

AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECTRONICS AND COMMUNICATION ENGINEERING DEPT.

DESIGN AND PERFORMANCE ANALYSIS FOR
PHOTOVOLTAIC SYSTEMS AT REMOTE EGYPTIAN SITES

By

Ahmed Ahmed Attia Sayedahmed ✓

B.Sc. in Electrical Engineering

A Thesis

Submitted in Partial Fulfilment for the
Requirement of the Degree of Master of
Science in Electrical Engineering

621.31244
A. A

Supervised By

Prof.Dr. HANY FIKRY MOHAMED RAGAIE

Faculty of Engineering

Ain Shams University

Dr. MOHAMED AFIFI EL-KOOSY

Military Technial College



CAIRO 1993

EXAMINER COMMITTEE

SIGNATURE

1. Prof. Dr. Mohamed Marzouk Ibrahim

Chief of Electronics and Communication
Engineering Dept.

M. Marzouk Ibrahim
.....

Faculty of Engineering, Ain Shams University

2. Prof. Dr. Sirag El-Din Sayed Habib

Professor of Electronics.

Sirag El-Din Sayed Habib
.....

Faculty of Engineering, Cairo University

3. Prof. Dr. Hany Fikry Mohamed Ragaie

Faculty of Engineering, Ain Shams University

Hany Fikry Mohamed Ragaie
.....

4. Dr. Mohamed Afifi El-Koosy

Military Technical College.

Mohamed Afifi El-Koosy
.....

Date: / /1992



STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Electrical Engineering.

The work included in this thesis was carried out by the author in the Armed Forces from Dec. 14, 1987 to.....

No part of this thesis has been submitted for a degree or a qualification at any other University or Institute.

Date:

Signature: *Ahmed Attia*

Name: Ahmed Ahmed Attia

ACKNOWLEDGEMENT

I am deeply indebted to Prof. Dr. *MOHAMED NABIL SALEH* Dean of the Faculty of Engineering, Ain Shams University, who was always willing to help, encourage and provide with his wise counsel and his many years of experience. I am very grateful to him for his good-natured patience and professional attitude.

I would like to express my deep appreciation to Prof. Dr. *HANY FIKRY RAGAIE* for his outstanding contribution and intelligent remarks. His encouragement and permanent support have helped greatly in making this work, I hope, fruitful. He spared no effort in giving advice whenever needed.

To Dr. *MOHAMED EL-KOOSY*, Words fail to express what is to be said about his contribution to this work. For him, I pay my sincerest thanks. His patience, helpful discussions, valuable suggestions and endless assistance have brought up this thesis the way it is.

Ain Shams University
Faculty of Engineering
Electronics & Comm. Engineering Dept.

Abstract of M.Sc. Thesis in Electrical Engineering
Submitted by: Ahmed Ahmed Attia Sayedahmed

Title of thesis:

Design and Performance Analysis for Photovoltaic
Systems at Remote Egyptian Sites.

Supervisors:

- (1) Prof. Dr. Hany Fikry Mohamed Ragaie
- (2) Dr. Mohamed Afifi El-Koosy

Registration date: 14/12/1987 Examination date:

ABSTRACT

This work presents an improvement to the methods previously developed for sizing optimal stand alone photovoltaic (PV) systems. The design approach utilizes the loss of load probability concept to quantify and analyse the overall behaviour of the PV system. The described algorithm enables the designer to determine the components of the system that correspond to minimum life cycle costs at certain prescribed power availability. The developed method is applied for sizing a stand alone PV system that supplies electrical power in a typical remote site chosen on the North Western Egyptian coast. The obtained results are discussed and compared with those obtained on applying the existing methods.

A Comprehensive economic study for the designed system is presented. The study includes the utilization of locally manufactured lead acid batteries which, throughout the presented work, are tested and modelled to be used in PV applications. The cost of energy produced in remote sites by alternative sources (diesel or electrical grid extension) are estimated and compared.

CONTENTS

	PAGE
INTRODUCTION.....	1
CHAPTER 1: SOLAR CELLS: OPERATION CHARACTERIZATION AND TECHNOLOGY	
1.1 Solar Cell Operation.....	5
1.2 Ideal Solar-Cell Current-Voltage Characteristics...	10
1.3 Solar Cell Parameters.....	21
1.3.1 Short circuit current (I_{sc}).....	21
1.3.2 Open circuit voltage (V_{oc}).....	22
1.3.3 Maximum power and fill factor.....	24
1.3.4 Cell efficiency.....	27
1.3.5 Solar cell spectral response.....	27
CHAPTER 2: STORAGE BATTERIES AND ELECTRONIC SYSTEM COMPONENTS	
2.1 Storage Batteries.....	30
2.1.1 Role of storage batteries.....	30
2.1.1.1 Power buffer between the array and loads.....	30
2.1.1.2 Energy storage.....	32
2.1.2 PV battery duty cycle.....	33
2.1.3 Types of batteries for PV applications.....	37
2.1.4 The operating principles of lead acid cells.	39

2.1.4.1 Discharge process.....	40
2.1.4.2 Charging process.....	42
2.1.5 Modelling and analysis of locally manufactured lead acid batteries for PV applications.....	46
2.1.5.1 Introduction.....	46
2.1.5.2 The voltage-current-state of charge model.....	47
2.2 Electronic Components of PV System.....	57
2.2.1 Introduction.....	57
2.2.2 Battery charge regulator (BCR).....	59
CHAPTER 3: PHOTOVOLTAIC SYSTEM SIZING	
3.1 Introduction.....	60
3.2 Loss-Of-Load Probability.....	62
3.3 Sizing Technique For Stand-Alone PV Power Systems: Algorithm Implementation and Application.....	65
3.3.1 Main features of the developed algorithm....	65
3.3.2 Description of the methodology.....	66
3.3.2.1 Determination of the optimum tilt angle.....	70
3.3.2.2 Obtaining minimum and maximum values of design insolation.....	70
3.3.2.3 Calculation of daily and hourly tilted insolation values.....	71
3.3.2.4 Calculation of LOLP.....	76

3.3.2.5 Calculation of the system life cycle cost.....	77
3.4 Results and Discussions.....	79
3.4.1 Introduction.....	79
3.4.2 Site and load characteristics.....	80
3.4.3 Results of the sizing technique.....	82
3.4.4 Simplified graphical method for stand-alone PV power systems sizing.....	91
3.4.5 Comparison between the developed technique and other sizing techniques.....	106
CHAPTER 4: ECONOMIC EVALUATION OF PV ENERGY COSTS.	
4.1 Introduction.....	117
4.2 PV System.....	118
4.3 Diesel Generator System.....	128
4.4 Electrical Grid Extension.....	133
4.5 Results and Discussions.....	135
4.6 Conclusion.....	138
CONCLUSION.....	141
REFERENCES.....	144
APPENDIX A.....	157

INTRODUCTION

INTRODUCTION

The significance of renewable energy sources has grown steadily since the last few years during the discussion of our future energy supplies. Public awareness has been awakened to the dangers of global climatic changes caused by burning fossil fuels as well as the limited nature of energy resources present in our environment. On the other hand, searching for a clean form of energy is becoming an essential demand facing the problem of pollution on the earth's crust. Therefore, great hopes have been attached to the increased use of renewable energy sources.

Photovoltaics (the technology of converting sunlight directly into electrical energy) represents one of the most versatile utilization methods and still possesses a high potential for further technical development.

Stand alone PV systems installed at remote sites have proved itself to be not only more convenient, but also the more economical solution. Their applications include vaccine refrigeration, telecommunication, water pumping and lighting.

As a renewable energy source, the PV system offer the following advantages:

- inexhaustible and free energy supplies.
- long system lifetime.
- no noise or other pollution.
- modular construction.

However, a number of important issues including cost, land area requirements, utility grid comparability, solar resource intermittency and storage will influence the rate and degree of PV market penetration.

Our work is concerned with the design and analysis of a small stand alone PV system supplies power to a typical remote Egyptian site. We address the problem of matching the load requirements with the mostly stochastic characteristics of incident solar radiation that is a fundamental problem facing system designers, and results in oversized and costly systems.

The principle of PV energy conversion is outlined in chapter one. Solar cell parameters, solar arrays and fabrication technology of solar cells and their encapsulation into modules and the associated cost are presented.

In the second chapter, the individual system components are described. A locally manufactured lead acid battery type

is experimentally tested. Its performance is measured in the cases of charging and discharging for a long period of time. A mathematical model that describes battery charging and discharging modes is developed and analysed.

Chapter three presents two developed techniques for the design of stand alone PV system, one of them depends on the use of computer programs and the other depends on a set of curves that match the nature of Egyptian climates.

The different factors that must be taken into consideration in sizing the PV system are presented. The load demand is specified to correspond to an actual load supplied by PV energy at a remote site near Mersa Matruh on the Egyptian Western desert. The sizing methodology is explained so as to obtain the system size that cover the load requirements while ensuring a certain degree of reliability with the minimum life cycle cost. The results of the developed algorithms together with the results of other sizing methods are compared and discussed.

In the fourth chapter, an economic analysis is conducted to calculate the cost of energy produced from the PV system that has been designed considering the incorporation of the examined local batteries and comparing the results with the installed systems using imported solar

batteries. The chapter also includes an economic study that identifies the best energy choice (PV-diesel-grid) to be used to feed different load demands at remote sites.

In the end, the conclusion and recommendations for future work are presented.

CHAPTER "1"