



**Energy Demand Side Management System for Smart
Houses and Buildings**

(Case Study: Sultanate of Oman)

Prepared by

Ghazi Suhail Bakhit Al-Barami

Supervised by

Assoc. Dr. Walid M. Emar

A Thesis

**Submitted to Faculty of Engineering as a Partial Fulfilment of the
Requirement for Master Degree in Engineering Project Management**


August 2019

AUTHORIZATION FORM

I, Ghazi Al-Barami, authorize the University of Isra to supply copies of my Thesis to libraries or establishments or individuals on request, according to the University of Isra regulations.

Signature:

Date:


18.19/11/19

COMMITTEE DECISION

This Thesis (ENERGY DEMAND SIDE MANAGEMENT SYSTEM
FOR SMART HOUSES AND BUILDINGS, (Case study: Sultanate of Oman))

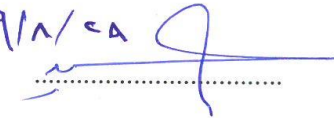
Was Successfully Defended and Approved on Sunday 25/08/2019

Examination Committee

Signature


Dr. Walid Emar (Supervisor)

Assoc. Prof. Of Electrical Engineering

C. 19/18/CA


Dr. Sameh AlSaqoor (Internal Examiner)

Assoc. Prof. Of Mechanical Engineering



Dr. Zayed Ali Huneiti (External Examiner)

Assoc. Prof. Of Electrical Engineering





TABLE OF CONTENTS

AUTHORIZATION FORM	II
COMMITTEE DECISION	III
TABLE OF CONTENTS	IV
LIST OF FIGURES	VII
LIST OF TABLES	IX
ACKNOWLEDGMENT	X
DEDICATION	XI
LIST OF ABBREVIATIONS OR SYMBOLS.....	XII
ABSTRACT.....	XIII
CHAPTER ONE: INTRODUCTION.....	1
1.1 OVERVIEW	2
1.2 SMART HOME	4
1.3 ELECTRICAL NETWORK STABILITY	6
1.3.1 VOLTAGE AND FREQUENCY COLLAPSE.....	8
1.4 Background and Motivations	9
1.5 Research Objectives & Contributions	10
CHAPTER TWO: LITERATURE REVIEW.....	13
2.1 HISTORICAL DEVELOPMENT.....	14
2.2 METHODOLOGY.....	16
CHAPTER THREE: ANALYSIS OF HOUSHOLD APPLIANCES	17
3.1 ELECTRICITY CONSUMPTION AT HOMES	18
3.2 OVERVIEW OF HOUSHOLD ELECTRICITY CONSIUMPTION VALUES	19
3.2.1 HOT WATER HEATING	20
3.2.2 KITCHEN.....	20
3.2.3 LIVING ROOM	21
3.2.4 WORKPLACE.....	21
3.2.5 HOUSE KEEPING.....	22
3.2.6 ENERGY CLASSES OF ELECTRICAL APPLIANCES	22
3.3 ENERGY CONSUMPTION AND USE IN OMAN	22
3.4 ELECTRICITY PRODUCTION IN OMAN	25

3.5	DISCUSSION AND RECOMENDATIONS	28
-----	-------------------------------------	----

CHAPTER FOUR: SMART HOME CONTROL PRINCIPLES..... 29

4.1	OVERVIEW	30
4.2	HOW DOES A SMART HOME SAVE ENERGY	31
4.3	CONTROL TECHNIQUES FOR SMART HOMES.....	32
4.3.1	WIRELESS PERSONAL AREA NETWORK (WPAN) TECHNIQUES	32
4.3.2	WIRED COMMUNICATION TECHNIQUES	33
4.3.3	AUTOMATIC CONTROL ACTIONS AT SMART HOMES	33
4.3.4	LIGHTING SETTING.....	34
4.3.5	REGULATORS	34
4.3.6	SENSORS	35
4.3.6.1	Sensors for All Residential Automation Areas.....	35
4.3.6.2	Temperature Sensor.....	35
4.3.6.3	Humidity Sensor.....	36
4.3.6.4	Motion Sensor Light.....	37
4.3.6.5	Air Quality and CO2 Sensors.....	39
4.3.6.6	Frost Protection Sensors	40
4.3.6.7	Control Panel.....	40
4.3.6.8	Magnetic Detectors.....	41
4.3.6.9	GSM Communicator	41
4.3.6.10	Security Systems.....	42
4.3.6.11	Wireless Devicess for Easier Life	43
4.4	PRACTICAL EXAMPLES OF USING SMART GRID SYSTEM.....	44
4.5	DISCUSSION AND RECOMMENDATIOIS	48

CHAPTER FIVE: CANALYSIS OF ENERGY CONSUMPTION IN ELECTRICAL INSTALLATION SYSTEM 49

5.1	OVERVIEW	50
5.2	ENERGY SAVING USING ELECTRICAL INSTALLATION SYSTEM RATIONALIZATION PRINCIPLES.....	50
5.2.1	HOW TO IMPLEMENT EFFICIENT ELECTRICAL INSTALLATION SYSTEM.....	51
5.2.1.1	Rationalization of Electricity Consumption in Lighting.....	54
5.2.1.2	General Lighting of Roads and Streets.....	55
5.2.1.3	Government Buildings	56
5.2.1.4	Heating and Air-conditioning Systems.....	56

5.2.1.5	Rationalization of Electricity Consumption in Air-conditioning System ...	56
5.2.1.6	Rationalization of Electricity Consumption in Hot Water Heaters	59
5.3	OPRACTICAL EXAMPLE OF USING RATIONALIZATION PRINCIPLES	60
5.4	DISCUSSION AND RECOMMENDATIONS	67
CHAPTER SIX: ENERGY DEMAND SIDE MANAGEMENT		68
6.1	OVERVIEW	69
6.2	LOAD AND ENERGY PRICING MANAGEMENT.....	70
6.2.1	ELECTRICITY TARIFF: TIME OF USE AND REAL TIME	71
6.3	DEMAND SIDE MANAGEMENT MAIN GOALS	73
6.4	ECONOMIC BENEFITS OF DEMAND SIDE MANAGEMENT	73
6.5	STEPS AND ACTIONS OF DEMAND SIDE MANAGEMENT	74
6.6	MATHEMATICAL MODEL AND DATA ANALYSIS OF DSM.....	75
6.6.1	MODEL PREDICTIVE CONTROL (MPC).....	75
6.6.2	DATA COLLECFTION	77
6.7	IMPLEMENTATION OF MPC USING MATLAB	78
6.7.1	ALGORITHM FOR MPC	79
6.8	SIMULATION RESULTS	83
CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS.....		84
7.1	CONCLUSION	85
7.2	RECOMMENDATIONS	89
REFERENCES.....		88
APPENDIX A.....		98
APPENDIX B		100
APPENDIX C		102

LIST OF FIGURES

No.		Page No.
1	1.1 Smart home	5
2	1.2 Overall performance characteristics of the system	8
3	3.1 Breakdown of electricity consumption in households	19
4	3.2. Sultanate of Oman	23
5	3.3. Annual energy consumption in GCC members, 2016	24
6	3.4 Energy demand scenario [7].	24
7	3.5: Contracted Generation Capacity of main interconnected system (MIS)	27
8	4.1 Low temperature sensor	36
9	4.2: Humidity sensor	37
10	4.3: Low-cost motion detector used to control lighting	38
11	4.4: Indoor Air Quality Sensor	39
12	4.5: frost protection thermostat	40
13	4.6: Smart home control panel	40
14	4.7: Magnetic field detector	41
15	4.8: GSM communicator	41
16	4.9: Security system	42
17	4.10: Wireless devices	43
18	5.1: Conventional ordinary bulb. Source: www.sangyug.com .	55
19	5.2: Illustration of fluorescent bulb. Source: www.fovitec.com	55
20	5.3: Monthly electricity consumption in kWh in Dhofar District.	62
21	5.4: The amount of hot water used for the types of washing machines by size.	63
22	5.5: Quantity of water used (estimated) for washing machines with upper door.	64
23	5.6: Electricity consumption values for washing machines when decrease temperature to 50 °C and 60 °C	65
24	6.1: Examples of RTP, CPP and TOU [64]	72
25	6.2: Block diagram of a MPC model	76

26	6.3: Example of Power system Load in one day in Oman	78
27	6.4: Example of Electrical energy price in the Market in Oman	78
28	6.5: Working trajectory of MPC for controlling the consumption in one month	80
29	6.6: Load duration curve control in one day in autumn	81
30	6.7: Load duration curve Modification in one day in autumn	82

LIST OF TABLES

Number		Page Number
1	1.1: Total Energy Production of Oman (2011)	3
2	1.2: Oman's TFC of Energy (2011) [9]	4
3	1.3: Frequency bands of power system network	8
4	3.1: Distribution of electricity consumption in households - total	18
5	3.2: Breakdown of electricity consumption in households	18
6	3.3: Tabulating of Energy demand scenario [7].	25
7	3.4. Electricity production and Consumption in Oman [7].	26
8	3.5. Some contracted generation capacity over 7 years	27
9	4.1: Results of the presence of sensor of persons availability to control	45
10	4.2: Results of using sensors for the presence of persons to control illumination in regular common places (second classification).	46
11	4.3: Results of the using the sensors for the presence to control illumination in irregular common places (third classification)	46
12	4.4: The mean of the results of using sensors for the presence of persons in different places	47
13	5.1: Some cooling capacities available on the market.	57
14	5.2: The limitation of the cooling capacity in BTU based on the surface of the area	57
15	5.3: List and number of elements connected to the power distribution of common areas of a large bulding	61
16	5.4: Estimated amount of hot water used	63
17	5.5: The amount of hot water used for the types of washing machines	64
18	5.6: Comparison of electricity consumption with wash cycle	65
19	6.1: Power consumption rates over almost one year in Sohar.	77
20	6.2: Power consumption rates between 07/2017and 06/2018 Wadi Aljjizi	77
21	6.3: Estimation cost savings of energy purchase during control	82

ACKNOWLEDGMENT

Praises be to Allah, who empowered me to do this research. I am very grateful to my principal supervisor, Dr. Walid Emar for his guidance on my research and his deep remarkable suggestions, patience and help to complete my Ms.C. study and thesis. He was always friendly, supportive, helpful and modern in his teaching approach. I would like to extend my thanks to the faculty members who have enriched my knowledge and have added great value to my perspectives of scientific research.

Last but not least, I would like to express my sincere appreciation to my wife and parents. Their love, encouragement and support give me the courage in facing any challenges during my whole life time.

DEDICATION

I dedicate this research to all who stood with me and encouraged me to end this thesis. My mom who sacrificed all what she owns to enable me occupying the highest rank and level. Dear father, who is a supporter for me in this life, who always stands beside me to overcome all the difficult conditions that face me. For the spiritual support of Dr Salim Ajami who encouraged me to take this step toward doing the Ms.C. study. My sweet wife who always stands beside me and creates an academic environment and atmosphere for doing well in my study.

LIST OF ABBREVIATIONS OR SYMBOLS

DSM	DEMAND SIDE MANAGEMENT
TOU	TIME-OF-USE
CPP	CRITICAL-PEAK PRICING
RTP	REAL-TIME PRICING
DER	DEMAND ENERGY REPOSE
HVAC	HEATING, VENTILATION AND AIR-CONDITIONING
LAN	LOCAL AREA NETWORK
GCC	GULF COOPERATION COUNCIL
OPWP	OMAN POWER AND WATER PROCUREMENT
IRENA	INTERNATIONAL RENEWABLE ENERGY AGENCY
WPAN	WIRELESS PERSONAL AREA NETWORK
MPC	MODEL PREDCTIVE CONTROL
LED	LIGHT EMITTING DIODE
AEE	ARAB ENERGY EFFICIENCY OFFICE
BTU	BRITISH THERMAL UNIT OF HEAT

ENERGY DEMAND SIDE MANAGEMENT SYSTEM FOR SMART HOUSES AND BUILDINGS

(CASE STUDY: SULTANATE OF OMAN)

Abstract

Energy saving is a very important issue that affects the end users, power system quality and the global environment. Through the periodic energy bills of various energy agencies in Oman, it is possible to search for the causes of excessive consumption to reduce it with the search for the optimal solution with alternative energy sources.

The main task of this thesis is to help reducing the electricity and energy costs by using Demand Side Management (DSM) approaches, such as Demand Response (DR) and Energy Efficiency through an intelligent network with an adequate electricity tariff. This paper focuses on using electricity prices that vary over time to change the intensity of energy from peak hours to off-peak hours. Therefore, it discusses the promotion of the modern electricity tariffs such as Time-of-Use (TOU), Critical-Peak Pricing (CPP) and Real-Time Pricing (RTP), also enlarges the demands of customers in managing the loads and DERs within the smart homes and buildings from both financial and environmental points of view.

The main goal of the research was to understand the basic metrics and interactions of the residential customer and the energy industry, which led to a reduction in peak demand. This research sought to identify the motivational and contextual factors involved in decision-making in order for a resident consumer to accept or not to take interventions to reduce demand at peak times.

The main research question for this work was:

What are the important factors, principles and action steps from the perspective of residential customers that should be taken to influence their change in electricity consumption during peak demand?

This research examined Sultanate of Oman as a case study and used a qualitative methodology to investigate the effectiveness of interventions of residential customers to reduce electricity demand as the descriptive study of this thesis.

The proposed energy side management method is the formulation and subsequent optimization of the energy side management using a model predictive control (MCP) to the problem of controlling the load shedding and peak demand reduction. As a result of that, an optimization algorithm for large-scale dynamic systems that take account of electricity costs, the work cycle, user requirements, system constraints and other input information is developed.

The work used data from the perspective of the consumer, which was collected directly by the researcher, or obtained from various sources related to the problem. These data were used to study the benefits of using demand side management.

This research examined a successful interdisciplinary approach from a consumer perspective and contributed significantly to understanding the fundamental dimension of socio-technical approaches to minimizing peak demand.

The experience of conducting a case study on achieving a steady decline in energy consumption during peak periods is rare, and thus provides a unique opportunity to explore this phenomenon in the Omani context. The results of the study have important implications for addressing issues related to peak demand reduction interventions and demand reduction policy tools, not only for energy providers but also for consumers.