AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Electrical Power& Machines Department

GENERATION EXPANSION PLANNING OF THE EGYPTIAN POWER SYSTEM CONSIDERING THE HIGH PENETRATION OF RENEWABLE ENERGY RESOURCES

A Thesis

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

In Electrical Engineering

Submitted By

Mohammed Moustafa Abd–Elzaher

M.Sc. of Electrical Engineering
Ain Shams University, 2012

Supervised By

Prof. Dr. Mohamed Abd El Latif Badr
Ain Shams University

Prof. Dr. Almoataz Youssef Abdelaziz
Ain Shams University

Asso. Prof. Saed Fouad Mekhamer
Ain Shams University

Dr. Eng. Hassan Mohamed Mahmoud
Egyptian Electricity Holding Company

Cairo – 2019

AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Electrical Power& Machines Department

GENERATION EXPANSION PLANNING OF THE EGYPTIAN POWER SYSTEM CONSIDERING THE HIGH PENETRATION OF RENEWABLE ENERGY RESOURCES

A Thesis
Submitted in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
In Electrical Engineering

Submitted By
Mohammed Moustafa Abd–Elzaher
M.Sc. of Electrical Engineering
Ain Shams University, 2012

Approved By	**Signature**
Prof. Dr. Alsaid Abdelaziz Othman Electrical Engineering Department Faculty of Engineering, Al Azhar University	……..
Prof. Dr. Tarek Saad Abdelsalam Electrical Power &Machines Department Faculty of Engineering, Ain Shams University	……..
Prof. Dr. Almoataz Youssef Abdelaziz Electrical Power &Machines Department Faculty of Engineering, Ain Shams University	……..

Cairo – 2019

AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Electrical Power& Machines Department

GENERATION EXPANSION PLANNING OF THE EGYPTIAN POWER SYSTEM CONSIDERING THE HIGH PENETRATION OF RENEWABLE ENERGY RESOURCES

A Thesis
Submitted in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
In Electrical Engineering

Submitted By
Mohammed Moustafa Abd–Elzaher
M.Sc. of Electrical Engineering
Ain Shams University, 2012

Supervised By	**Signature**
Prof. Dr. Almoataz Youssef Abdelaziz Faculty of Engineering, Ain Shams University	……..
Associate Prof. Said Fouad Mekhamer Faculty of Engineering, Ain Shams University	……..
Dr. Eng. Hassan Mohamed Mahmoud Egyptian Electricity Holding Company	……..

Cairo – 2019

STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Doctor of Philosophy in Electrical Engineering (Electrical Power &Machines Department).

The work included in this thesis was carried out by the author at the Electrical Power &Machines Department, Faculty of Engineering, Ain Shams University in collaboration with the Egyptian Electricity Holding Company.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

Name : Mohammed Moustafa Abd–Elzaher

Signature :

Date : / /

CURRICULUM VITAE

Name of the Researcher	:	Mohammed Moustafa Abd–Elzaher
Date of Birth	:	21October 1984
Place of Birth:	:	Qalyoubia – Egypt
First University Degree:	:	M.Sc. in Electrical Engineering
Faculty:	:	Ain Shams Faculty of Engineering
Name of University:	:	Ain Shams University
Date of Degree:	:	2012
Position:	:	Division Chief Planning Engineer – Strategic Planning Sector - Egyptian Electricity Holding Company
Technical Committees Membership:	:	Member in the Council on Large Electric Systems (CIGRE), World Energy Council (WEC) Energy Youth Committee and International Electro-technical Commission (IEC) national committees.
E-mail:	:	Engmmzaher2006@yahoo.com
Signature:	:	
Date:	:	/ /

Acknowledgment

Thanks God for a lot of merits that led to the successful completion of this work.
I wish to express my deep appreciation and sincere gratitude to **Prof. Dr. Mohamed Abd El Latif Badr and Prof. Dr. Almoataz Yousef Abdelaziz,** Electrical Power & Machines Department, Faculty of Engineering, Ain Shams University, for their supervision, helpful advice and valuable guidance throughout the course of this work.

My deep thanks to **Asso. Prof. Saed Fouad Mekhamer,** Electrical Power & Machines Department, Faculty of Engineering, Ain Shams University, for his supervision, helpful advice and valuable guidance throughout the course of this work.

My thanks are extended to **Dr. Hassan M Mahmoud**, Head of the IT sector, Egyptian Electricity Holding Company for his supervision, helpful advice and valuable guidance throughout the course of this work.
I would like to thank the staff of Strategic Planning Sector in Egyptian Electricity Holding Company mainly, **Eng. Ghada Mohamed Boghdady,** Head of the Strategic Planning sector for her sincere help and support.

Finally, I take pride in dedicating the current PhD thesis work to my beloved family; mother, father and my sister who had sacrificed their comforts and struggled to support and encourage me during this research. Without your sincere support and encourage, I would have never accomplished this work.

Contents

List of Figures

Chapter 5

Chapter 6

List of Tables

Table **Page**

List of Abbreviations

AGC: Automatic Generation Control

A.G.R: Average Growth Rate

AHN: Augmented Hopfield Network

AI: Artificial Intelligence

CCS: Carbon Capture and Storage

CCGT: Combined Cycle Gas Turbine

COPT: Capacity Outage Probability Table

CSP: Concentrated Solar Power

DNI: Direct Normal Irradiance

DP: Dynamic Programming

DSM: Demand Side Management

ED: Economic Dispatch

ELCC: Effective Load Carrying Capability

EMA: Egyptian Meteorological Authority

EFOR: Equivalent Forced Outage Rates

EFP: Equivalent Firm Power

ECP: Equivalent Conventional Power

EEHC: Egyptian Electricity Holding Company

EU: European Union

EUE: Expected Unserved Energy

FEPL-MILP: Flexibility Enhanced Priority List-Mixed Integer Linear Programming

FEPL: Flexibility Enhanced Priority List

FL: Fuzzy Logic

FOR: Forced Outage Rates

GA: Genetic Algorithms

GEP: Generation Expansion Planning

GHG: Green House Gas

GHI: Global Horizontal Irradiance

GT: Gas Turbine

HF: High Flexible

HFO: Heavy Fuel Oil

HNN: Hopfield Neural Network

IEA: International Energy Agency

IEEE: Institute of Electrical and Electronics Engineers

IRENA: International Renewable Energy Agency

ISCC: Integrated Solar Combined Cycle Power Plant

LCC: Load Carrying Capability

LCOE: Levelized Cost of Electricity

LDC: Load Duration Curve

LF: Low Flexible

LFO: Light Fuel Oil

LOLH: Loss of Load Hours

LOLE: Loss Of Load Expectation

LOLP: Loss Of Load Probability

LT: Long Term

MF: Medium Flexible

MILP: Mixed Integer Linear Programming

MLE: Maximum Likelihood Estimation

MLL: Minimum Load Level

MOERE: Ministry of Electricity and RES

MOP: Ministry of Petroleum

MSG: Minimum Stable Generation

NASA: National Aeronautics and Space Administration

NECC: National Electricity Control Center

NEM: National Electricity Market

NG: Natural Gas

Non-VRES: Non-variable RES

NREA: New and Renewable Energy Authority NREA

NREL: National Renewable Energy Laboratory

NWP: Numerical Weather Prediction

OC: Operation Cost

O&M: Operation and Maintenance

PHES: Pumped Hydro Energy Storage

PJM: Pennsylvania-New Jersey-Maryland

PL: Priority List

PMF: Probability Mass Function

PV: Photovoltaic

PDA: Probabilistic Dynamic Approach

PSO: Particle Swarm Optimization

RES: Renewable Energy Resources

R.M: Reserve Margin

SA: Simulated Annealing

SCUC: Security Constrained Unit Commitment

SoDa: Solar Radiation Data

SQP: Sequential Quadratic Programming

TARES: Technical Assistance to Support the Reform of the Energy Sector

TS: Tabu Search

TSC: Total System Cost

UC: Unit Commitment

UCC: Unit Construction and Commitment

UCR: Unit Commitment Risk

USA: United States of America

VRES: Variable Renewable Energy Resources

VG: Variable Generation