Conceptual and Validation Study for Short Term Load Forecasting Approach Realizing Smart Grid Energy Management

By

Amr Ahmed Aydarous Mohamed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ELECTRICAL POWER AND MACHINES ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Conceptual and Validation Study for Short Term Load Forecasting Approach Realizing Smart Grid Energy Management

By

Amr Ahmed Aydarous Mohamed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ELECTRICAL POWER AND MACHINES ENGINEERING

Under the Supervision of

Prof. Mohamed A. Moustafa Hassan

……

Professor of Electrical Power and Machines Department
Faculty of Engineering, Cairo University

Dr. Mostafa A. Elshahed

……

Assistant Professor of Electrical Power and Machines Department
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Conceptual and Validation Study for Short Term Load Forecasting Approach Realizing Smart Grid Energy Management

By

Amr Ahmed Aydarous Mohamed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ELECTRICAL POWER AND MACHINES ENGINEERING

Approved by the
Examining Committee

_____
Prof. Mohamed A. Moustafa Hassan, Thesis Main Advisor

_____
Prof. Magdy Abd El-Ghany Soliman, Internal Examiner

_____
Dr. Hassan Mohamed Mahmoud, External Examiner
First Undersecretary for IT Systems,
Ministry of Electricity and Renewable Energy,
Egypt.

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Engineer's Name: Amr Ahmed Aydarous
Date of Birth: 2 / 9 / 1983
Nationality: Egyptian
E-mail: Amr.aydarous@gmail.com
Phone: 01117733352
Address: 1100

Registration Date: 1 / 3 / 2014
Awarding Date: 14 / 7 /2018
Degree: Master of Science
Department: Electrical Power and Machines Engineering

Supervisors:
Prof. Mohamed A. Moustafa Hassan
Dr. Mostafa A. Elshahed

Examiners:
Dr. Hassan Mohamed Mahmoud (External examiner)
First Undersecretary for IT Systems, Ministry of Electricity and Renewable Energy, Egypt
Prof. Magdy Abd El-Ghany (Internal examiner)
Prof. Mohamed A. Moustafa Hassan (Thesis main advisor)

Title of Thesis:

Conceptual and Validation study for Short Term Load Forecasting Approach Realizing Smart Grid Energy Management

Key Words:
energy management; evolutionary optimization techniques; multi stages forecasting; short term load forecasting; smart grid.

Summary:

The energy sector is one of the major sectors where big steps can be taken towards a sustainable future. This thesis represents a study to determine the most effective and accurate technique for Short Term Load Forecasting (STLF) that can be done through Integrated Intelligent Energy Management processes for Smart Grid. The Load Forecasting shall be based on the historical data only. This study compared the results of 56 different scenarios in the number of inputs, different algorithms, and input method. ANN, PSO, MAACPSO, and ANFIS were used as different algorithms. Different input methods include a new proposed method which considers Multi Stages Forecasting. Study verification is done by testing versus other practical STLF methods using traditional inputs. The proposed method results are auspicious with reduced Mean Absolute Error.

Acknowledgments

All the praises and thanks are to Allah.

The Prophet Muhammed (ﷺ) said, "*He who does not thank the people is not thankful to Allah.*" [*]

For that, I would like to express my sincere gratitude to my supervisors, Professor Mohamed A. Moustafa Hassan, and Dr. Mostafa A. Elshahed. I really feel privileged to work under their supervision and grateful to their kind help and support.

Special thanks to Professor Mohamed A. Moustafa Hassan for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my study.

Moreover, I would like to thank all professors in thesis committee: Prof. Magdy Abd El-Ghany and Dr. Hassan Mahmoud, for their careful review and insightful comments.

---

[*] Sunan Abi Dawud 4811

Dedication

I would like to take this opportunity to express my deep sense of respect and gratitude to:

My Mother, *the first who taught me to live*;
My Father, Eng. Ahmed Aydarous, *the first who taught me engineering sense*;
My Brother, Eng. Ramy Aydarous, *the first who taught me creativity meaning*.

I dedicate this work to my son, Haroun Aydarous, as a motivation to pursue his own path in studies.

Table of Contents

ACKNOWLEDGMENTS ..... **I**

DEDICATION ..... **II**

TABLE OF CONTENTS ..... **III**

LIST OF TABLES ..... **VI**

LIST OF FIGURES ..... **VII**

NOMENCLATURE ..... **X**

ABSTRACT ..... **XIII**

CHAPTER 1 : PREFACE **1**

1.1. BACKGROUND 1
1.2. OBJECTIVES 2
1.3. HYPOTHESIS 2
1.4. METHODOLOGY 2
1.5. THESIS STRUCTURE 3

CHAPTER 2 : SMART GRID **5**

2.1. INTRODUCTION 5
2.2. UNDERSTATING SMART GRID 5
2.2.1. Main Functions and Features 6
2.2.2. Benefits 9
2.2.3. Employed Technologies 12
2.2.4. Adopted Principals 14
2.3. PROMOTERS TO SMART GRID 17
2.3.1. Shortcomings in Conventional Grid 17
2.3.2. The Relationship Between Smart Grid and Conventional Grid 19
2.4. CHALLENGES TO SMART GRID 20
2.4.1. Technical Challenges 20
2.4.2. Financial Challenges 21
2.4.3. Business Challenges 22
2.4.4. Community Challenges 23
2.5. SUMMARY OF THE CHAPTER 25

CHAPTER 3 : ENERGY MANAGEMENT FOR SMART GRID **27**

3.1. INTRODUCTION 27
3.2. ENERGY MANAGEMENT BACKGROUND 27
3.2.1. Introduction to Microgrid 28
3.2.2. Trends in Energy Management Concept 29
3.2.3. Energy management Standards 29
3.2.4. Demand Side Management 30
3.2.5. Demand Response 33

3.2.6. Control Systems for Energy Management 38
3.3. ENERGY MANAGEMENT SYSTEMS FOR MICROGRIDS 38
3.3.1. Centralized Energy Management 40
3.3.2. Distributed Energy Management 42
3.3.3. Decentralized Energy Management 43
3.4. INTEGRATED INTELLIGENT ENERGY MANAGEMENT SYSTEM 44
3.5. SUMMARY OF THE CHAPTER 47

CHAPTER 4 : SHORT TERM LOAD FORECASTING APPROACH 49

4.1. INTRODUCTION 49
4.2. ELECTRICAL LOAD AND RELATIVE FACTORS 49
4.3. LOAD FORECASTING 50
4.3.1. Load Forecasting Classifications 50
4.3.2. Short Term Load Forecasting 52
4.3.3. Evolution of Short Term Load Forecasting Researches 52
4.4. STLF PROPOSED CONCEPT 54
4.5. THE METHOD OF STATEMENT FOR THE PROPOSED APPROACH 55
4.5.1. STLF Technique 55
4.5.2. STLF Data Set 55
4.5.3. STLF Data Set Size 58
4.6. SUMMARY OF THE CHAPTER 59

CHAPTER 5 : IMPLEMENTATION AND RESULTS 61

5.1. INTRODUCTION 61
5.2. DATA SET CREATION 61
5.2.1. Data Source 61
5.2.2. PHM dataset 63
5.2.3. PDM dataset 63
5.2.4. PWM dataset 64
5.2.5. PYM dataset 65
5.2.6. MSM dataset 66
5.2.7. 4DM dataset 66
5.2.8. 1DM dataset 66
5.3. IMPLEMENTATION USING ANN 67
5.3.1. ANN Matlab Toolbox Over View 67
5.3.2. ANN Case 1 Results 72
5.3.3. ANN Case 2 Results 82
5.4. IMPLEMENTATION USING PSO 92
5.4.1. Over View on The Used PSO Algorithm 92
5.4.2. PSO Case 1 Results 94
5.4.3. PSO Case 2 Results 104
5.5. IMPLEMENTATION USING MAACPSO 114
5.5.1. Over View on The Used MAACPSO Algorithm 114
5.5.2. MAACPSO Case 1 Results 116
5.5.3. MAACPSO Case 2 Results 126
5.6. IMPLEMENTATION USING ANFIS 136

5.6.1. Over View on ANFIS MAT Lab Tool Box 136
5.6.2. ANFIS Case 1 Results 140
5.6.3. ANFIS Case 2 Results 150

CHAPTER 6 : RESULT ANALYSIS AND VERIFICATION 161

6.1. INTRODUCTION 161
6.2. RESULTS ANALYSIS 161
6.2.1. All Results Analysis 161
6.2.2. Frist Methods' Group Results Analysis 164
6.2.3. Multi Stage's stages Results Analysis 166
6.2.4. All Data Input Methods' Results Analysis 171
6.3. COMPARISON STUDY 172
6.3.1. Comparison of One day load forecasting 172
6.3.2. Comparison to Other input method 175

CHAPTER 7 CONCLUSIONS AND FUTURE WORKS 183

7.1. CONCLUSIONS 183
7.2. FUTURE WORKS 183

REFERENCES 185

APPENDIX A 204

APPENDIX B 206

APPENDIX C 208

List of Tables

Table 2.1: Smart grid benefits returned on the consumers 10
Table 2.2: Environmental benefits delivered from Smart grid Technologies 11
Table 2.3: Stakeholder economic benefits through the smart grid system. 12
Table 2.4: Key technologies of Smart Grid through the Power System. 12
Table 2.4 (Continue): Key technologies of Smart Grid through the Power System. 13
Table 2.4 (Continue): Key technologies of Smart Grid through the Power System. 14
Table 3.1: DR in both of Conventional and Smart Grid. 34
Table 3.2: Advantages and Disadvantages of Centralized Energy Management 41
Table 3.3: Advantages and Disadvantages of Distributed Energy Management 42
Table 3.4: Advantages and Disadvantages of Decentralized EM 43
Table 3.5: IIEM Main Sub-systems/Equipment 47
Table 4.1: The Variation in the Time Interval Span for Each of LF Types 51
Table 5.1: Results of implementation of ANN for MSM Case 1 75
Table 5.2: Results of implementation of ANN for MSM Case 2 85
Table 5.3: Results of implementation of PSO for MSM Case 1 97
Table 5.4: Results of implementation of PSO for MSM Case 2 107
Table 5.5: Results of implementation of MAACPSO for MSM Case 1 119
Table 5.6: Results of implementation of PSO for MSM Case 2 129
Table 5.7: Results of implementation of ANFIS for MSM Case 1 143
Table 5.8: Results of implementation of PSO for MSM Case 2 153
Table 6.1: All results of case 1 162
Table 6.2: All results of case 2 163
Table 6.3: Results of Frist Methods Group - Case 1 165
Table 6.4: Results of Frist Methods Group - Case 2 165
Table 6.5: Multi Stage's stages Results - Case 1 167
Table 6.6: Multi Stage's stages Results - Case 2 169
Table 6.7: All Data Input Methods' Results - Case 1 171
Table 6.8: All Data Input Methods' Results - Case 2 171
Table 6.9: The Best Input Dataset for each Algorithm in Both Cases 172
Table 6.10: Forecasted load data for 24 hours on 30th July, 2016 174
Table 6.11: Arrangement for Results of Forecasted load data 175
Table 6.12: Forecasted data using Electricity Load Forecasting by Ameya Deoras 180
Table A.1: Sample table of ISO-NE Control Area Worksheet for 1/1/2016 204
Table 1.B: TWO TARGET DATA SETS (TDS). 206
Table 1.C: Execution time for Case 1 Scenarios. 208
Table 2.C: Execution time for Case 2 Scenarios. 208

List of Figures

Figure 1.1: A diagram showing the thesis structure. 4
Figure 2.1: Load Shaping 7
Figure 2.2: Relation between Smart Grid Functions with Each Other. 8
Figure 2.3: Smart Grid Integration Solutions Architecture 15
Figure 2.4: Sustainable energy flow in the Smart Grid 17
Figure 2.5: Conventional Grid Architecture 18
Figure 2.6: Smart Grid Architecture 19
Figure 2.7: Down-Top and Top-Down organization approaches illustration diagrams 23
Figure 3.1: Demand Side Management Progression 33
Figure 3.2: Different demand response mechanism 35
Figure 3.3: Hierarchical Control Structure 39
Figure 3.4: General architecture of Central EMS. 40
Figure 3.5: General model of Smart Grid 45
Figure 3.6: General Model of Smart City 45
Figure 3.7: General Model of Smart Home 46
Figure 3.8: Connection scheme between the IIEM and Grid Systems 46
Figure 4.1: Load Forecasting Classification 51
Figure 4.2: Load Forecasting and STLF Published Papers in Each 5-Year 52
Figure 4.3: Load Forecasting and STLF Published Papers in The Last 10 Years 53
Figure 4.4: Three Dimension Combined Scenarios 55
Figure 4.5: Samples of Each Type of Data Sets within First Group 57
Figure 4.6: Successive Stages of Multi Stage Method 58
Figure 5.1: Input Dataset Modification According to Target Dataset 65
Figure 5.2: Main GUI of NN Matlab Toolbox 67
Figure 5.3: GUI for the Function Fitting Tool 68
Figure 5.4: Fitting Tool: Select Data Window 68
Figure 5.5: Fitting Tool: Validation and Test Data Window 69
Figure 5.6: Fitting Tool: Train Network Window 69
Figure 5.7: Fitting Tool: Network Training Progress Window 70
Figure 5.8: Fitting Tool: Updated Train Network Window 71
Figure 5.9: Fitting Tool: Save Results Window 71
Figure 5.10: Results of implementing ANN on PHM data set for Case 1 73
Figure 5.11: Results of implementing ANN on PDM data set for Case 1 74
Figure 5.12: Results of implementing ANN on PWM data set for Case 1 76
Figure 5.13: Results of implementing ANN on PYM data set for Case 1 77
Figure 5.14: Results of implementing ANN on MSM data set for Case 1 78
Figure 5.15: Results of implementing ANN on 4DM data set for Case 1 80
Figure 5.16: Results of implementing ANN on 1DM data set for Case 1 81
Figure 5.17: Results of implementing ANN on PHM data set for Case 2 83
Figure 5.18: Results of implementing ANN on PDM data set for Case 2 84

Figure 5.19: Results of implementing ANN on PWM data set for Case 2 86
Figure 5.20: Results of implementing ANN on PWM data set for Case 2 87
Figure 5.21: Results of implementing ANN on MSM data set for Case 2.....88
Figure 5.22: Results of implementing ANN on 4DM data set for Case 2.....90
Figure 5.23: Results of implementing ANN on 1DM data set for Case 2.....91
Figure 5.24: Results of implementing PSO on PHM data set for Case 1.....95
Figure 5.25: Results of implementing PSO on PDM data set for Case 1.....96
Figure 5.26: Results of implementing PSO on PWM data set for Case 1.....98
Figure 5.27: Results of implementing PSO on PYM data set for Case 1.....99
Figure 5.28: Results of implementing PSO on MSM data set for Case 1 100
Figure 5.29: Results of implementing PSO on 4DM data set for Case 1 102
Figure 5.30: Results of implementing PSO on 1DM data set for Case 1 103
Figure 5.31: Results of implementing PSO on PHM data set for Case 2.....105
Figure 5.32: Results of implementing PSO on PDM data set for Case 2.....106
Figure 5.33: Results of implementing PSO on PWM data set for Case 2.....108
Figure 5.34: Results of implementing PSO on PYM data set for Case 2.....109
Figure 5.35: Results of implementing PSO on MSM data set for Case 2 110
Figure 5.36: Results of implementing PSO on 4DM data set for Case 2 112
Figure 5.37: Results of implementing PSO on 1DM data set for Case 2 113
Figure 5.38: Results of implementing MAACPSO on PHM data set for Case 1.....117
Figure 5.39: Results of implementing MAACPSO on PDM data set for Case 1.....118
Figure 5.40: Results of implementing MAACPSO on PWM data set for Case 1.....120
Figure 5.41: Results of implementing MAACPSO on PYM data set for Case 1.....121
Figure 5.42: Results of implementing MAACPSO on MSM data set for Case 1 122
Figure 5.43: Results of implementing MAACPSO on 4DM data set for Case 1.....124
Figure 5.44: Results of implementing MAACPSO on 1DM data set for Case 1.....125
Figure 5.45: Results of implementing MAACPSO on PHM data set for Case 2.....127
Figure 5.46: Results of implementing MAACPSO on PHM data set for Case 2.....128
Figure 5.47: Results of implementing MAACPSO on PWM data set for Case 2.....130
Figure 5.48: Results of implementing MAACPSO on PYM data set for Case 2.....131
Figure 5.49: Results of implementing MAACPSO on MSM data set for Case 2 132
Figure 5.50: Results of implementing MAACPSO on 4DM data set for Case 2.....134
Figure 5.51: Results of implementing MAACPSO on 1DM data set for Case 2.....135
Figure 5.52: Main GUI of ANFIS Matlab Toolbox 136
Figure 5.53: ANFIS Editor with training data loaded 137
Figure 5.54: ANFIS Editor Parameters 138
Figure 5.55: Export Output results to Workspace 139
Figure 5.56: Results of implementing ANFIS on PHM data set for Case 1 141
Figure 5.57: Results of implementing ANFIS on PDM data set for Case 1 142
Figure 5.58: Results of implementing ANFIS on PWM data set for Case 1 144
Figure 5.59: Results of implementing ANFIS on PYM data set for Case 1 145
Figure 5.60: Results of implementing ANFIS on MSM data set for Case 1.....146
Figure 5.61: Results of implementing ANFIS on 4DM data set for Case 1.....148
Figure 5.62: Results of implementing ANFIS on 1DM data set for Case 1.....149

Figure 5.63: Results of implementing ANFIS on PHM data set for Case 2 151
Figure 5.64: Results of implementing ANFIS on PDM data set for Case 2 152
Figure 5.65: Results of implementing ANFIS on PWM data set for Case 2 154
Figure 5.66: Results of implementing ANFIS on PYM data set for Case 2 155
Figure 5.67: Results of implementing ANFIS on MSM data set for Case 2.....156
Figure 5.68: Results of implementing ANFIS on 4DM data set for Case 2.....158
Figure 5.69: Results of implementing ANFIS on 1DM data set for Case 2.....159
Figure 6.1: MAE (MW) for All Scenarios of Case 1 163
Figure 6.2: MAE (MW) for All Scenarios of Case 2 164
Figure 6.3: Multi Stage's stages MAE (MW) in Line Charts - Case 1 168
Figure 6.3: Multi Stage's stages MAPE (%) in Line Chart - Case 1.....168
Figure 6.5: Multi Stage's stages MAE (MW) in Line Charts - Case 2 170
Figure 6.6: Multi Stage's stages MAPE (%) in Line Chart - Case 2.....170
Figure 6.7: Multi Stage's stages MAPE (%) in Line Chart - Case 2.....173
Figure 6.8: ISO-NE website front page snapshot.....176
Figure 6.9: System Load Graph for 30th of June, 2016.....176
Figure 6.10: Data Downloading 177
Figure 6.11: Excel sheet notes snapshot.....178
Figure 6.12: Dataset snapshot collection.....178
Figure 6.13: 24-hour Forecasted Load Curve.....181
Figure 6.14: MAPE (%) for All the Three Comparator Studies.....181
Figure 1.B: MAPE (%) for Proposed input methods in TDS-1 and TDS-2.....206
Figure 2.B: Multi Stage's stages Results Analysis......207
Figure 3.B: Arrangement of MAPE (%) for Proposed input methods.....207

Nomenclature

1DM	1 Datum Method
4DM	4 Data Method
ANFIS	Adaptive Neuro-Fuzzy Inference System
AMI	Advanced Smart Infrastructure
ASM	Advanced Smart Meter
AHUs	Air Handling Units
ASM	Ancillary Services Markets
AI	Artificial Intelligence
ANN	Artificial Neural Network
AR	Auto Regressive
AGC	Automatic Generation Control
ARIMA	Auto Regressive Integrated Moving Average
ARMA	Auto Regressive Moving Average
BAS	Building Automation Systems
BCS	Building Control Systems
BEMSs	Building Energy Management Systems
BMS	Building Management Systems
CEMS	Centralized Energy Management System
CPP	Critical Peak Price
DA_CC	Congestion Component Of The Day Ahead Price
DA_DEMD	Day-Ahead Demand
DA_EC	Energy Component Of The Day Ahead Price
DEMS	Decentralized Energy Management System
DRB	Demand Reduction Bidding
DR	Demand Response
DSM	Demand Side Management
DLC	Direct Load Control
DENISE	Distribución Energética Inteligente, Seguray Eficiente
DERs	Distributed Energy Resources
DG	Distributed Generation

DSR	Distributed Spinning Reserve
DC	Distribution Controller
DSM	Distribution Management System
DS	Distribution Substation
EPRI	Electric Power Research Institute
EA	Emergency Actions
EC	Energy Conservation
EE	Energy Efficiency
EMS	Energy Management System
ESD	Energy Storage Device
FMS	Feeder Management System
FT	Flat Tiered
GIS	Geographic Information Systems
GUI	Graphical User Interface
GHG	Green House Gases
HVAC	Heating, Ventilation, And Air Conditioning
HEMS	Home Energy Management Systems
ICT	Information And Communication Technologies
IEEE	Institute Of Electrical And Electronics Engineers
IRON	Integral Resource Optimization Network
IIEM	Integrated Intelligent Energy Management System
IEDs	Intelligent Electronic Devices
IEC	International Electro Technical Commission
ISO	International Organization For Standardization
I/P	Interruptible Program
LF	Load Forecasting
LTLF	Long Term Load Forecasting
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MTLF	Medium Term Load Forecasting
MWh	Mega Watt Hour
MG	Micro Grid
MGCC	Micro Grid Central Controller