the energy collected directly from sunlight. Solar power is the conversion of sunlight into electricity, referred to as photovoltaics. Photovoltaic systems are already an important part of our lives, powering many of the small calculators and wrist watches we use every day.

Over the last few decades, the developments in solar energy applications have made it possible to use solar energy for most of our energy needs. At present, solar energy applications are well developed for heating and cooling of buildings, electricity production for stationary and mobile applications, and for environmental cleanup.

Solar technologies are broadly categorized as either passive or active, depending on how they capture, convert, and distribute sunlight. Passive solar technologies involve selection of materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of building the sun. Active solar technologies make use of photovoltaic panels, pumps, and fans to convert sunlight into useful outputs.

Some of the advantages of solar energy are:

- Solar power can be used in both large-scale applications and in smaller systems for homes.
- Business and industry can diversify their energy sources, improve efficiency, and save money by choosing solar technologies for heating and cooling, industrial processes, electricity, and water heating.
- Homeowners can use solar technologies for heating, cooling, and water heating, and these technologies may produce enough electricity to operate “off-grid” or sell the extra electricity to the utilities, depending on local programs.
- The use of solar heating and daylighting design strategies can help both homes and commercial buildings operate more efficiently.

The scientific stage is set for rapid progress in solar energy research. There have been advances in nanoscience and nanotechnology, allowing unprecedented manipulation of the nanoscale structures, controlling solar capture, conversion, and storage. Light interacts with materials on the scale of its wavelength, a few hundred nanometers. Energy capture occurs via excited electron states confined by defect structures or interfaces to dimensions of tens of nanometers. Conversion of excited electrons to fuels such as ethanol, methane, or hydrogen occurs in chemical reactions at the scale of molecules. These nanoscale processes have never been more accessible to observation and manipulation.
The Handbook of Research on Solar Energy Systems and Technologies, which is divided into 20 chapters, addresses the research priorities in the topical area of solar energy. The Handbook provides up-to-date and relevant information regarding current and future research in:

- Photovoltaic Devices (polycrystalline thin film photovoltaics; nanocrystalline silicon solar cells, non-silicon based photovoltaics; CdTe based solar cells; polymer based solar cells; tandem solar cells and third generation solar cells).
- Nanostructures for solar energy conversion
- Solar energy conversion materials
- Solar energy storage
- The economics of solar energy
- Application of nanotechnology innovations to solar energy technologies

Chapter 1 focuses on the control and conversion of solar energy. The conversion of solar energy into thermal and electrical energy constitutes a key topical area for renewable energy. Solar electric systems find applications in rural electricity generation, water pumping, and satellite communications. Solar power is harvested and stored by charging rechargeable batteries. This chapter describes design and implementation of a solar battery charger using a single ended primary inductance converter (SEPIC).

Chapter 2 presents coverage of different methods and technologies used for the solar thermal storage in the terrestrial and space applications. The performance enhancement of these technologies using nanotechnology is also described. Moreover, this chapter provides coverage of various economic and environmental feasibility studies focusing on the storage of solar energy. Recommendations are made for developing new methods and enhancing the performance of existing techniques used to store solar energy.

In the case of solar energy, it is shown that optimal energy is obtained when the rays of the sun are incident normally on the collecting surface. Therefore, several techniques and experiments have been conducted recently to develop efficient solar tracking systems. Solar panel tracking systems optimize energy output of photovoltaic panels by positioning them to follow the sun’s path throughout the day. The sun’s position in the sky varies both with installation location, the seasons, and the time of day. Currently, most solar panels have fixed orientation to the sky and do not turn to follow the sun. To increase the unit area illumination of sunlight on solar panels, the design of a solar tracking electricity generation system is described in Chapter 3. The design mechanism holds the solar panel and allows the panel to track the sun’s movement during the day and improve the overall electricity generation. This system can achieve the maximum illumination and energy concentration and cut the cost of electricity by requiring fewer solar panels. An electro-optical control unit tracks the sun by a solar detecting device that is sensitive to solar radiance. The simulation is experimental results verifying the effectiveness of the light tracking solar system is presented in this chapter.

The photovoltaic (PV) systems extensively use advanced power electronics technologies. Power electronics provides a useful means of efficiency improvement in the photovoltaic and the solar-thermal energy systems. Furthermore, the use of appropriate power electronics enables solar generated electricity to be integrated into power grid. Chapter 4 provides a detailed description of the current advances in power electronics that enable the photovoltaic systems to become a real power source for the power utility grid and for many stand-alone applications. The future developments in power electronics and controls that are expected to lead to more efficient solar energy systems and devices are also discussed in this chapter.
Currently, there is a significant research interest in third generation thin-film solar cells such as all-silicon tandem solar cells and multi-junction solar cells targeting substantial improvements in energy conversion efficiency leading to a reduction in the overall power costs. The semiconductor bandgap can be controlled by quantum-confinement of carriers in small quantum-dots dispersed in an amorphous matrix of silicon oxide, nitride, and polymer materials. Cells based on “hot” carriers are also of great interest since they offer the potential for very high efficiency from simple device structures. Chapter 5 provides a detailed account of the first, second, and the third generation of solar cells.

It has been shown that the use of nanotechnology in the form of quantum dots, nanorods, and nanotubes, results in an enhancement of absorption of sunlight and an increase in the efficiency of photovoltaic cells. Chapter 6 provides a comprehensive coverage of the nanotechnology applications in photovoltaic systems. The chapter describes the use of nanotechnology in the implementation of low cost, highly efficient, and easy to implement photovoltaic cells. Future research directions are also discussed in this chapter.

Chapter 7 focuses on Copper Indium Gallium Selenide (CIGS) and the nanocrystaline silicon solar cells. Heterojunctions based on CIGS have been studied for several years, and have shown very stable performance in field tests. The chapter covers various preparation methods for CIGS solar cells, the effects of composition ratio on the performance, doping profiles, alternative buffer layers, low cost fabrication techniques, as well as global market trends. Nanocrystalline silicon films have also recently attracted attention for use in photovoltaic solar cells as they provide an approach which results in lower cost and higher efficiency than conventional solar cells. Furthermore, silicon based nanoparticles or superlattices may be integrated with other materials for bandgap-engineered devices. Designed appropriately, variation of the effective bandgap across the device allows a larger portion of the solar spectrum to be coupled into the solar cell increasing the conversion efficiency.

Surface plasmons are oscillations of electrons arising from surface effects of light interaction with materials having significant free carrier densities. Surface plasmons have been recently utilized in a variety of methods used to increase the efficiency of solar cells. Research on silicon-based plasmonic solar cells has made use of the high scattering cross sections and favorable angular distributions of noble metal nanoparticle-scattered radiation to increase absorption of thin silicon devices. Chapter 8 focuses on the surface plasmon-enhanced thin film silicon solar cells. The chapter provides a comprehensive description of the current research related to these cells.

Polymer solar cells are cheaper to produce than conventional inorganic solar cells and can be processed at relatively low temperatures. The polymer solar cells can be fabricated on surfaces of arbitrary shape and flexibility. Therefore, polymer solar cells are likely to play an important role in addressing, at least in some small part, future energy needs. Chapter 9 provides coverage of the physics of polymer solar cells with a special emphasis on the computational tools. Two computer simulation models discussed in this chapter include the drift diffusion model and the Monte Carlo model.

Solar cells made from III-V materials are expensive, but outperform other solar cells. The polycrystalline III-V thin film solar cells on dissimilar substrates such as metal or glass can provide a low-cost venue for photovoltaic solar energy. The highly developed technology base of III-V semiconductors should favor this approach. Chapter 10 provides a detailed account of III-V solar cells. Different approaches for development of III-V solar cells are analyzed and compared with each other. The future prospects for low-cost III-V compound solar cells are also discussed in this chapter.

Chapter 11 provides an overview of the analytical techniques used for solar cells material characterization. The advantages and disadvantages of such techniques are compared. Most of these materials characterization techniques are based on the same principle, that is, an incident beam of photons or
charged particles interacting with specimen resulting in various types of signals. An appropriate detection system is used to collect these signals, and then the data are analyzed to gain information regarding the material properties being studied. The analytical techniques described in this chapter are categorized as imaging, compositional analysis, and the structural analysis methods.

Chapter 12 provides description of a mechatronic real-time solar tracker. The tracking array for the solar cell is pivoted on two axes using stepper motors to reflect the effects of daily and seasonal trajectories of the sun. The solar tracker described in this chapter is an example of the application of mechantronics in the discipline of renewable energy. The chapter content provides details regarding the design, programming, and the prototyping of this solar tracking system.

Computer simulations are commonly used for analyzing solar energy systems. The interaction of light with matter at a nanoscale level provides useful information regarding the structured and dynamical properties of photonic devices. The use of computer simulations will continue to increase as the researchers and developers face the challenges associated with the design and development of new devices and systems. Although Chapter 13 focuses on the development and application of the Finite Difference Time-Domain method to solar energy systems, it provides an overview of the new computational models covering the latest developments in nanophotonics technologies. The key improvements in the numeric solvers and new usability features are also described in this chapter.

Image processing is extensively utilized in solar cell research, device development, process control, and quality assurance. The use of solar image processing is expanding due to performance enhancement of commercial CCD and infrared cameras. Chapter 14 provides a comprehensive description of the key solar image processing methods and their applications. However, the emphasis of this chapter is on monocrystalline and polycrystalline silicon solar cells using infrared and visible wavelengths.

Artificial intelligence (AI) techniques are of significant importance in modeling, analysis, and prediction of the performance of renewable energy systems. Chapter 15 provides a comprehensive coverage of the commonly used artificial intelligence (AI) techniques in solar energy. The chapter places an emphasis on neural networks, fuzzy logic, and genetic algorithms. Selected AI applications in solar energy are also described in this chapter. Instead of complex rules and mathematical routines, AI techniques are able to learn the key information patterns within a multidimensional information domain. Design, control, and operation of solar energy systems require long-term series of meteorological data such as solar radiation, temperature or wind data. Such long-term measurements are often non-existent for most of the interest locations or, wherever they are available, they suffer of a number of shortcomings (e.g. poor quality of data, insufficient long series, etc.). To overcome these problems, AI techniques appear to be one of the strongest candidates.

Chapter 16 provides a detailed account of the time series and neural network methodologies used for solar radiation forecasting. The time series methodologies described in this chapter include autoregressive (AR), moving average (MA), autoregressive moving average (ARMA), and autoregressive integrated moving average (AIMA). The chapter also presents a detailed comparison of the solar radiation forecasting techniques. The advantages and disadvantages of using the neural network approach for solar radiation forecasting are outlined in this chapter.

Chapter 17 provides a description of the different solar thermal applications of greenhouse structure. Greenhouse structures are used to provide the ideal conditions required for the growth of agricultural crops throughout the year. Topics covered in the chapter include an introduction to the concept and importance of greenhouse technology, solar thermal applications in different greenhouse systems, and the use of photovoltaic systems for greenhouse drying. In this chapter, there is a special emphasis on greenhouse fish pond system design and working principles.
As Saudi Arabia is going through a significant economic and technological development, the country needs additional electric power generation to sustain the economic growth. Fossil fuels, however, are not sustainable as they are subject to eventful depletion. Chapter 18 provides an examination of power generation alternatives for Saudi Arabia. Since the country is blessed with an abundant solar flux throughout the year, the construction of solar powered electrical generation plants in Saudi Arabia is proposed. However, due to the availability of different solar technologies, it is important to determine the optimal technology. In this chapter, a mathematical model called Hierarchical Decision Model (HDM) is used to make the technology selection.

Given the expanding use of solar energy, there is a need to educate society about solar energy. Thus, solar energy education and training programs should be developed at different educational levels to fulfill this need. Such programs need to recognize the environmental value of solar energy and the life cycle advantages of solar energy systems. Chapter 19 provides an overview of the status of solar energy education and training in the United States. Though the focus of this chapter is on the solar energy education and training programs provided by the academic institutions in the USA, a short description of non-academic programs is also provided.

Chapter 20 describes a project-based international collaboration in renewable energy systems design and implementation. The collaboration involves several educational institutions in Europe and USA. Working in teams, the undergraduate students at the partner institutions gain valuable experience in renewable energy systems design and construction. The participating students also learn effective teamwork and project management skills.

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