TAMER KHATIB | WILFRIED ELMENREICH

SIMPLIFIED GREEN CODES

Modeling of PHOTOVOLTAIC SYSTEMS *Using* MATLAB®

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MODELING OF PHOTOVOLTAIC SYSTEMS USING MATLAB®

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Tamer is a photovoltaic power systems professional. He holds a B.Sc. degree in electrical power systems from An-Najah National University, Palestine, as well as a M.Sc. and a Ph.D. degrees in photovoltaic power systems from National University of Malaysia, Malaysia. In addition, he holds a habilitation degree in renewable and sustainable energy from the University of Klagenfurt, Austria. Currently he is an assistant professor at Energy Engineering and Environment Department, An-Najah National University, Nablus, Palestine. So far, he has published over 85 published research articles, meanwhile his current h-index is 14. Moreover, he has supervised six Ph.D. and four M.Sc. researches. He is a senior member of IEEE Power and Energy Society and member of the International Solar Energy Society.

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FOREWORD

Recently, photovoltaic system theory became an important aspect that is considered in educational and technical institutions. Therefore, the theory of photovoltaic systems has been assembled and introduced in a number of elegant books. In the meanwhile, the modeling methodology of these systems must be also given a focus as the simulation of these systems is an essential part of the educational and the technical processes in order to understand the dynamic behavior of these systems. Thus, this book aims to present simplified coded models for these systems' component using Matlab. The choice of Matlab codes stands behind the desire of giving the student or the engineer the ability of modifying system configuration, parameters, and rating freely. This book comes with five chapters covering system's component from the solar source until the end user including energy sources, storage, and power electronic devices. Moreover, common control methodologies applied to these systems are also modeled. In addition to that auxiliary components to these systems such as wind turbine, diesel generators and pumps are considered as well.

In general the readership of this book includes researchers, students, and engineers who work in the field of renewable energy and specifically in photovoltaic system. Moreover, the book can be used mainly or partially as a textbook for the following courses:

Modeling of photovoltaic systems
Modeling of solar radiation components
Computer application for photovoltaic systems
Photovoltaic theory

The authors of this book believe that this book will helpful for any researcher who is interested in developing Matlab codes for photovoltaic systems, whereas many of the basic parts of system models are provided.

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To my daughter Rayna who will be in a dire need for green energy when she understands the contents of this book and to my wife Aida.

Tamer Khatib

To my daughters Gretchen and Viviane and to my wife Claudia.

Wilfried Elmenreich

CONTENTS

1

MODELING OF THE SOLAR SOURCE

1.1 INTRODUCTION

Solar energy is the portion of the Sun's radiant heat and light, which is available at the Earth's surface for various applications of generating energy, that is, converting the energy form of the Sun into energy for useful applications. This is done, for example, by exciting electrons in a photovoltaic cell, supplying energy to natural processes like photosynthesis, or by heating objects. This energy is free, clean, and abundant in most places throughout the year and is important especially at the time of high fossil fuel costs and degradation of the atmosphere by the use of these fossil fuels. Solar energy is carried on the solar radiation, which consists of two parts: extraterrestrial solar radiation, which is above the atmosphere, and global solar radiation, which is at surface level below the atmosphere. The components of global solar radiation are usually measured by pyranometers, solarimeters, actinography, or pyrheliometers. These measuring devices are usually installed at selected sites in specific regions. Due to high cost of these devices, it is not feasible to install them at many sites. In addition, these measuring devices have notable tolerances and accuracy deficiencies, and consequently wrong/missing records may occur in a measured data set. Thus, there is a need for modeling of the solar source considering solar astronomy and geometry principles. Moreover, the measured solar radiation values can be used for developing solar radiation models that describe the mathematical relations between the solar radiation and the meteorological variables such as ambient temperature,

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humidity, and sunshine ratio. These models can be later be used to predict solar radiation at places where there is no solar energy measuring device installed.

1.2 MODELING OF THE SUN POSITION

As a fact, the Earth rotates around the Sun in an elliptical orbit. Figure 1.1 shows the Earth rotation orbit around the Sun. The length of each rotation the Earth makes around the Sun is about 8766 h, which approximately stands for 365.242 days.

From the figure, it can be seen that there are some unique points at this orbit. The winter solstice occurs on December 21, at which the Earth is about 147 million km away from the Sun. On the other hand, at the summer solstice, which occurs on June 21, the Earth is about 152 million km from the Sun. However, to provide more accurate points, the Earth is closest to the Sun (147 million km) on January 2, and this point is called perihelion. The point where the Earth is furthest from the Sun (152 million km) is called aphelion and occurs on July 3.

For an observer standing at specific point on the Earth, the Sun position can be determined by two main angles, namely, *altitude angle* (α) and *azimuth angle* (θ_S), as seen in Figure 1.2.

From Figure 1.2 the altitude angle is the angular height of the Sun in the sky measured from the horizontal. The altitude angle can be given by

$$\sin\alpha = \sin L \sin\delta + \cos L \cos\delta \cos\omega \tag{1.1}$$

where L is the latitude of the location, δ is the angle of declination, and ω is the hour angle.

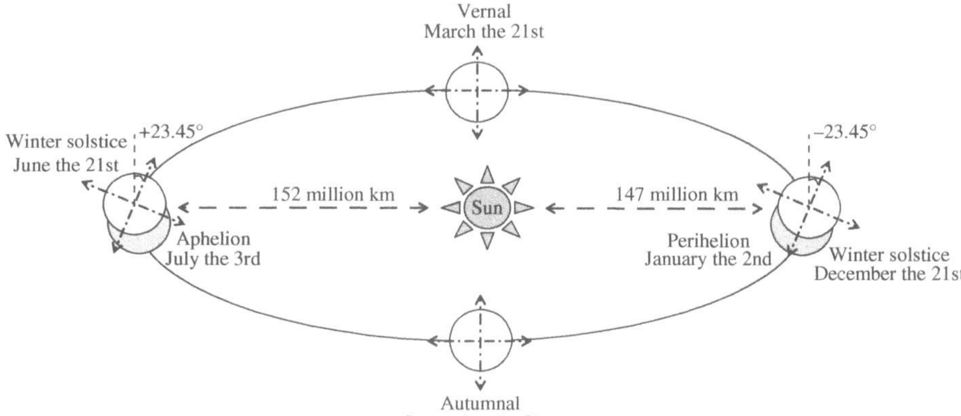

FIGURE 1.1 Earth rotation orbit around the Sun.