Renewable Energy

Renewable Energy:

Selected Issues Volume I

Edited by

Manuel Pérez-Donsión, Silvano Vergura
and Gianpaolo Vitale

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FOREWORD

Research on Renewable Energy contains several aspects of scientific interest, while also presenting political and ethical implications. In fact, the reduction of the cost of energy obtained by using renewable sources is a way to reduce poverty in disadvantaged countries and regions. Many renewable energy sources, such as solar and wind, differently from fossil fuel resources located in the subsoil, are available all around the world. With reference to electricity production, the reduction of the combustion of fossil fuels lessens the concentration of carbon dioxide, CO_2, in the atmosphere, opposing the increase of the earth's average temperature. Moreover, many of the products originated from the combustion of fossil fuel resources are detrimental to people's health.

From the scientific point of view, several challenges come from the intermittent nature of energy sources such as wind, solar photovoltaic and solar thermal. These challenges are addressed with research on power electronics converters, storage systems with their respective modelling and control algorithms, Artificial Intelligence techniques, new materials and production technologies, numerical analysis techniques and many others, in a multidisciplinary approach. In the future, this research has the aim of reducing costs and finding alternative energy sources that are competitive with fossil fuels. Consequently, the efforts of the scientific community will contribute to improve the quality of life in the planet.

With these objectives, hundreds of researchers, scientists, and engineers attend the International Conference on Renewable Energy and Power Quality (ICREPQ) annually.

This book summarizes ten years of contributions to the topics described above. It contains a selection of the best papers presented at the ICREPQ conferences from 2003 to 2012. These contributions have been selected by a team of voluntary reviewers, with two to four reviewers assigned to each paper. At the end of this process only about 5% of all presented papers were selected. Considering each paper had been reviewed before, to be accepted for the conference, the selected papers represent "the best of the best". Moreover, the authors have modified and updated the original contribution to be included as a chapter of this book. The contributors to this book span the globe, with about 200 authors from 20 different countries, some of whom are the leading authorities in their areas of expertise.

The conference takes place in Spain, and each year a different city is involved. In the last ten years the following cities have hosted the conference: Vigo (9th-11th April 2003); Barcelona (31st March-2nd April 2004); *Zaragoza* (Saragossa) (16th-18th March 2005); Palma de Mallorca (5th-7th April 2006); *Sevilla* (Seville) (28th-30th March 2007); Santander (12th-14th March 2008); Valencia (15th-17th April 2009); Granada (23rd - 25th March 2010); Las Palmas de Gran Canaria (13th-15th April 2011); Santiago de Compostela (28th-30th March 2012).

In these conferences, 3102 papers have been submitted, 2022 have been accepted and 1788 have been presented. This confirms a high participation level and fulfils the intention of the organizers to provide an opportunity for academics, scientists, engineers, manufacturers and users from all over the world to come together in a pleasant location to discuss recent developments in the areas of Renewable Energy and Power Quality.

All published papers are available on the conference website: http://www.icrepq.com/

With reference to renewable energy, the conference topics include, but are not limited to:

- Wind energy, small hydro energy, solar energy, photovoltaic energy, ocean Energy.
- Geothermal, biomass, co-generation.
- Classical and special electrical generators: Theory, design, analysis, losses, efficiency.
- Heating and cooling, vibration and noise, modelling and simulation, control strategies.
- Protection systems, maintenance, mechanical behaviour, new methods of testing, parallel operation, transmission system, stability.

- Power plants. Distributed generation. Fuel cells. Hybrid Systems.
- Microgrids. Smartgrids. Original solutions.
- Energy conversion, conservation and energy efficiency.
- Energy saving policy. Energy storage. Batteries.
- Energy and the environment. Ecological balance. Ecosystem.
- Application of the renewable energy. Best practice projects.
- Legislation in the area of renewable energies.
- Biomass combustion techniques. The energy use of agricultural and forest residues.
- Production and energy exploitation of biogas. Environment. Social importance.
- Interconnection and transmission problems.
- Planning and control of power systems taking into account renewable energy. Stability.
- Economic analysis of the power system taking into account renewable energy.
- Electricity Market Structures. Regulation/de-regulation of the power market. Influence of the renewable energy.
- Models and simulation of the power systems. Models and estimation of loads. Software tools.
- Application of the communications, internet, artificial intelligence for renewable energy.
- Security assessment and risk analysis in renewable energy.
- Electric vehicles.
- Electrical Machines & Drives, Power electronics and Control strategies for renewable energy applications.
- Monitoring and Diagnostics of electrical machines & drives, Tools for Diagnostics, Test for Predictive Maintenance in Renewable.
- Sensors and actuators for renewable energy applications.
- Renewable Energies Teaching.

Finally, the purpose of this book is to provide an up-to-date reference, useful for researchers, technicians and engineers looking for the state-of-the-art in the field of renewable energy. The book contains both theoretical and practical applications.

OUTLINE OF THE BOOK

The book is divided into nine parts:

- **Part I** deals with Data Management. It contains three contributions: the first one presents a method for clustering data coming from a photovoltaic plant and the other two are focused on forecast techniques.
- **Part II** deals with Distributed Generation Issues. There are eight contributions, discussing different aspects of the connection of a converter, processing the electrical energy coming from a renewable source, to the grid.
- **Part III** deals with Fuel Cells and Electric Vehicles. Four chapters examine in depth modelling aspects with different methodologies, including neural networks; an urban bus based on hydrogen and photovoltaic power is also described.
- **Part IV** deals with Hybrid Systems. The implications of the contemporary use of different power sources in different configurations, including storage systems, are examined over eight chapters.
- **Part V** deals with Microgrids. Several issues related to management analysis and economic implications are examined in eight chapters.
- **Part VI** deals with Solar Technologies. It is composed of nine chapters containing different contributions dealing with modelling, optimal design, control algorithms and practical applications.
- **Part VII** deals with Power Electronics for Renewable Energies. The attention of the four chapters is focused on the power conversion systems.
- **Part VIII** deals with Wind and Marine Power Generation. Ten chapters contain aspects connected to turbine analysis and modelling, addressing both wind and marine conversion; additionally, a wind harvesting solution is described.
- **Part IX** is a miscellany of different case studies with particular attention to practical applications.

To Whom this Book is Addressed

This book is intended primarily to meet the demands of professional engineers and researchers dealing with renewable energy exploitation, but it should also prove useful to postgraduate level students. It can be used as a reference book for engineers, physicists and mathematicians who are interested and involved in operation, project management, design, and analysis of renewable sources equipment. Each chapter contains references that allow the treated topic to be further deepened.

ACKNOWLEDGMENTS

First of all thanks to Professor Manuel Perez Donsión, of the University of Vigo (Spain), for the tireless and invaluable effort in the organization of the ICREPQ conferences.

Special thanks go to all voluntary reviewers. Each of them reviewed about 500 papers to complete the selection for this book; their great effort made this book possible. They are:

- Abdul-Ganiyu Adisa Jimoh, prof. Rand Water Professorial Chair in Electrical Engineering, Tshwane University of Technology, Private Bag X680, Pretoria 0001, South Africa.
- Antonio Gagliano. Department of Industrial Engineering, University of Catania
- Ramon Bargalló Perpiñà. Professor of Electrical Engineering Department at the EUETIB, Polytechnic University of Catalonia, Barcelona, Catalonia.
- Toshihisa Funabashi. Social Infrastructure Systems Business Group, Meidensha Corporation, ThinkPark Tower, 2-1-1, Osaki, Shinagawa-ku, Tokyo 141-6029 (Japan).
- Gorazd Štumberger. University of Maribor, Slovenia
- Tiberiu Tudorache. Assoc. prof. dr. eng. of the University Politehnica of Bucharest, Electrical Engineering Faculty, Office: EA113, 313 Spl. Independentei, Sect. 6, Code 060042, Bucharest, Romania.
- Etim U. Ubong, PhD, Dr. Techn. Kettering University, Flint, Michigan, USA.
- Silvano Vergura. Tenured Assistant Professor at Technical University of Bari, Professor of Electrotechnics, Bari, Italy
- Gianpaolo Vitale. Professor of Power Electronics at the University of Palermo, Senior researcher of National Research Council (CNR), Institute of Intelligent Systems for Automation (ISSIA) - UOS Palermo, Italy.

The Editors are grateful to the Technical University of Bari, Italy, and to ISSIA-CNR (Institute of Studies on Intelligent System for Automation, Italian National Research Council) for their institutional support.

Thanks to Dr. Filipe Tadeu Oliveira who has patiently and aptly assisted the authors in the manuscript revision.

Thanks to Cambridge Scholars Publishing for offering the possibility to publish this book on Renewable Energy, containing the most relevant papers of the last ten years of the International Conference on Renewable Energy and Power Quality (ICREPQ).

Finally, special thanks go to all the authors. Nowadays, writing a book follows a logic opposite to what is usually demanded of researchers. Nowadays, researchers are increasingly urged to submit projects, obtain financial support for research and publish as much and as quickly as possible; therefore, they are somewhat discouraged from dedicating time to writing a systematic compilation of their activities, in spite of the fact that this is a fundamental task to further improve research on a more meditated basis.

How to Use this Book

This book can be used in different ways. By looking at the titles of each part, the reader can identify the fields of interest. Each chapter is self-consistent since it comes from a scientific paper. References of each paper are useful to achieve further information.

BIOGRAPHIES OF THE EDITORS

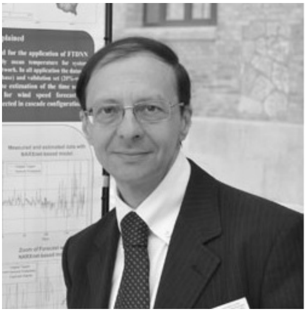
Manuel Pérez-Donsión received his MSc in Industrial Engineering from the Polytechnic University of Catalonia in 1980, and his PhD from the University of Vigo in 1986. In 1987 he became a Full Professor at this university.

Among other academic positions, he was the Dean of the *Escuela Técnica Superior de Ingenieros Industriales y Minas* from 1995 to 2001. From 2001 to 2004 he was also the Head of the Department of Electrical Engineering. He is a member of the International Steering Committee of ICEM and a member of the Scientific Committee of different conferences and journals. He is the President of the "European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)", "European Association for the Development of Electrical Engineering (EADEE)" and "Spanish Association for the Development of Electrical Engineering (AEDIE)"; he is also the Vice-President of the "Portuguese Association for the Development of Electrical Engineering (APDEE)". He was awarded the Gold Insignia of the "Green Week Foundation" and received four awards of Electrical Engineering journals. His main research interests are related to:

- Power Quality
- Renewable Energy, with special emphasis on Small Hydro and Wind Energy.
- Electric Machines Modelling, Diagnostics and Control

- Permanent Magnet Synchronous Motors
- Transient Stability of Electrical Power Systems.

He is the author of two research books and four other books, over one hundred research papers, some of which presented at national and international conferences, and others were published in relevant journals. He has also been involved in several research projects. In the last years he has taught Quality and Utilization of Electrical Energy and Control of Electrical Motors for undergraduate students, and Special Electrical Motors, Renewable Energies and Power Quality for postgraduate students.



Gianpaolo Vitale received his “*laurea*” degree in Electronic Engineering from the University of Palermo (Italy) in 1988. From 1994 to 2001 he was a researcher and since 2002 he has been a senior researcher of the I.S.S.I.A. - C.N.R. (Institute on Intelligent Systems for Automation). He received the national scientific qualification (“*Abilitazione scientifica nazionale*”) as full professor on electric energy engineering (cod. 09/E2) in 2013. He teaches “Power Electronics” in the MD course on electronic engineering at the University of Palermo. He was the supervisor of research projects on electromagnetic compatibility of electric drives and intelligent management of electric energy supplied by renewable sources. He is the person in charge of the research project "RITmare, Italian Research for the sea” for the unit of Palermo of ISSIA. He is senior member of IEEE (Institute of Electrical and Electronics Engineers) since 2012 and member of IEEE Vehicular Technology Society, IEEE Industrial Electronics Society and IEEE Electromagnetic Compatibility Society and he is a reviewer for several journals and conferences.

He is the co-author of two books and over one hundred scientific articles, of which 34 were published on international ISI journals.

His current research interests are in the fields of Power Electronics, Power Generation from renewable sources and problems related to Electromagnetic Compatibility. E-mail: gianpaolo.vitale (at) cnr.it.

Silvano Vergura received his MSc degree and his PhD degree in Electrical Engineering from the Technical University of Bari, Italy, in 1999 and 2003, respectively. Since 2007 he has been a Tenured Assistant Professor in the Technical University of Bari, where he is currently teaching Electrotechnics and Circuit Simulation. His main research interests concern the monitoring of renewable energy sources. He has devoted particular attention to the energy performance analysis of photovoltaic plants by means of statistical approaches and infrared analysis. Nowadays he is also involved in studying the issues of renewable energy sources in the context of the Smart Cities. Another research area concerns the modelling and simulation of switching circuits. Co-simulation, homotopy methods and topological techniques are the principal approaches utilized to study the transient analysis of switching circuits. He is in charge of the project "Performance analysis of concentrating solar plant", and of the activity "Diagnosis of low-voltage grid" within the national project RESNOVAE. He has one patent on the automatic control of the aging of a PV module and he has designed and implemented several software programs: DISS (diagnostics for solar systems), PVSimulink, CLISEF, PVLabview, ThermoSOFT.

He is member of IEEE (Institute of Electrical and Electronics Engineers) since 2004 (senior member since 2014), member of IEEE Industrial Electronics Society and Power and Energy Circuits and Systems (PECAS) and serves as reviewer for several journals and conferences. He is the author of over 60 international publications and 2 books on Electrotechnics. He is a member of the technical committees of ICREPQ, EESMS, and Connected SmartCity.

E-mail: silvano.vergura (at) poliba.it

PART I:

DATA MANAGEMENT

CHAPTER ONE

DATA CLUSTERING FOR ACCURATE ENERGY PLANNING OF A PHOTOVOLTAIC PLANT

ANNALISA DI PIAZZA,[1]
MARIA CARMELA DI PIAZZA,[1]
GIANPAOLO VITALE[1]

Abstract

This chapter deals with a statistical approach to manage sampled data coming from a photovoltaic installation. The proposed method adopts k-means clustering and the normal density probability distribution. This allows the problem of PV plant energy assessment to be simplified with respect to obtaining the desired information by managing a large amount of experimental observations. The proposed methods represent useful tools for an appropriate energy planning in distributed generation systems.

Keywords: Photovoltaic energy; Distributed generation; Energy Planning; Renewable energy; Statistics.

Introduction

An accurate energy planning in a distributed generation system requires appropriate knowledge of the renewable energy source capability. When a photovoltaic plant is involved, in particular, the source capability is strictly correlated with the characteristics of the installation site, especially with reference to solar irradiance as it is proportional to the electrical energy deliverable by the PV source. Usually, the PV plant

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[1] CNR - National Research Council, ISSIA - Institute of Intelligent Systems for Automation - UOS Palermo. Via Dante, 12 - 90141 Palermo, Italy.
Email: mariacarmela.dipiazza@ieee.org, gianpaolo.vitale@ieee.org, a.dipiazza@pa.issia.cnr.it

energy characterization is based on a long time sampling of the main parameters (PV field temperature, solar irradiance, power and energy supplied to the grid, etc.). In such a way, it is possible to build databases. On the other hand, the databases often contain a great amount of data from which it is difficult to extract information of interest. As an example, the sampling of solar irradiance takes into account data corresponding to low values that do not contribute to the power delivered by the plant. Therefore, the development of analytical tools for the estimation of the quantity of electrical energy generated by a PV plant on a given scale of time is reputed to be very useful. In particular, the possibility to find out, from the electrical and climatic experimental observations, the most significant data to characterise the site of installation, from the energy capability point of view, is advantageous.

The development of forecasting models for spatial and temporal distributions of climatic variables has been widely treated in technical literature, within the scope of energy assessment.

In this field, the synergic use of suitable data processing techniques and estimation methods, either based on a statistical or a neural approach, represents the most promising way for the set-up of complete and reliable climatic databases and for the modelling and forecasting of the considered phenomena [1]-[2].

In this chapter, two statistical tools are explained; they will be used to obtain an effective estimation of the energy produced by a photovoltaic array over a five-months period of time, the former being based on the k-means clustering methods and the latter on the description of the solar irradiance daily trends through normal probability distributions [3]-[7]. The proposed methods allow:

1. Extracting, from a given scale of time-based experimental measurements, the sub-sets of data which can describe the energy capability of the PV plant with good accuracy (k-means clustering approach);
2. Obtaining the energy capability information of the PV plant by describing the solar irradiance trend, on a chosen scale of time, through a continuous function simply defined by two parameters (representation of daily solar irradiance by normal probability distributions).

This chapter is based on the revised version of the paper presented at the International Conference on Renewable Energies and Power Quality (ICREPQ’08) [8].

Experimental Plant

The experimental data was obtained in a plant installed on the roof of a footbridge at the University of Palermo – Faculty of Engineering.

The plant was set up by ENEA (Italian National Agency for New Technologies, Energy and Environment).

The electrical features of the array, under standard test conditions, are the following: open circuit voltage, $V_{oc}(stc)$: 228.2V; short circuit current, $I_{sc(stc)}$: 9.2A; maximum power voltage, $V_{mp(stc)}$: 185.5 V and maximum power current, $I_{mp(stc)}$: 8A. In figure 1, a view of the PV array is given.

The PV plant is equipped with a data acquisition system that measures the following parameters: panel temperature, solar irradiance, DC voltage and current supplied by the solar array to the inverter, AC voltage, current and power supplied by inverter to the grid [9]-[10].

By performing measurements from June to October during the whole day and sampling every 10 minutes, a set of more than 12000 couples of experimental values of current and voltage, corresponding to maximum power points (MPPs), for solar irradiance and temperature ranging between 500 W/m^2 and 1100 W/m^2 and 20 and 50°C, respectively, were acquired.

Figure 1: View of the PV array

A representation of the number of samples versus solar irradiance and temperature is sketched in figure 2, where it can be noted that much data corresponds to low values of solar irradiance. In particular, only 2295 are situated, for solar irradiance and temperature, between 500 W/m^2 and 1100 W/m^2, and between 20ºC and 50°C, respectively.

In [8], a simple clustering of maximum power point data on the basis of solar irradiance and temperature was presented. However, the problem consisted in the correct choice of irradiance and temperature intervals and, consequently, in identifying the most representative cluster, in terms of energy capability.

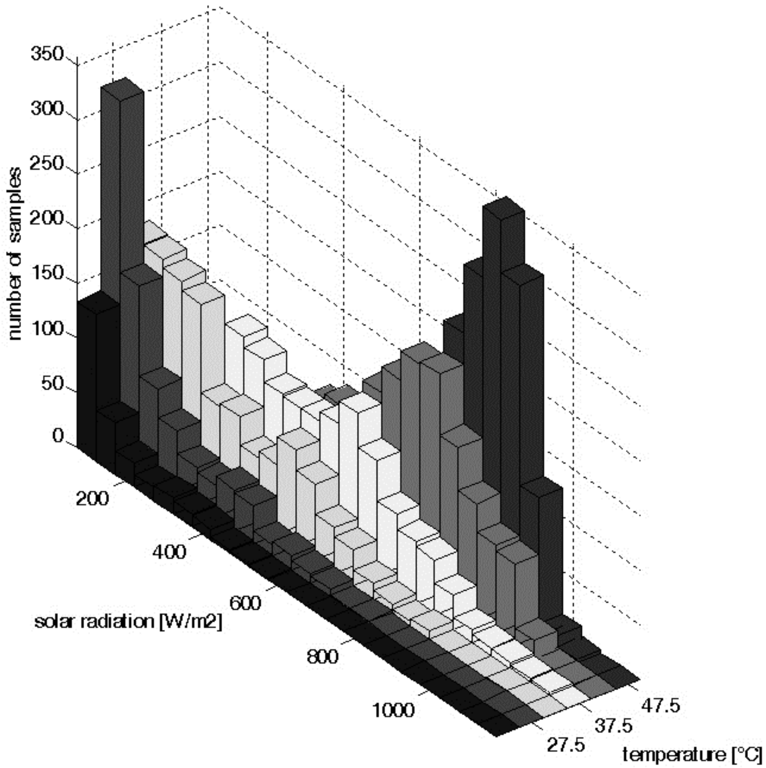

Figure 2: Bar diagram representation of the sampled data

K-means Clustering Method

The k-means clustering is basically a partitioning method. For a given set of observed data, the k-means method performs the partition into k mutually exclusive clusters. Unlike the hierarchical clustering methods, k-means clustering does not create a tree structure to describe the groupings in data, but rather creates a single level of clusters, using the actual observations of objects or individuals in data, and not just their proximities. These features make k-means clustering more suitable for clustering large amounts of data, as in the case under study.

K-means clustering treats each observation in data as an object having a location in space. It finds a partition in which objects within each cluster are as close to each other as possible, and as far from objects in other clusters as possible. Each cluster in the partition is defined by its member objects and by its centroid, or center. The centroid for each cluster is the point to which the sum of distances from all objects in that cluster is minimized. The method of k-means computes cluster centroids, to minimize the sum with respect to a specified measurement [3]-[6].

A flowchart describing the algorithm is given in figure 3. The first step consists in the assignment of the number of clusters; then the centroids are arbitrarily assigned. In the next step, each object is assigned to a cluster on the basis of the minimum distance from the centroid, a new centroid is calculated and the distance between the centroid and each object is further minimized by moving an object from one cluster to another. This procedure is repeated until no object has to be moved. A simple example with four objects with coordinates (1,1), (2,1), (6,3), (7,5) to be grouped into two clusters is drawn in figure 4. In particular, figure 4a shows the arbitrary assignation of two centroids that coincide with two objects; in figure 4b each object is assigned to a centroid on the base of its minimum distance; in figure 4c, a new centroid is calculated taking into account the three objects; finally, in figure 4d, an object is moved from one cluster to another so that the distance between the centroids and each object is further minimized.

The application of the k-means method for the partition of data coming from the studied PV plant was performed within the Matlab® environment. In particular, the embedded k-means function is used to obtain a vector of indices, indicating to which of the k clusters it has assigned each observation in the data, and an algorithm, set-up on purpose by the authors, is employed to extract the sets of data assigned to each cluster.

The k-means function uses an iterative algorithm that minimizes the sum of distances from each object to its cluster's centroid, over all clusters. This algorithm moves objects between clusters until the sum cannot be further decreased. The result is a set of clusters that are as compact and well-separated as possible.